Hawaiian Islands Climate Vulnerability and Adaptation Synthesis

2018

EcoAdapt™

Meeting the challenges of climate change

PACIFIC ISLANDS CLIMATE CHANGE COOPERATIVE

Cover photos: U.S. Fish and Wildlife Service

Hawaiian Islands Climate Vulnerability and Adaptation Synthesis

2018

www.EcoAdapt.org

Citation
Gregg, R.M., editor. 2018. Hawaiian Islands Climate Vulnerability and Adaptation Synthesis. EcoAdapt, Bainbridge Island, WA.

For more information on this report and other products, please contact Rachel@EcoAdapt.org and visit http://bit.ly/HawaiiClimate.

Produced in cooperation with the Pacific Islands Climate Change Cooperative with funding from the U.S. Fish and Wildlife Service

This page is intentionally left blank.

Preface

The Pacific Islands Climate Change Cooperative (PICCC) partnership began working with EcoAdapt in 2015 on the Hawaiian Islands Climate Synthesis, a project that has been central to the Hawaiian Islands Terrestrial Adaptation Initiative (HITAI). The PICCC partners developed the HITAI in 2014 to better prepare Hawaiʻi for the impacts of climate change by providing targeted science, communication, and evaluation products and services to resource managers and decision makers. The initiative has been driven by management needs, and its products were developed by working closely and iteratively with science, policy, conservation, and communications experts. In just the last two years, over 300 individuals within Hawaiʻi have actively participated in and shaped the HITAI. The initiative has brought together local, county, state, federal, and non-governmental resource managers to discuss challenges, share knowledge, identify needs, and prioritize key actions for reducing the vulnerability of Hawaiʻi's natural and biocultural resources to climate change. This report, *Hawaiian Islands Climate Vulnerability and Adaptation Synthesis,* was made possible by the dedicated involvement of all of these individuals and the remarkable efforts of EcoAdapt to synthesize the vast body of information they generated.

The PICCC is a self-directed conservation alliance made up of local, state, federal, indigenous, and NGO member organizations from Hawaiʻi and the US-Affiliated Pacific Islands. The PICCC partnership developed the adaptation initiative model to support two primary shared goals as articulated in their 2014-2019 strategic plan: facilitate climate adaptation + foster partnerships. The first goal is achieved by supporting resource managers with science, tools, and techniques for planning and implementing climate adaptation actions. The second goal is achieved by maintaining and cultivating relationships with partners who are key to creating the optimal policy, organizational, and community conditions for adaptation to occur. By working on these two goals in tandem, the PICCC set out to achieve its vision of assisting partners in adapting to climate change for the continuing benefit of the people of the Pacific Islands.

The HITAI was developed to meet both goals. The PICCC partners embarked on the HITAI with the shared commitment to advance conservation planning in Hawaiʻi in order to address the inevitable realities of change and further develop the PICCC partnership as a collaborative, results-oriented enterprise. The multi-pronged approach to the HITAI (science syntheses, policy analyses, and communications products) provides resource managers and decision makers with shared strategies, tools, and information necessary to address current climate change stressors and prepare for significant changes yet to come.

The PICCC partnership is proud of the work accomplished in cooperation with EcoAdapt and Hawaiʻi's resource management community. To learn more about other projects and products of the HITAI effort, please visit the PICCC website at www.piccc.net.

This report and associated products are dedicated to the memory of Lloyd Loope, who worked tirelessly to protect Hawai'i's native species. Lloyd's commitment to the Hawaiian conservation community and his humble approach to his work were apparent in his efforts on this project, particularly for the vulnerability assessment of Maui's natural resources. Mahalo, Lloyd.

Contributing Authors: Rachel M. Gregg, Jessi Kershner, Laura Hilberg, Whitney Reynier

Acknowledgements
This work would not have been possible without the active participation of a large number of individuals. The project team would like to acknowledge our Stakeholder Working Group members who provided guidance throughout the project, the more than 250 individuals and organizations who participated in and contributed their mana'o and expertise during the vulnerability assessment and adaptation workshops, and the volunteer peer reviewers who donated their time and expertise. Mahalo nui loa as well to the following individuals for providing project guidance and support: Lucas Fortini, U.S. Geological Survey; Scott Fretz, Division of Forestry and Wildlife; Laura Brewington, East-West Center; Jeannine Rossa, Moloka'i Climate Change Network; Joy Hiromasa Browning, U.S. Fish and Wildlife Service; Pam Eaton, County of Maui; and J. Rubey, Pacific Birds Habitat Joint Venture. Thank you to those who assisted with workshop facilitation, including Jonathan Likeke Scheuer and John Parks; and to those who donated meeting space, including Ric Lopez, Institute of Pacific Islands Forestry and Ka'au Abraham, Hawaiian Islands Humpback Whale National Marine Sanctuary. We hope that our products will promote and support your efforts to create a climate-informed future for the Hawaiian Islands.

Stakeholder Working Group
Colleen Cole, Three Mountain Alliance
Darcy Hu, Hawai'i–Pacific Islands Cooperative Ecosystem Studies Unit
Dennis LaPointe, U.S. Geological Survey, Pacific Island Ecosystems Research Center
Ed Misaki, The Nature Conservancy
Erica von Allmen, Auwahi Forest Restoration Project
Jason Jeremiah, Kamehameha Schools
Jim Kraus, Hakalau Forest National Wildlife Refuge
Kapua Kawelo, O'ahu Army Natural Resource Program
Leah Laramee, Division of Forestry and Wildlife
Marigold Zoll, Division of Forestry and Wildlife
Matt Brown, U.S. Fish and Wildlife Service
Megan Laut, U.S. Fish and Wildlife Service
Paul Higashino, Kaho'olawe Island Reserve Commission
Pōmaika'i Kaniaupio-Crozier, Pu'u Kukui Watershed Preserve
Rhonda Loh, National Park Service
Scott Fretz, Division of Forestry and Wildlife
Sherri Mann, Division of Forestry and Wildlife
Skippy Hau, Division of Aquatic Resources
Susan Cordell, U.S. Forest Service, Pacific Southwest Research Station
Trae Menard, The Nature Conservancy
Vickie Caraway, U.S. Fish and Wildlife Service
Victoria Keener, East-West Center

List of workshop participants and peer reviewers. Experts indicated with an asterisk (*) completed multiple reviews.

Name	Affiliation	Workshop Participant	Peer Reviewer
Abby Frazier	U.S. Forest Service		X
Afsheen Siddiqi	DLNR Division of Forestry and Wildlife	X	
Albert Perez	Maui Tomorrow Foundation	X	
Ali Andrews	Tetra Tech	X	
Alison Ainsworth	Hawaiʻi Volcanoes National Park	X	
Alison Cohan	The Nature Conservancy	X	
Amanda Hardman	DLNR Division of Forestry and Wildlife	X	
Andrea Buckman	Leeward Haleakalā Watershed Restoration Partnership	X	
Anela Evans	Pūlama Lānaʻi	X	
Angela Anderson	Hawaiian Islands Land Trust	X	
Annalise Kehler	County of Maui Department of Planning	X	
Anne Walton*	Natural Resource Management Consultant	X	X
Anonymous*	Commission on Water Resource Management		X
Anonymous*	County of Maui Department of Water Supply		X
Anonymous	DLNR Division of Forestry and Wildlife		X
Anonymous	DLNR Division of Forestry and Wildlife		X
Anonymous	Hanalei Watershed Hui		X
Anonymous	Kākoʻo ʻŌiwi		X
Anonymous	Kamehameha Schools		X
Anonymous	Pacific Birds Habitat Joint Venture		X
Anonymous	University of Hawaiʻi		X
Anonymous	University of Hawaiʻi-Hilo		X
Anonymous*	University of Hawaiʻi-Mānoa College of Tropical Agriculture and Human Resources		X
Anonymous	Waikoloa Dry Forest		X
Aric Arakaki	Ala Kahakai National Historic Trail	X	
Aunty Ehulani Kane	Na Puʻuwai Native Hawaiian Rural Health Center	X	
Aunty Keri Zacher	Molokaʻi Climate Change Network	X	
Ben Nyberg	National Tropical Botanical Garden	X	
Ben Reder	DLNR Office of Conservation and Coastal Lands	X	
Benjamin Sullivan	County of Kauaʻi Office of Economic Development	X	
Bethany Chagnon	U.S. Fish and Wildlife Service	X	
Bill Lucey	Kauaʻi Invasive Species Council	X	
Brad Romine	DLNR Office of Conservation and Coastal Lands	X	X
Butch Haase	Molokaʻi Land Trust	X	
Carlie S. Wiener	COSEE Island Earth/University of Hawaiʻi		X
Chad Wiggins	The Nature Conservancy	X	
Chentel Villa	Ka Honua Momona	X	
Christian Giardina	Institute of Pacific Islands Forestry	X	
Christian Vlautin	Kauaʻi Nēnē Habitat Conservation Plan	X	X
Christopher Brosius	West Maui Mountains Watershed Partnership	X	
Chuck Chimera*	Maui Invasive Species Committee		X
Clay Chow	DLNR Division of Forestry and Wildlife	X	
Clay Trauernicht	University of Hawaiʻi Cooperative Extension, Pacific Fire Exchange	X	

Name	Affiliation	Workshop Participant	Peer Reviewer
Colleen Cole	Three Mountain Alliance	X	
Courtney Grantham	DLNR Division of Forestry and Wildlife	X	
Dan Eisenberg	East Maui Watershed Partnership	X	
Dan McNulty-Huffman	County of Maui Department of Planning	X	
Dan Polhemus	U.S. Fish and Wildlife Service	X	X
Dan Sailer	Oʻahu Army Natural Resources Program	X	
Darcy Hu	Hawaiʻi – Pacific Islands Cooperative Ecosystem Studies Unit	X	X
Darla White	DLNR Division of Aquatic Resources	X	
Dave Helweg	Pacific Islands Climate Science Center	X	
David Raikow	National Park Service Pacific Island Network	X	
Delwyn Oki*	U.S. Geological Survey, Pacific Islands Water Science Center		X
Diana Crow	Ulupalaukua Ranch	X	
Dietra Myers-Tremblay	DLNR Division of Forestry and Wildlife		X
Donnie Rayome	U.S. Forest Service	X	
Edith Atkins	DLNR Division of Forestry and Wildlife	X	
Elizabeth Witkowski	Puʻukohola Heiau National Historic Site	X	
Elliott Parsons	DLNR Division of Forestry and Wildlife	X	X
Emily Fielding	The Nature Conservancy	X	
Emma Anders	Hawaiʻi Conservation Alliance	X	
Erica von Allmen*	Auwahi Forest Restoration Project		X
Erin Bishop	Oʻahu Invasive Species Committee	X	
Eryn Opie	DLNR Division of Forestry and Wildlife	X	
Eva Blumenstein	County of Maui Department of Water Supply	X	
Fern Duvall	DLNR Division of Forestry and Wildlife	X	X
Fred Reppun	University of Hawaiʻi-Mānoa College of Tropical Agriculture and Human Resources		X
Fritz Klasner	Office of Maunakea Management	X	X
Gail Peiterson	Punahou School	X	
Glenn Higashi	DLNR Division of Aquatic Resources		X
Gordon Tribble	U.S. Geological Survey, Pacific Island Ecosystems Research Center		X
Gracie Allen	DLNR Division of Forestry and Wildlife	X	
Hanna Mounce	Maui Forest Birds Recovery Project	X	X
Hannah Kihalani Springer	Kaʻūpūlehu Marine Advisory Committee, Conservation Council for Hawaiʻi	X	
Heather Tonneson	Hulēʻia National Wildlife Refuge (Kauaʻi National Wildlife Refuge Complex)	X	
Hiʻilei Kawelo	Paepae o Heʻeia	X	
J. Rubey	Pacific Birds Habitat Joint Venture	X	
James Bruch	Kahoʻolawe Island Reserve Commission	X	
James Crowe	Hawaiian Islands Land Trust	X	
James Roumasset	University of Hawaiʻi-Mānoa Department of Economics		X
Jamie Harris	DLNR Division of Forestry and Wildlife	X	
Jason Jeremiah	Kamehameha Schools	X	

Name	Affiliation	Workshop Participant	Peer Reviewer
Jason Vercelli	DLNR Division of Forestry and Wildlife	X	
Jay Pennemin	Maui Nui Seabird Recovery Project	X	
Jeannine Rossa	Molokaʻi Climate Change Network, EcoLink Consulting, University of Hawaiʻi	X	
Jeff Dack	County of Maui Department of Planning	X	
Jenna Masters	DLNR Division of Forestry and Wildlife	X	
Jennifer Vander Veur	Kahoʻolawe Island Reserve Commission	X	
Jim Kraus	Hakalau Forest National Wildlife Refuge and Big Island National Wildlife Refuge Complex	X	
Joby Rohrer	Oʻahu Army Natural Resources Program	X	
Jodi Chew	U.S. Forest Service	X	
Joey Char	Kamehameha Schools	X	
John Delay	Honolulu Community College	X	
John Marra	NOAA Pacific Region Climate Services	X	
Joy Hiromasa Browning	U.S. Fish and Wildlife Service	X	
Juanita Colon	Molokaʻi Climate Change Network, Kawela Homeowner's Association	X	
Kainana Francisco	Institute of Pacific Islands Forestry		X
Kapua Kawelo	Oʻahu Army Natural Resources Program	X	X
Karl Magnacca	Oʻahu Army Natural Resources Program	X	
Kathryn Fiedler	University of Hawaiʻi-Mānoa College of Tropical Agriculture and Human Resources Kauaʻi County	X	
Katie Ersbak	Hawaiʻi Association of Watershed Partnerships	X	
Katie Nalesere	DLNR Division of Aquatic Resources	X	
Katy Hintzen	University of Hawai'i Sea Grant; NOAA Hawaiian Islands Sentinel Site Cooperative	X	
Kevin Chang	Kuaʻāina Ulu ʻAuamo (KUA)		X
Kevin Sullivan*	Hawaiʻi County Planning Department	X	X
Kimberly Burnett	University of Hawaiʻi Economic Research Organization		X
Kirsten Oleson	University of Hawaiʻi-Mānoa Department of Natural Resources and Environmental Management		X
Lance K. De Silva	DLNR Division of Forestry and Wildlife	X	
Laura Brewington	East-West Center	X	
Laura McIntyre	Hawaiʻi State Department of Health	X	
Lea Hong	Trust for Public Lands	X	
Leah Laramee	DLNR Division of Forestry and Wildlife	X	
Lenore Ohye	Commission on Water Resource Management	X	
Lisa Cali Crampton*	DLNR Division of Forestry and Wildlife	X	X
Lloyd Loope	U.S. Geological Survey Biological Resources Division, Haleakalā Field Station	X	
Lorena Wada (Aunty Tap)	U.S. Fish and Wildlife Service		X
Lucas Behnke	The Nature Conservancy	X	
Lucas Fortini	U.S. Geological Survey, Pacific Island Ecosystems Research Center	X	
Lyman Abbott	Kahoʻolawe Island Reserve Commission	X	
Makaʻala Kaaumoana	Hanalei Watershed Hui	X	
Malia Nanbara	DLNR Division of Forestry and Wildlife	X	

Name	Affiliation	Workshop Participant	Peer Reviewer
Malia Nobrega-Olivera	Hawaiʻinuiākea School of Hawaiian Knowledge, Loli Aniau Makaʻala Aniau	X	
Margaret Clark	National Tropical Botanical Garden	X	
Marigold Zoll	DLNR Division of Forestry and Wildlife	X	X
Mark Deakos	Hawaiʻi Association for Marine Education and Research	X	
Maryanne Maigret	Puʻuhonua o Hōnaunau National Historical Park	X	
Matthew Keir	Laukahi: The Hawaiʻi Plant Conservation Network	X	
Melissa Fisher	The Nature Conservancy	X	
Melissa Price	University of Hawaiʻi-Mānoa	X	
Meredith Speicher	National Park Service	X	
Michael Mitchell	Hulēʻia National Wildlife Refuge (Kauaʻi National Wildlife Refuge Complex)	X	
Michelle Clark	U.S. Fish and Wildlife Service	X	
Michelle Elmore	Oʻahu Army Natural Resources Program		X
Nāmaka Whitehead	Kamehameha Schools	X	
Nancy McPherson	Department of Hawaiian Homelands	X	
Natalie Kurashima	Kamehameha Schools	X	
Noelani Puniwai	University of Hawaiʻi-Hilo Pacific Internship Programs for Exploring Science (PIPES), University of Hawaiʻi-Mānoa Kamakakūokalani Center for Hawaiian Studies	X	
Olu Campbell	Office of Hawaiian Affairs	X	
Pablo Beimler	Hawaiʻi Wildfire Management Organization	X	
Pam Eaton	County of Maui Department of Planning	X	
Pam Townsend	County of Maui Department of Water Supply	X	
Patty Pali	Plant Extinction Prevention Program of Molokaʻi	X	
Paul Banko	U.S. Geological Survey, Pacific Island Ecosystems Research Center		X
Paul Higashino	Kahoʻolawe Island Reserve Commission	X	
Paul Hosten	Kalaupapa National Historical Park	X	
Paul Krushelnycky	University of Hawaiʻi-Mānoa College of Tropical Agriculture and Human Resources	X	
Philipp LaHaela Walter	DLNR Division of Forestry and Wildlife	X	
Pomaikaʻi Kaniaupio-Crozier	Puʻu Kukui Watershed Preserve	X	
Rachel Lentz	Center for Island Climate Adaptation and Policy	X	
Rachel Neville	Oʻahu Invasive Species Committee	X	
Rachel Rounds	U.S. Fish and Wildlife Service	X	
Rachel Sprague	Pūlama Lānaʻi	X	
Ranae Ganske-Cerizo	Central Maui, Hana, Olinda-Kula, and West Maui Soil and Water Conservation Districts	X	
Randi Riggs	U.S. Fish and Wildlife Service	X	X
Randy Bartlett	Hawaiʻi Invasive Species Council	X	
Rebecca Most	The Nature Conservancy	X	
Rebecca Ostertag	University of Hawaiʻi-Hilo Department of Biology	X	
René Siracusa	Mālama O Puna	X	
Rhonda Loh	Hawaiʻi Volcanoes National Park	X	
Ric Lopez	Institute of Pacific Islands Forestry	X	

Name	Affiliation	Workshop Participant	Peer Reviewer
Rick Gmirkin	Ala Kahakai National Historic Trail	X	
Rob Hauff	DLNR Division of Forestry and Wildlife		X
Rob Parsons	County of Maui Environmental Coordinator's Office	X	
Robert Yagi	Waikoloa Dry Forest	X	
Robin Knox*	Southwest Maui Watershed Project	X	X
Ruby Pap	University of Hawaiʻi Sea Grant	X	X
Ryan Monello	Hawaiʻi Volcanoes National Park	X	
Sandy Ma	Hawaiʻi Coastal Zone Management Program	X	
Sara Bowen	Mālama Hulēʻia	X	
Scott Fisher	Hawaiian Islands Land Trust	X	
Scott Fretz*	DLNR Division of Forestry and Wildlife	X	X
Scott Laursen	University of Hawaiʻi-Hilo, Pacific Islands Climate Science Center	X	
Seana Walsh	National Tropical Botanical Garden	X	
Seema Balwan	National Oceanic and Atmospheric Administration Office of Coastal Management	X	
Sharde Freitas	Department of Hawaiian Homelands	X	
Sharon Ziegler-Chong	University of Hawaiʻi-Hilo Pacific Island Program for Exploring Science (PIPES), Hawaiʻi Cooperative Studies Unit	X	
Sheri Mann	DLNR Division of Forestry and Wildlife	X	
Sherri Paul	DLNR Division of Forestry and Wildlife	X	
Sierra McDaniel	Hawai'i Volcanoes National Park	X	
Skippy Hau*	DLNR Division of Aquatic Resources	X	X
Springer Kaye	Big Island Invasive Species Committee	X	
Steph Dunbar-Co	The Nature Conservancy	X	
Stephanie Franklin	DLNR Division of Forestry and Wildlife	X	
Steve Kendall	Hakalau Forest National Wildlife Refuge	X	
Susan Ching Harbin	Plant Extinction Prevention Program of Hawai'i	X	
Susan Cordell	U.S. Forest Service, Pacific Southwest Research Station	X	X
Suzanne Conlon	Kealia Pond National Wildlife Refuge	X	
Tammy Duchesne	Kaloko-Honokōhau and Puʻuhonua o Hōnaunau National Historical Parks	X	
Tanya Rubenstein	DLNR Division of Forestry and Wildlife	X	
Thomas Kaiakapu	DLNR Division of Forestry and Wildlife	X	
Tiare Lawrence	Hawaiʻi Alliance for Progressive Action	X	
Tiffany Anderson	University of Hawaiʻi-Mānoa Coastal Geology Group		X
Tiffany Bostwick*	County of Maui Department of Planning	X	X
Trae Menard	The Nature Conservancy	X	
Uncle Herbert Hoe	Ka Honua Momona	X	
Uncle Mac Poepoe	Hui Mālama O Moʻomomi, Aha Kiole o Molokaʻi	X	
Uncle Malcolm Mackey	Molokaʻi Climate Change Network	X	
Vickie Caraway	U.S. Fish and Wildlife Service	X	
Victoria Keener	East-West Center	X	
Wendy Kishida	Plant Extinction Prevention Program of Hawai'i	X	
Will Weaver	Koʻolau Mountains Watershed Partnership		X
Woody Mallinson	Haleakalā National Park	X	X

Table of Contents

Introduction

The Hawaiian Islands encompass a dynamic region featuring iconic habitats and species at risk from a number of stresses. Climate change impacts, coupled with land-use changes, the spread of invasive species, and population growth and development, all have important implications for the ecosystem services upon which more than 1.4 million people rely. The goal of the Hawaiian Islands Climate Synthesis Project was to develop science-based syntheses of current and projected future climate impacts on and adaptation options for terrestrial and freshwater resources of the main Hawaiian Islands.[1] This project convened Hawaiʻi's resource managers and conservation planners to discuss these challenges, share knowledge, identify needs, and prioritize key actions to reduce the vulnerability of resources to climate change. Project objectives included:

- Improving understanding of why important resources may be vulnerable to changing climate conditions;
- Identifying what adaptation actions can be implemented to reduce vulnerabilities and minimize climate-related losses through management and collaboration; and
- Co-generating products to facilitate climate-informed decision-making by land managers.

Climate adaptation enables decision makers to take a deliberate approach to evaluating vulnerabilities and designing strategies to enable climate-informed conservation and management. The framework applied in this project supported the evaluation of current management activities in light of climate change, in addition to the design of potential future approaches to address key vulnerabilities.

This report synthesizes the results of the major project components – climate impacts assessment, vulnerability assessment, and adaptation planning – and provides an inter-island analysis of the findings. The **Project Methods and Workshop Activities** section provides an overview of the climate adaptation planning process and the methodology used for the vulnerability assessment and adaptation planning workshops. The **Overview of Climate Trends and Projections** section presents the climate impacts synthesis, followed by the **Vulnerability Assessment and Adaptation Planning Results** sections on overall trends and summaries by island. More detailed information is available in the individual vulnerability assessment syntheses and adaptation summaries,[2] and should be referred to for decision support.

Project Methods and Workshop Activities

Climate Adaptation Planning Overview

Climate change is the most pressing societal challenge of our time. It is already affecting natural and cultural resources and the human communities that depend on them. These impacts will exacerbate current resource challenges in the Hawaiian Islands, such as rapid population growth and development, demand for water resources, land use and degradation, and the spread of invasive species. Resource

[1] From 2014-2016, Ka Honua Momona and the PICCC partnered on the Molokaʻi Climate Change Collaboration project to host a workshop series that brought together climate scientists and local experts to identify climate-related risks and vulnerabilities, and brainstorm potential solutions and partnerships for the island. EcoAdapt and the PICCC were invited to participate in a one-day workshop with the Molokaʻi Climate Change Network in April 2017 to discuss adaptation options. An overview of available literature on observed and projected climate changes for Molokaʻi and the main Hawaiian Islands is provided in Appendix A.

[2] Available at http://bit.ly/HawaiiClimate.

managers and conservation planners are faced with the challenge of developing and implementing strategies that are suitable under changing climate conditions. Strategies undertaken to address the causes and effects of global climate change are classified as either *mitigation* or *adaptation*. Mitigation strategies aim to reduce the rate and extent of change by reducing greenhouse gas emissions or enhancing carbon uptake and sequestration. Adaptation strategies help people prepare for, respond to, and/or recover from the unavoidable effects of climate change. The adaptation planning process (Figure 1) reflects the intentional integration of climate change into resource management and conservation. These actions may include current management approaches, modifications to current strategies, and/or new and novel approaches to address climate change.

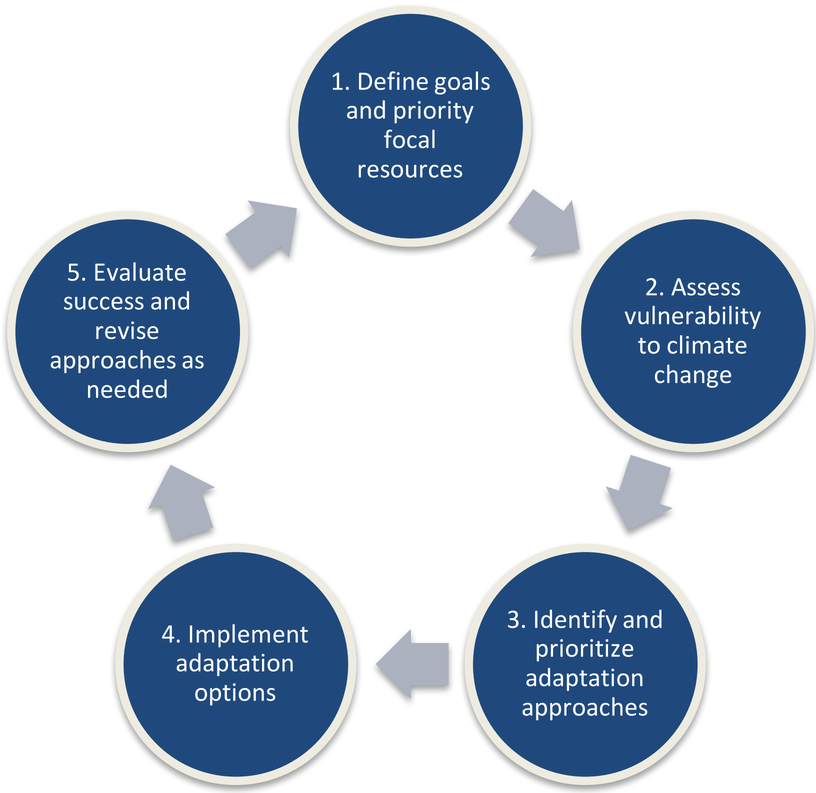

Figure 1. Climate adaptation planning process.

This project used a collaborative, expert elicitation-based approach involving stakeholders from federal and state agencies, universities, and non-governmental organizations. Expert elicitation is an effective approach in situations where there is greater uncertainty about future climate projections, but where stakeholders are able to contribute detailed knowledge and expertise about the ecology, management, and threats to regional resources of concern. To ensure that the process and products met the decision-making needs of the Hawaiian Islands, we convened a Stakeholder Working Group comprising scientists, landowners, resource managers, and conservation practitioners with a range of expertise in natural and cultural resources management.

Stakeholder Working Group

Regional stakeholders were invited to participate in a Stakeholder Working Group (Table 1) in order to provide input on focal resource selection and product formats, participate in and co-host island workshops, and, depending on expertise, serve as peer reviewers. Active participation of these representatives was essential as (1) they are the sources of much of the knowledge about the ecology, management, and decision-making needs of the focal region; and (2) they are the professionals who will use the results of the project.

Table 1. Stakeholder Working Group Participants.

Name	Affiliation
Colleen Cole	Three Mountain Alliance
Darcy Hu	Hawaiʻi – Pacific Islands Cooperative Ecosystem Studies Unit
Dennis LaPointe	U.S. Geological Survey, Pacific Island Ecosystems Research Center
Ed Misaki	The Nature Conservancy
Erica von Allmen	Auwahi Forest Restoration Project
Jason Jeremiah	Kamehameha Schools
Jim Kraus	Hakalau Forest National Wildlife Refuge
Kapua Kawelo	Army Natural Resource Program
Leah Laramee	Division of Forestry and Wildlife
Marigold Zoll	Division of Forestry and Wildlife
Matt Brown	U.S. Fish and Wildlife Service
Megan Laut	U.S. Fish and Wildlife Service
Paul Higashino	Kahoʻolawe Island Reserve Commission
Pōmaikaʻi Kaniaupio-Crozier	Puʻu Kukui Watershed Preserve
Rhonda Loh	National Park Service
Scott Fretz	Division of Forestry and Wildlife
Sherri Mann	Division of Forestry and Wildlife
Skippy Hau	Division of Aquatic Resources
Susan Cordell	U.S. Forest Service, Pacific Southwest Research Station
Trae Menard	The Nature Conservancy
Vickie Caraway	U.S. Fish and Wildlife Service
Victoria Keener	East-West Center

Focal Resources Selection

The Stakeholder Working Group convened in February 2016 to identify a suite of focal resources to serve as the foci of the vulnerability assessment. Participants were asked to identify resources (e.g., habitats, species, and ecosystem services) of the highest and broadest management, cultural, and socioeconomic concern across the main Hawaiian Islands. A draft list of 68 resources was generated; due to time and funding constraints, the assessment focused on evaluating the vulnerability of key habitats and ecosystem services common across the islands:

- *Habitats*
  - Alpine/subalpine
  - Coastal (e.g., shrub, dune, beach, salt marsh, anchialine pools)
  - Aquatic (e.g., perennial streams, intermittent streams, wetlands)
  - Dry forest
  - Mesic/wet forest
- *Ecosystem services* (or benefits people obtain from ecosystems [MEA 2005])
  - Food and fiber
  - Fresh water (supply, quality)
  - Flood and erosion control
  - Cultural knowledge and heritage values (e.g., cultural landscapes and practices)

- Aesthetic values
- Recreation and tourism

At each vulnerability assessment workshop, participants selected which habitats, sub-habitats, and ecosystem services would be evaluated (Table 2).

Table 2. Resources evaluated during the vulnerability assessment workshops on each island.

	Maui Nui	O'ahu	Hawai'i	Kaua'i
Habitats				
Beaches and shorelines	X	X	X	X
Estuaries and coastal wetlands	X	X	X	X
Anchialine pools	X		X	X
Freshwater wetlands (lowland, upland)	X	X	X	X
Groundwater, seeps, and springs	X		X	
Streams	X	X	X	X
Dry forest	X	X	X	
Mesic/wet forest	X	X	X	X
Alpine/subalpine	X		X	
Ecosystem Services				
Cultural knowledge and heritage	X	X	X	X
Flood and erosion control	X	X	X	X
Fresh water (supply and quality)	X	X	X	X
Food/fiber	X		X	X
Aesthetic values	X			
Recreation and tourism	X			

Climate Trends and Projections

Conducting complex scientific analyses, particularly those that involve climate modeling, can be both expensive and time consuming. To more effectively use limited resources, we created a state-of-the-science assessment relying primarily on a thorough review of the most up-to-date literature on climate impacts and conditions for the Hawaiian Islands, including peer-reviewed scientific literature, assessments, and agency and non-governmental reports. This included direct consideration and discussion of uncertainty, and was used to inform the vulnerability assessment.

Vulnerability Assessment

Vulnerability is defined as a function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2013; Figure 2).

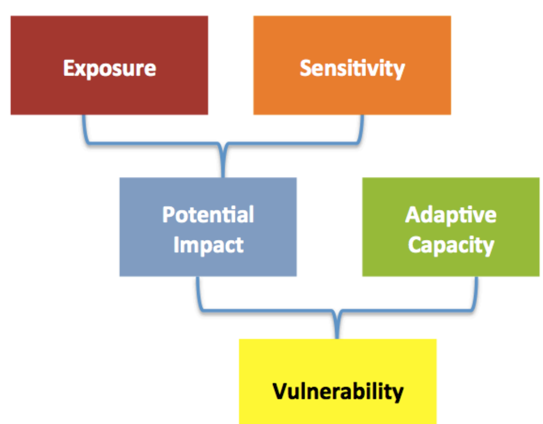

Figure 2. Components of vulnerability (IPCC 2013).

Exposure is a measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011). **Sensitivity** is a measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011). **Adaptive capacity** refers to the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability Assessment Model

The vulnerability assessment model applied in this process was developed by EcoAdapt[3] (Hutto et al. 2015; EcoAdapt 2014a; EcoAdapt 2014b; Kershner 2014), and includes evaluations of relative vulnerability by local stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to focal habitats and ecosystem services. Stakeholders evaluated vulnerability of each resource by discussing and answering a series of questions for sensitivity and adaptive capacity. Habitat exposure was evaluated by EcoAdapt using future climate projections from the scientific literature; ecosystem service exposure was evaluated by workshop participants using the climate impacts table provided by EcoAdapt. Each vulnerability component (i.e. sensitivity, adaptive capacity, and exposure) was divided into specific elements. For example, habitats included three elements for assessing sensitivity and five elements for adaptive capacity. Elements for each vulnerability component are described in more detail below.

In-person workshops were held on Maui, Oʻahu, Kauaʻi, and Hawaiʻi between August 2016 and January 2017.[4] Participants self-selected habitat and ecosystem service breakout groups and evaluated each resource's vulnerability.[5] Participants were first asked to define key ecological attributes, sub-habitats, and sites of biological and cultural importance for each of the overarching habitat groups in order to identify island-specific characteristics.

Workshop participants assigned one of five rankings (High, Moderate-High, Moderate, Low-Moderate, or Low) for sensitivity and adaptive capacity. Stakeholder-assigned rankings for each component were then converted into scores (High-5, Moderate-High-4, Moderate-3, Low-Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall score. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity; this was due to greater uncertainty about the magnitude and rate of future change. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - Adaptive Capacity

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings, and uses these rankings to estimate the overall level of confidence for each component of vulnerability as well as overall vulnerability.

---

[3] Sensitivity and adaptive capacity elements were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2012, and Lawler 2010.

[4] The vulnerability assessment workshop approach was not applied to Molokaʻi as PICCC funded Ka Honua Momona to identify climate-related risks and vulnerabilities through a 2014-2016 workshop series.

[5] The evaluation for dry forest on Oʻahu was completed via online survey.

Rankings and scores presented should be considered measures of relative vulnerability and confidence (i.e. comparing the level of vulnerability between the focal resources evaluated in this project).

Vulnerability Assessment Model Elements – Habitats & Ecosystem Services

Sensitivity & Exposure (Applies to Habitats and Ecosystem Services)

- **Climate and Climate-Driven Factors:** e.g., air temperature, precipitation, freshwater temperature, sea surface temperature, sea level rise, soil moisture, altered streamflows
- **Disturbance Regimes:** e.g., wildfire, flooding, drought, insect and disease outbreaks, wind
- **Future Climate Exposure:** e.g., consideration of projected future climate changes (e.g., temperature and precipitation) as well as climate-driven changes (e.g., altered fire regimes, altered flow regimes, shifts in vegetation types). Experts were provided with a summary of historical, current, and projected future climate changes for the main Hawaiian Islands.
- **Non-Climate Stressors:** e.g., land-use conversion (e.g., residential or commercial development), agriculture and/or aquaculture, transportation corridors (e.g., roads, railroads, trails), water diversions, invasive and other problematic species, pollution and poisons, etc. For non-climate stressors, experts were asked to evaluate sensitivity, whether the habitat or ecosystem service is currently exposed to that stressor, and whether the pattern of exposure is widespread and/or consistent across the study area or is highly localized (e.g., exposure to aquaculture is highly localized but exposure to invasive grasses is often widespread).

Adaptive Capacity (Applies to Habitats)

- **Extent and Integrity:** e.g., habitats that occur in multiple locations vs. single, small areas; high integrity vs. degraded habitats
- **Habitat Isolation:** e.g., adjacent to other native habitat types vs. isolated habitats, barriers to dispersal (e.g., development, energy productions, roads, water diversions)
- **Resistance and Recovery:** *resistance* refers to the stasis of a habitat in the face of change, *recovery* refers to the ability to "bounce back" more quickly from stressors once they do occur
- **Habitat Diversity:** e.g., diversity of component native species and functional groups in the habitat
- **Management Potential:** e.g., ability of resource managers to alter the adaptive capacity and resilience of a habitat to climatic and non-climate stressors (societal value of habitats, ability to alleviate impacts)

Adaptive Capacity (Applies to Ecosystem Services)

- **Intrinsic Value and Management Potential:** e.g., ability of managers to alter the adaptive capacity and resilience of a service to climatic and non-climate stressors (societal value of ecosystem services, ability to alleviate impacts)

Scientific Literature Review and Peer-Review Process

Vulnerability and confidence rankings and scores for a given element were supplemented with information from the scientific literature. The final vulnerability assessment synthesis for a given resource includes stakeholder-assigned rankings, confidence evaluations, and narratives summarizing expert opinions and information from the scientific literature. The individual vulnerability assessments received additional peer review to help address discrepancies and uncertainties. Peer reviewers were identified by workshop participants, the Stakeholder Working Group, the PICCC Steering Committee, and through the scientific literature.

Adaptation Planning

Adaptation actions are taken to either avoid or take advantage of climate change impacts, either by decreasing vulnerability or increasing resilience. Climate adaptation approaches typically fall into one or more of the following categories:

- **Resistance**. Implementation of these strategies and actions can help to prevent the effects of climate change from reaching or affecting a resource with the goal of maintaining relatively unchanged conditions. Examples include using hard infrastructure to protect vulnerable habitats and preventing the spread of invasive weeds.
- **Resilience**. These strategies and actions can help a resource withstand the impacts of climate change by avoiding the effects of or recovering from changes. The goal of these strategies is to accommodate some change but encouraging a return to prior conditions. Examples include promoting native genotypes and restoring coastal wetlands to buffer storm surge.
- **Response (or Transition)**. Response or transition strategies and actions intentionally accommodate change and enable resources to adaptively respond to changing and new conditions. Examples include identifying and protecting climate refugia (i.e. areas likely to maintain more stable climatic conditions over time), assisted colonization of species, or accepting loss of habitats and letting nature take its course.
- **Knowledge**. These strategies and actions are aimed at gathering more information about climate changes, impacts, and/or the effectiveness of management actions in addressing the challenges of climate change. The goal of these strategies is to use the best information to inform activities in terms of what, when, where, and how an action is implemented.
- **Collaboration**. Collaboration strategies and actions aim to coordinate adaptation efforts across various groups (e.g., sectors, governments, project teams). They may help align budgets and priorities for a program of work across lands, or establish or expand collaborative monitoring efforts or projects, among others.

Adaptation Workshop Activities: Day 1

In-person adaptation workshops were held on Maui, Oʻahu, Kauaʻi, and Hawaiʻi between April and June 2017. Participants identified both current and future management goals for each of the focal habitats (and related ecosystem services). The purpose of identifying current management goals was to provide a foundation for evaluating whether and how climate change might affect the ability to achieve a given goal, and to develop options for reducing vulnerabilities through revised management activities. For each management goal, participants identified potential risks using the results of the vulnerability assessment. This activity was followed by the evaluation of current management actions, including whether, in their current form, they could help to reduce identified climate and non-climate vulnerabilities and/or how they can be modified to better address the challenges presented by a changing climate. Following the evaluation of potential vulnerabilities of current management goals and actions, participants explored potential future management goals and adaptation strategies, and identified more specific adaptation actions to reduce vulnerabilities or increase resilience of the selected focal resources. Workshop participants evaluated action effectiveness and feasibility; identified the timeframe for action implementation; described where and how to implement the action; evaluated the degree to which a particular action could be reversed or undone if needed; and identified collaboration and capacity needs.

Action effectiveness in reducing vulnerability:
- High: action is very likely to reduce vulnerability and may benefit additional goals
- Moderate: action has moderate potential to reduce vulnerability, with some limits to effectiveness
- Low: action is unlikely to reduce vulnerability

Action implementation feasibility:
- High: there are no obvious barriers to implementation
- Moderate: it may be possible to implement the action, although there may be challenges or barriers
- Low: there are obvious and/or significant barriers to implementation that may be difficult to overcome

Implementation timeframe: Identify when a particular action could feasibly be implemented.
- Near: 0-5 years
- Mid: 5-20 years
- Long: >20 years

Where/How to implement: Identify the management, ecological, or site conditions where the action could be most appropriately applied, and how to apply this action given vulnerabilities.

Reversibility of the action:
- Easy: the action could likely be quickly reversed with minimal cost and risk to the resource
- Moderate: the action may be able to be reversed with moderate cost risk to the resource
- Hard: the action would likely be difficult to reverse and would incur high costs/risks to the resource

Collaboration and capacity: Identify any other agencies, organizations, or people needed to collaborate with in order to implement an action, as well as capacity needs such as data, staff time and resources, funding, or policy changes, among others.

Adaptation Workshop Activities: Day 2

The second day of the adaptation workshops was dedicated to designing adaptation approaches to address specific natural and cultural conservation activities that occur across the islands. Themes were identified before the workshops by the Stakeholder Working Group and included:
- Native ecosystems and rare species conservation
- Invasive species management
- Water resources planning
- Land-use planning
- Cultural resources and practices preservation

Participants identified regional goals for island-wide conservation activities that intersect habitats and ecosystem services (e.g., removing invasive species, restoring floodplain function), and prioritized key vulnerabilities of the goals to climate and non-climate stressors. For each priority vulnerability, participants developed a list of potential adaptation options. For each priority adaptation strategy, participants then identified specific actions and order of implementation, as well as potential challenges to an action's implementation and possible solutions.

These workshop activities generated a range of recommended adaptation actions that could be implemented both now and in the future. Users of this report are encouraged to explore additional adaptation actions that may help reduce vulnerabilities, increase resilience, or capitalize on opportunities presented by climate change (EcoAdapt 2016; EcoAdapt 2017; Gregg et al. 2011; Gregg et al. 2012; Gregg et al. 2016; Gregg et al. 2017; Hutto et al. 2015; Kershner 2014; Kershner et al. 2015; Score et al. 2017).

Molokaʻi Adaptation Workshop

EcoAdapt and the PICCC were invited to participate in a discussion with the Molokaʻi Climate Change Network in April 2017 to discuss adaptation options. The PICCC had previously funded Ka Honua Momona to create a workshop series that brought together climate scientists and local experts to identify climate-related risks and vulnerabilities, and brainstorm potential solutions and partnerships focused on restoration and community engagement. During the meeting, participants shared updates on the status of various project ideas generated at the previous workshops, and discussed challenges and opportunities for additional project ideas. Participants also generated a list of priority projects for implementation.

Overview of Climate Trends and Projections

The following climate impacts synthesis provided the foundation for the climate exposure component of the vulnerability assessment. A table of observed and projected climatic changes and impacts, including island-specific trends and projections, can be found in Appendix A.

Air Temperature

Records indicate that global surface air temperatures have increased at an average rate of 0.07°C (0.13°F) per decade since 1880, with more rapid warming at 0.17°C (0.3°F) per decade since 1970 (NOAA NCEI 2016a). In the Hawaiian Islands, similar rates have been observed, with records indicating that air temperatures have increased by 0.04°C (0.07°F) per decade between 1919–2006, with accelerated increases of 0.2°C (0.36°F) per decade since 1975 (Giambelluca et al. 2008). High-elevation sites, those at more than 800 m (2.625 ft), warmed by 0.27°C (0.49°F) per decade, compared to 0.09°C (0.16°F) per decade for low-elevation sites (Giambelluca et al. 2008). For example, the annual number of freezing days on Haleakalā declined between 1958–2009 (Hamilton 2013), and temperatures at the summit of Mauna Loa increased 1.5°C (2.7°F) per decade between 1958–2008 (de Silva 2012). In general, there is high certainty that air temperatures will continue to increase in the Hawaiian Islands. Projections include increases of 2°C (3.6°F) to 3.5°C (6.3°F) in mean annual temperature by 2100, with more significant increases at higher elevations (Zhang et al. 2016), and more frequent and intense extreme heat days (Keener et al. 2012).

Precipitation

Precipitation is strongly influenced by high interannual and interdecadal climatic variability as a result of the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO events, including El Niño (warm phase) and La Niña (cold phase), typically persist for 6–18 months and shift every 3–7 years (Cane 2005), while PDO phases typically cycle every 20–30 years (D'Aleo and Easterbrook 2010). Both ENSO and PDO events influence rainfall patterns, storms, trade winds, and ocean temperature. In the Hawaiian Islands, La Niña events have historically been correlated with higher precipitation while El Niño events have been correlated with lower precipitation, and correlations have been magnified by changes in the PDO phase; however, in the last decade there has been a decoupling of these modes and precipitation patterns (Chu & Chen 2005).

Since 1920, precipitation has decreased across the Hawaiian Islands, with the strongest drying trends occurring over the last 30 years (Frazier et al. 2016; Frazier & Giambelluca 2017). Observed rainfall patterns are highly variable between islands and between dry (May–October) and wet (November–April) seasons (Frazier & Giambelluca 2017). Dry-season precipitation has declined for most areas on Maui and Lānaʻi, particularly in leeward sites; across Kauaʻi and Oʻahu, with the largest declines at high elevations; and across the island of Hawaiʻi, with the greatest declines on the leeward side. Kahoʻolawe experienced more modest drying, while Molokaʻi experienced a slight increase per decade (Frazier & Giambelluca 2017). Maui experienced the greatest wet-season precipitation decline of any island in the state, with decreases of 27.6 mm (1.08 in) per decade from 1920–2012. Wet-season precipitation has also declined across Kauaʻi, with the largest declines at high elevations and on the windward side; across Oʻahu, with the largest declines at moderate and high elevations, especially on the leeward side; and across the island of Hawaiʻi, with the largest declines on the leeward side, especially in the Kona region (Frazier & Giambelluca 2017).

Projections of future precipitation trends for the Hawaiian Islands are highly uncertain. These projections vary with respect to both the direction and magnitude of change (i.e. whether precipitation will increase or decrease and by how much). Multiple possibilities exist for future trends in precipitation and vary by island. For example, Keener et al. (2013) project that by 2071–2099, future precipitation trends may include little to no change on Maui, no change to moderate decrease on Kauaʻi, slight decrease or no change on Oʻahu, and slight increase or no change on Hawaiʻi. Elison Timm et al. (2015) project mostly substantial decreases in precipitation, particularly in dry leeward areas, and slight increases in wet windward areas. Zhang et al. (2016) project mostly substantial increases in precipitation in windward areas with slight decreases in dry leeward areas.

Extreme Precipitation and Storms

Since 1980, there has been an overall trend toward decreased frequency of moderate to high-intensity extreme events, and an increase in the frequency of low-intensity events in the Hawaiian Islands (Chu et al. 2010). Tropical storm frequency was particularly high from 1982–1994 with a mean of 4.31 storms per year in the region; tropical storm frequency has increased slightly since 1966 (Chu 2002). Projections of extreme precipitation and tropical storm trends are highly uncertain because of the variability associated with precipitation projections. Possible future scenarios include a reduced frequency of extreme precipitation events by 2100, particularly in dry areas (Elison Timm et al. 2011, 2013); little to no change in the frequency of extreme precipitation events by 2100 (Takahashi et al. 2011); a significant increase in extreme precipitation events by 2100 (Zhang et al. 2016); and an increased frequency and strength of tropical storm activity (Murakami et al. 2013).

Wind and Circulation Patterns

Since the 1990s, the Pacific trade winds (both the Walker and Hadley cells) have increased, corresponding with a negative PDO phase (England et al. 2014). Trade wind direction has shifted from predominantly northeast to east between 1973 and 2009 (Garza et al. 2012), which represents a cyclical shift that is known to complete its cycle approximately every 45 years (Wentworth 1949). The frequency and strength of trade wind inversion (TWI) occurrence increased steadily between 1973 and 2013, with a sharp upward shift in TWI frequency, increasing by an average of 16% starting in 1990 (Longman et al. 2015); this shift has been associated with declines in high-elevation rainfall. ENSO and PDO events affect the proportion of days with a TWI. For example, during the warm phases of ENSO (El Niño) and PDO, mean TWI frequency is higher during the wet season and lower during the dry season, resulting in winter drought; during the cool phases of ENSO (La Niña) and PDO, mean TWI frequency is higher during the dry season and lower during the wet season, resulting in drier summers (Longman 2015).

Large-scale atmospheric processes drive wind and circulation patterns, which complicate projections. Surface winds are strongly influenced by oceanic factors. Surface wind speed projections by 2100 include decreases (Storlazzi et al. 2015), and slight increases in speed and frequency of strong wind days (Zhang et al. 2016). TWI frequency and height are variable depending on location, time of day, season, and phase of ENSO and PDO. An 8% increase in TWI frequency of occurrence is projected by 2100 (Zhang et al. 2016), while small (Zhang et al. 2016, 2017) to significant (~160 m [525 ft]; Lauer et al. 2013) decreases in TWI base height may also be possible. More frequent TWI events would likely limit montane vegetation and water resources (Cao et al. 2007; Fortini et al. 2015).

Streamflow

Between 1943 and 2008, there was an observed 22% decline in streamflow and 23% decline in baseflow compared to 1913–1943 across the Hawaiian Islands with larger declines during the dry season (Bassiouni & Oki 2013). Streamflow between January to March is typically low following El Niño events, and high following La Niña events; this pattern is enhanced during positive PDO phases (Bassiouni & Oki 2013). No regional streamflow projections are available, but if mean annual precipitation declines, there may be a continuing decline of low flows and baseflow, and flashier and/or more variable streamflow (Strauch et al. 2015). Streamflow is closely related to changes in both precipitation and temperature, but is also impacted by land cover and vegetation composition, substrate, groundwater withdrawals, and management practices.

Drought

More severe drought conditions in the Hawaiian Islands are typically associated with El Niño years (Chu et al. 2010; Dolling et al. 2009). Drought events have increased in duration across all islands since the 1950s (Chu et al. 2010). For example, on Mauna Kea, drought conditions were observed in 74% of months (98 of 132 months) between 2000 and 2011. Few studies have projected drought risk, although drought projections are closely related to those for precipitation, which are highly variable and associated with high uncertainty. Based on data from Chu et al. (2010) and Takahashi et al. (2011), Keener et al. (2012) note that most islands will likely experience similar or increasing drought risk by 2080–2100 compared to 1950–2009 drought trends. For example, there is potential increased drought risk for low- and mid-elevation leeward areas on Maui and Hawaiʻi, west Molokaʻi, Lānaʻi, Kahoʻolawe, and low-elevation leeward areas of Kauaʻi and Oʻahu; and potential decreased risk on mid-elevation windward slopes of Haleakalā, and at the highest elevations on Kauaʻi and Oʻahu (Keener et al. 2012).

Soil Moisture

No information is available about soil moisture trends in the Hawaiian Islands over time. However, soil moisture is typically lower on leeward sides and higher on windward sides (Longman 2015), and lower in the dry season than during the wet season (Dolling et al. 2005). Soil moisture is primarily dependent on precipitation amount, as well as soil properties, slope, temperature, humidity, and vegetation types present. Warmer temperatures and/or low humidity reduce soil moisture by increasing evaporation and plant transpiration. Although precipitation projections are highly uncertain, increased temperatures are very certain, and are likely to result in reduced soil moisture under most precipitation possibilities. Soil moisture is likely to decline in the future, especially if precipitation decreases as air temperatures increase (Longman 2015).

Stream Temperature

No information is available about stream temperature trends in the Hawaiian Islands over time. However, stream temperatures are typically lower in the wet season than during the dry season (MacKenzie et al. 2013), and lower in forested areas compared to urban areas (Brasher 2003). No regional studies have been published on stream temperature projections, but researchers generally agree that stream temperatures will increase as air temperature increases (Gehrke et al. 2011).

Wildfire

There has been an observed increased in area burned in the Hawaiian Islands between 1904 and 2011 with high interannual variability (Trauernicht et al. 2015). Wildfire frequency is positively correlated with human activity and population growth (Trauernicht et al. 2015). From 1976–1997, large wildfires typically occurred during the spring and summer after an El Niño event (Chu et al. 2002). The majority of wildfires typically occur between June and August when conditions are warm and dry; these summer fires account for 57% of the annual area burned on Maui, 39% of the annual area burned on Kauaʻi, 60% of the annual area burned on Oʻahu, and 31% of the annual area burned on Hawaiʻi (Chu et al. 2002). Although there are no wildfire projections available, wildfire is strongly correlated with dry conditions, and precipitation projections are highly uncertain. However, wildfire will likely increase if drought events increase (Trauernicht et al. 2015). The probability of fire occurrence in grassland, shrubland, and forest areas on the leeward side of the island of Hawaiʻi is expected to roughly double; wildfire risk is highest at mid-elevation sites and in grasslands (Wada et al. 2017).

Sea Level Rise

Warming air and ocean temperatures cause rising sea levels due to melting glaciers and ice sheets, and increased heat uptake and thermal expansion of the oceans. On average, the global sea level has risen eight inches since 1880 (Walsh et al. 2014). In the Hawaiian Islands, extreme sea level rise events (a combination of sea level rise, tides, and storms) have increased in frequency from every 20 years to every five years (Firing & Merrifield 2004). These increases have been measured at stations throughout the islands, ranging from an average increase of 1.26 mm/year (0.06 in/year) at Oʻahu's Mokuoloe station to 3.01 mm/year (0.13 in) at Hawaiʻi's Hilo station (NOAA/National Ocean Service 2017). Beaches have been steadily eroding throughout the region since the early 1900s, including 60% of Oʻahu's beaches and 85% of Maui's beaches (Romine & Fletcher 2012).

Although there is widespread agreement that the rate of sea level rise will continue to increase, projections vary widely depending on whether or not they include large-scale climate variability (ENSO, PDO) and the contribution of ice-sheet collapse. For example, by 2100, global sea level projections range from 0.3–1.2 m (0.98–3.9 ft) (Kopp et al. 2014) to 0.3–2.5 m (0.98–8.2 ft) (Sweet et al. 2017). Relative sea level may be higher in the Hawaiian Islands compared to global levels, ranging from 0.4 to 3.3 m (1.3 to 10.8 ft; Sweet et al. 2017). Generally, models agree that the rate of rise is expected to be faster than previously observed. Beaches are expected to experience exacerbated rates of erosion compared with historic loss; for example, by mid-century, 87% of Maui's beaches and 100% of Kauaʻi's beaches are likely to be eroding. Sea level rise will continue to contribute to increased saltwater intrusion, shoreline loss, marine inundation, and groundwater inundation (Cooper et al. 2013; Ferguson & Gleeson 2012; Kane et al. 2015; Rotzoll & Fletcher 2013).

Coastal Flooding and Saltwater Intrusion

Sea level rise has contributed to both marine inundation (i.e. flooding in areas with a direct hydrological connection to the ocean) and groundwater inundation (i.e. flooding in areas with an indirect hydrological connected due to elevated water table (Rotzoll & Fletcher 2013). Although there are no downscaled sea level rise projections for the region, it is likely that coastal flooding and saltwater intrusion will increase as sea levels rise (Rotzoll et al. 2010). Saltwater intrusion is also impacted by recharge rates and groundwater pumping/withdrawals; withdrawals likely play a larger role in saltwater intrusion than does sea level rise (Ferguson & Gleeson 2012).

Sea Surface Temperature

Globally, average sea surface temperatures have increased 0.9°C (1.5°F) over the past century (NOAA NCEI 2016b). Between 1970 and 2010, there was an observed 0.07°C to 0.23°C (0.13°F to 0.41°F) increase per decade in the Pacific Ocean (Australian Bureau of Meteorology & CSIRO 2011; IPCC 2013). In general, sea surface temperatures correspond to changes in air temperature and large-scale climate variability events, such as ENSO and PDO. Sea surface temperature patterns over the tropical Pacific are influenced by ocean circulation (e.g., currents and mixing) and surface flux adjustments (e.g., wind speed, evaporation). Ocean temperatures are projected to increase by 2100. Global temperatures are projected to increase 0.71°C to 2.73°C (1.28°F to 4.91°F) by 2090–2099 compared to 1990–1999 measurements (Bopp et al. 2013). Pacific Ocean temperatures are projected to increase 1.3°C and 2.7°C (2.3°F and 4.9°F) by 2100 compared to 1970–2010 measurements (Australian Bureau of Meteorology & CSIRO 2011).

Ocean pH

As atmospheric carbon dioxide (CO_2) levels have increased, oceans have absorbed approximately one-third of the total human-generated CO_2 emissions (NRC 2010). Since 1750, the mean surface ocean pH decreased from 8.2 to 8.1 units (IPCC 2013), which corresponds to a 26% increase in ocean acidity (Eversole & Andrews 2014). From 1998–2007, surface pH in the Central North Pacific decreased by 0.0019 to 0.0002 per year (Dore et al. 2009). There is high certainty that ocean pH will decline because changes in pH correspond very closely to the amount of atmospheric CO_2 absorbed by oceans (e.g., a ~30% increase in CO_2 absorbed by oceans has been associated with a ~30% drop in pH since pre-industrial times; Bopp et al. 2013; Gattuso et al. 2015; IPCC 2013).

Vulnerability Assessment and Adaptation Planning Results: Overall Trends

Vulnerability Assessment Summary

The vulnerabilities for all habitats and ecosystem services across the main Hawaiian Islands are summarized in Figures 3–6. These figures are plotted by potential impact (i.e. climate and non-climate sensitivity and exposure) and adaptive capacity, with those habitats or services appearing in the upper left quadrant evaluated as less vulnerable (i.e. those with low potential impact, high adaptive capacity) than those appearing in the lower right quadrant (i.e. those with high potential impact, low adaptive capacity). The results and trends presented are comparable only within the habitats and ecosystem services considered here, and are not standardized in any way to other climate change vulnerability assessments. The information supporting these results is available in the individual vulnerability assessment syntheses,[6] and should be referred to before using the overall results and trends in decision-making.

One significant finding for this vulnerability assessment: every resource evaluated received a moderate or higher vulnerability ranking. This is unusual when compared to other vulnerability assessments, particularly on the U.S. mainland, where at least one resource (e.g., habitat, species) typically receives a lower vulnerability ranking. Moderate or higher vulnerability rankings in this assessment are likely due to several factors including: (1) the significant impacts of non-climate stressors such as invasive species, habitat conversion, and changes in disturbance regimes that have resulted in species loss and habitat degradation; (2) the (comparatively) narrow thermal ranges that tropical species occupy; and (3) island endemism and limited ability to move upslope in response to climate warming.

Terrestrial Habitats

Across islands, most terrestrial habitats were evaluated as having overall moderate vulnerability (Table 3; Figure 3). Five terrestrial habitats — Hawaiʻi alpine/subalpine and dry forest, Maui Nui dry forest, and Oʻahu mesic and dry forests — were the exceptions, and were evaluated as having moderate-high vulnerability. Overall, Hawaiʻi dry forest and Oʻahu mesic forest were the most vulnerable, with high sensitivity and exposure to both climate and non-climate stressors and low adaptive capacity. Low adaptive capacity evaluations were due to low geographic extent and integrity and a low ability to resist and/or recover from the impacts of stressors.

Table 3. Overall vulnerabilities for terrestrial habitats.

Island	Habitat	Overall Vulnerability
Hawaiʻi	Alpine/Subalpine	Moderate-High
Hawaiʻi	Dry Forest	Moderate-High
Maui Nui	Dry Forest	Moderate-High
Oʻahu	Dry Forest	Moderate-High
Oʻahu	Mesic Forest	Moderate-High
Maui Nui	Alpine/Subalpine	Moderate
Hawaiʻi	Lowland Wet Forest	Moderate
Hawaiʻi	Mesic/Montane Wet Forest	Moderate
Kauaʻi	Mesic Forest	Moderate
Maui Nui	Mesic Forest	Moderate

[6] Available at http://ecoadapt.org/programs/awareness-to-action/HawaiianIslands/products

Island	Habitat	Overall Vulnerability
Kauaʻi	Wet Forest	Moderate
Maui Nui	Wet Forest	Moderate
Oʻahu	Wet Forest	Moderate

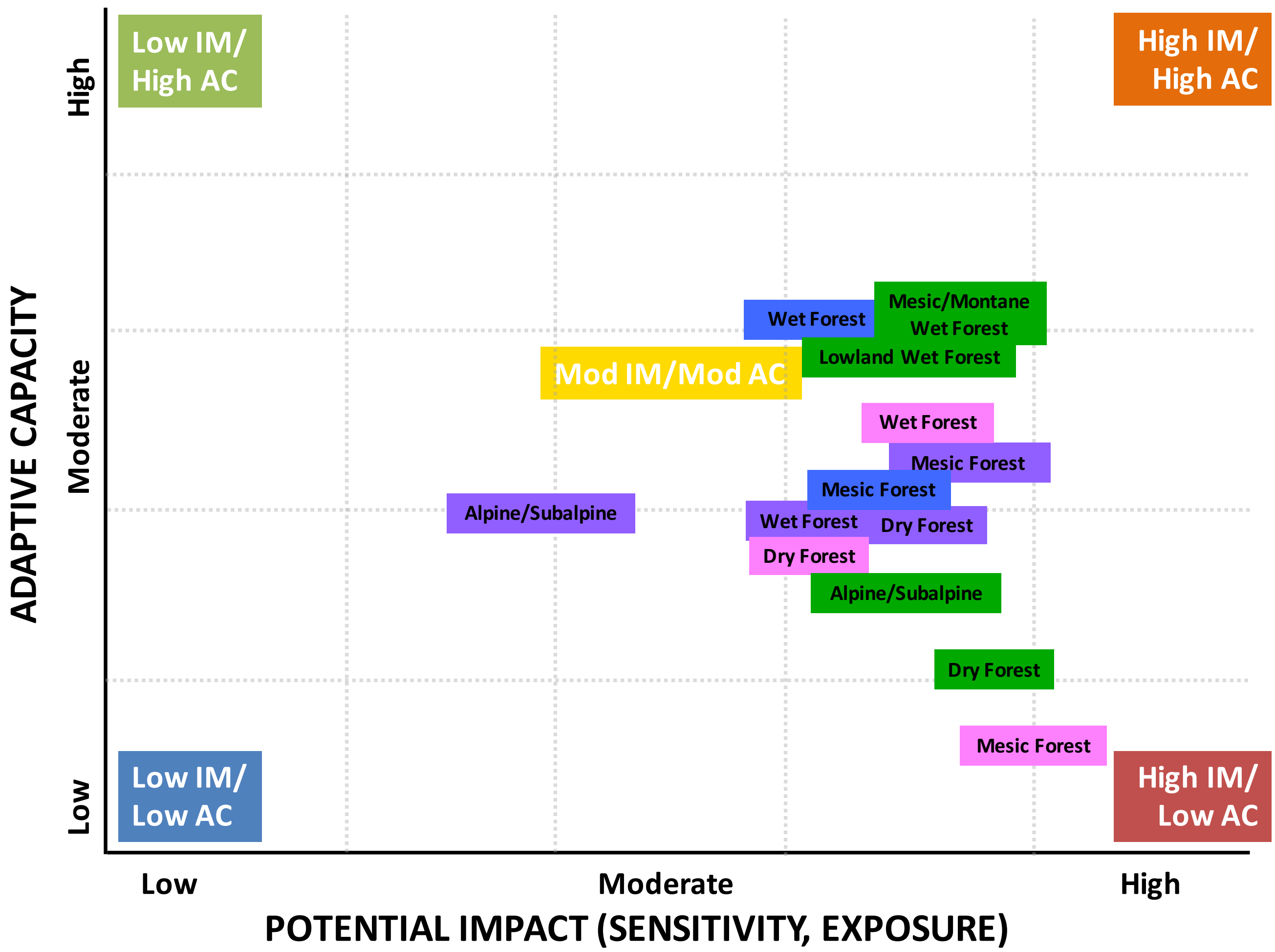

Figure 3. Overall vulnerabilities of 13 terrestrial habitats based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. Color code: Maui Nui (purple), Oʻahu (pink), Kauaʻi (blue), Hawaiʻi (green).

Alpine and subalpine habitats on Maui and Hawaiʻi were both evaluated as having low-moderate adaptive capacity and moderate-high or high sensitivity and exposure to projected climate changes. Alpine and subalpine habitats are most sensitive to factors that increase water stress, including changes in the amount and timing of precipitation, drought, and soil moisture, as well as changes in the frequency of the TWI that could exacerbate dry conditions. Alpine and subalpine habitats on Hawaiʻi received a higher overall vulnerability ranking (i.e. moderate-high) primarily due to the impact of non-climate stressors (e.g., roads, highways and trails; invasive species; recreation; development), which reduce habitat extent and fragment or degrade remaining habitat areas. Conversely, Maui alpine and subalpine habitats received an overall moderate vulnerability ranking, due to the lower impact of non-climate stressors on these habitats.

All dry forest habitats were evaluated as having moderate-high sensitivity and exposure to projected climate changes and low or low-moderate adaptive capacity. Dry forests are primarily sensitive to climate changes that reduce available moisture, including changes in precipitation patterns and drought, as well as those changes that increase vulnerability to invasive grasses, including fires and storm damage. Similar to alpine and subalpine habitats, variations in the effect of non-climate stressors on dry forest habitats appear to be the primary driver of differences between islands. Non-climate stressors on both Maui Nui and Hawaiʻi were evaluated as having a high impact on dry forest habitats whereas Oʻahu was evaluated as moderate. Significant non-climate stressors for all dry forest habitats include residential and commercial development, agriculture, invasive flammable grasses and trees/shrubs, and invasive ungulates and mammalian predators. Hawaiʻi dry forest habitats were also evaluated as having lower adaptive capacity than those on Maui Nui or Oʻahu, due to lower diversity, public value, and societal support scores.

Aside from Oʻahu mesic forest, all mesic and wet forests were evaluated as having overall moderate vulnerability, with moderate-high sensitivity and exposure to climate and non-climate stressors and moderate to moderate-high adaptive capacity. Oʻahu mesic forests were scored as having overall moderate-high vulnerability, with high sensitivity and exposure to climate and non-climate stressors and low adaptive capacity. Oʻahu mesic forests are sensitive to climatic changes that alter water availability, such as changes in precipitation and soil moisture, drought, increased air temperature, and changes in trade winds, which affect forest distribution, productivity, and vegetative composition. Oʻahu mesic forests exhibit low adaptive capacity due to low geographic extent, high levels of current invasion, low public value and capacity to manage or alleviate impacts, and a low ability to resist and/or recover from the impacts of stressors. In general, across islands, mesic forests received slightly higher vulnerability rankings compared to wet forests.

Aquatic Habitats

The majority of the 12 habitats assessed were scored as having moderate-high sensitivity and exposure to projected climate changes and low-moderate to moderate adaptive capacity (Figure 4). In general, aquatic habitats are sensitive to climate changes that reduce water availability and quality, including shifts in precipitation amount and timing, drought, and extreme precipitation events and tropical storms. Two aquatic habitats — Kauaʻi and Oʻahu lowland wetlands — were evaluated as having the highest overall vulnerability ranking (moderate-high; Table 4) due to a combination of slightly higher scores for sensitivity and exposure and lower scores for adaptive capacity. Maui Nui groundwater and seeps and springs habitats were assessed as having the highest sensitivity and exposure to climate and non-climate stressors, with non-climate stressors driving the higher overall score. Significant non-climate stressors included residential and commercial development, pollution and poisons, and water diversions, which negatively impact groundwater recharge and water quality. Kauaʻi upland wetlands were evaluated as having the highest adaptive capacity (moderate-high) of all aquatic habitats due to a moderate-high ability to resist and/or recover from the impacts of stressors, high habitat diversity, high societal value and support, and a high ability to manage or alleviate climate impacts.

Table 4. Overall vulnerabilities of aquatic habitats.

Island	Habitat	Overall Vulnerability
Kauaʻi	Lowland Wetlands	Moderate-High
Oʻahu	Lowland Wetlands	Moderate-High
Hawaiʻi	Freshwater Wetlands/Ponds/Brackish	Moderate
Hawaiʻi	Groundwater	Moderate
Maui Nui	Groundwater/Seeps/Springs	Moderate
Hawaiʻi	Lowland Freshwater Wetlands	Moderate
Hawaiʻi	Streams	Moderate
Kauaʻi	Streams	Moderate
Maui Nui	Streams	Moderate
Oʻahu	Streams	Moderate
Kauaʻi	Upland Wetlands	Moderate
Oʻahu	Upland Wetlands	Moderate

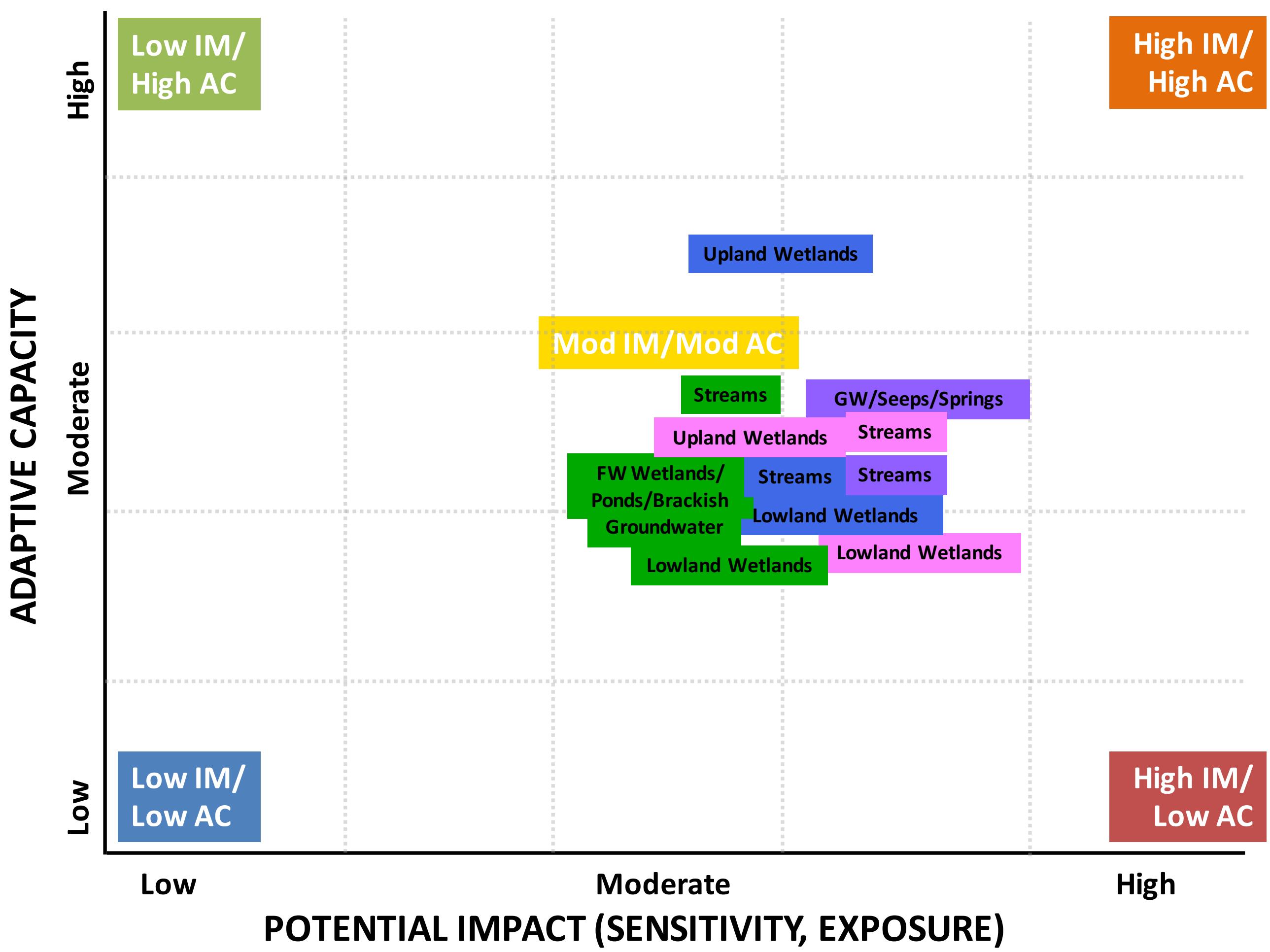

Figure 4. Overall vulnerabilities of 12 aquatic habitats based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. GW=groundwater. FW=freshwater. Color code: Maui Nui (purple), Oʻahu (pink), Kauaʻi (blue), Hawaiʻi (green).

Coastal Habitats

Of the 15 coastal habitats evaluated, eight were assessed as having overall moderate-high or high vulnerability and seven were assessed as having moderate vulnerability (Table 5). Each island (or island group) had at least one coastal habitat evaluated as moderate-high or high vulnerability, with Kauaʻi assessed as having three highly vulnerable coastal habitats: sandy beaches/sand dunes, caves, and rocky shorelines/cliffs. All coastal habitats were assessed as having moderate-high or high sensitivity and exposure to climate and non-climate stressors, but exhibited highly variable degrees of adaptive capacity, ranging from low (e.g., caves, anchialine pools; Figure 5) to moderate-high (e.g., cliffs/beaches, estuaries/tidal wetlands/coastal freshwater).

Table 5. Overall vulnerabilities of coastal habitats.

Island	**Habitat**	**Overall Vulnerability**
Kauaʻi	Sandy Beaches/Sand Dunes	High
Oʻahu	Sandy Shorelines	High
Hawaiʻi	Anchialine Pools	Moderate-High
Maui Nui	Anchialine Pools	Moderate-High
Maui Nui	Beaches/Shorelines	Moderate-High
Kauaʻi	Caves	Moderate-High
Oʻahu	Estuaries	Moderate-High
Kauaʻi	Rocky Shorelines/Cliffs	Moderate-High
Hawaiʻi	Cliffs/Beaches	Moderate
Kauaʻi	Cultural Coastal	Moderate
Hawaiʻi	Estuaries	Moderate
Kauaʻi	Estuaries/Coastal Wetlands	Moderate
Maui Nui	Estuaries/Tidal Wetlands/Coastal Freshwater	Moderate
Hawaiʻi	Fishponds	Moderate
Oʻahu	Rocky Shorelines	Moderate

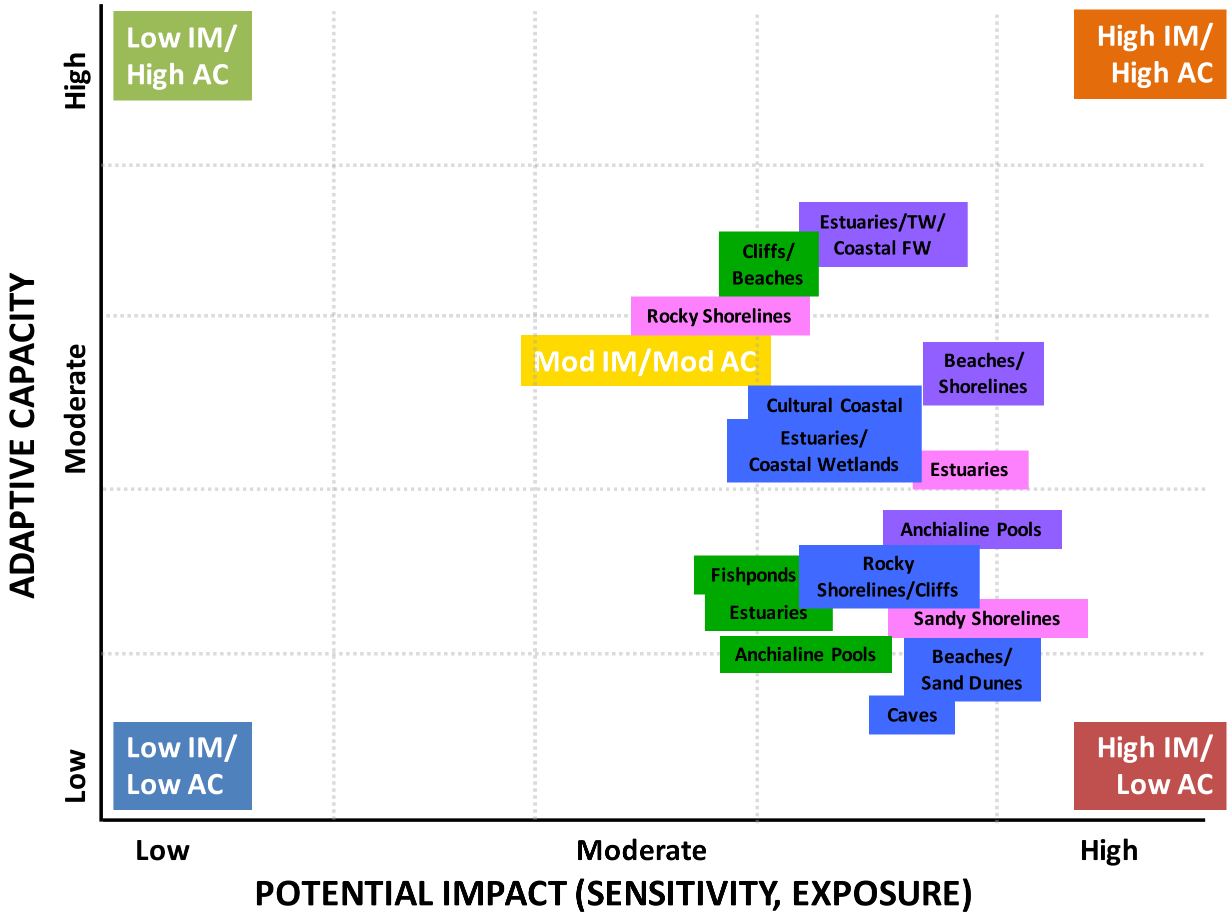

Figure 5. Overall vulnerabilities of 15 coastal habitats based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. TW=tidal wetlands. FW=freshwater. Color code: Maui Nui (purple), Oʻahu (pink), Kauaʻi (blue), Hawaiʻi (green).

Overall, Kauaʻi sandy beaches/dunes and Oʻahu sandy shorelines were the most vulnerable, with high sensitivity and exposure to both climate and non-climate stressors and low or low-moderate adaptive capacity. Sandy beaches and shorelines exhibit sensitivity to sea level rise, tropical storms, and extreme precipitation events that accelerate coastal erosion and increase susceptibility to inundation. Non-climate stressors such as coastal development, roads, recreation, and invasive species can exacerbate coastal habitat loss and degradation. Maui Nui beaches and shorelines were also evaluated as quite vulnerable (moderate-high vulnerability), and exhibited similarly high sensitivity and exposure to climate and non-climate stressors. However, Maui Nui beaches and shorelines were assessed as having higher adaptive capacity than those on Kauaʻi and Oʻahu (moderate vs. low), as many of these habitats are highly managed and have some type of protected status and are highly valued by the public.

Anchialine pools on both Hawaiʻi and Maui Nui were evaluated as having overall moderate-high vulnerability, due to a combination of moderate-high or high sensitivity and exposure to climate and non-climate stressors and low or low-moderate adaptive capacity. Anchialine pools are sensitive to changes in pool depth and salinity, which can be caused by climatic changes such as shifts in precipitation, drought, tropical storms, sea level rise, and saltwater intrusion, as well as non-climate stressors such as groundwater development, water diversions, invasive species, and residential and commercial development. Anchialine pools exhibit lower adaptive capacity due to habitat isolation and barriers to new pool formation (e.g., development, roads), low societal support and capacity to manage or alleviate impacts, and a low ability to resist and/or recover from the impacts of stressors. Kauaʻi cultural coastal habitats, which include salt ponds, fishponds, kalo (taro), and iwi, and Hawaiʻi fishponds were evaluated as having overall moderate vulnerability.

Rocky shorelines, including Hawaiʻi cliffs/beaches, Kauaʻi rocky shorelines/cliffs and caves, and Oʻahu rocky shorelines, ranged from moderate-high to high sensitivity and exposure to climate and non-climate stressors. These habitats are sensitive to climatic factors that increase erosion and inundation and alter sediment delivery, such as sea level rise, wind, and tropical storms. Compared to sensitivity and exposure results, adaptive capacity evaluations exhibited high variability, with Kauaʻi rocky shorelines/cliffs and caves receiving low adaptive capacity scores and Oʻahu rocky shorelines and Hawaiʻi cliffs/beaches receiving moderate-high scores. Kauaʻi rocky shorelines and caves are isolated habitats with a low ability to resist and/or recover from the impacts of stressors. Additionally, while these habitats have higher public value, there is little ability to manage or alleviate the impacts of stressors.

Most estuarine habitats were evaluated as having moderate vulnerability, with Oʻahu estuaries as the exception (moderate-high vulnerability). All estuaries were assessed as having moderate-high sensitivity and exposure to climatic changes such as sea level rise, saltwater intrusion, altered streamflow regimes, and increased sea surface temperature. Similar to rocky shorelines, adaptive capacity evaluations for estuarine habitats varied significantly (low to moderate-high). Hawaiʻi estuarine habitats were assessed as having low adaptive capacity, due to habitat isolation, low habitat diversity, low societal support for management, and a low likelihood of managing or alleviating the impacts of stressors. Conversely, Maui Nui estuaries and tidal wetlands were evaluated as having much higher adaptive capacity (moderate-high), due to higher scores for habitat diversity and likelihood of managing or alleviating the impacts of stressors.

Ecosystem Services

Of the 20 ecosystem services evaluated, 13 were assessed as having overall moderate-high or high vulnerability and seven were assessed as having low to moderate vulnerability (Table 6). Each island had at least two ecosystem services evaluated as moderate-high or high vulnerability (Table 6), with Maui Nui assessed as having five highly vulnerable services: cultural knowledge and heritage values, flood and erosion control, fresh water, food and fiber, and recreation and tourism. Potential impact (i.e. sensitivity and exposure) scores were quite variable for all ecosystem services evaluated across the islands, ranging from low (e.g., food/fiber: invasive species, aesthetic values; Figure 6) to high (e.g., Oʻahu and Maui Nui cultural knowledge/heritage values). Similarly, adaptive capacity scores ranged from low (e.g., cultural knowledge/heritage values) to moderate-high (e.g., food fiber: invasive species, fresh water).

Table 6. Overall vulnerabilities of ecosystem services.

Island	**Habitat**	**Overall Vulnerability**
Maui Nui	Cultural Knowledge/Heritage Values	High
Oʻahu	Cultural Knowledge/Heritage Values	High
Maui Nui	Flood/Erosion Control	High
Hawaiʻi	Food/Fiber	High
Kauaʻi	Food/Fiber: Native species	High

Island	Habitat	Overall Vulnerability
Maui Nui	Fresh Water	High
O‘ahu	Fresh Water	High
Hawai‘i	Cultural Knowledge/Heritage Values	Moderate-High
Hawai‘i	Flood/Erosion Control	Moderate-High
Kaua‘i	Flood/Erosion Control	Moderate-High
Maui Nui	Food/Fiber: Reef/nearshore, native forest plants	Moderate-High
Kaua‘i	Fresh Water	Moderate-High
Maui Nui	Recreation/Tourism	Moderate-High
Maui Nui	Aesthetic	Moderate
Kaua‘i	Cultural Knowledge/Heritage Values	Moderate
O‘ahu	Flood/Erosion Control	Moderate
Maui Nui	Food/Fiber: Canoe plants	Moderate
Hawai‘i	Fresh Water	Moderate
Kaua‘i	Food/Fiber: Non-native species	Low-Moderate
Kaua’i	Food/Fiber: Invasive species	Low

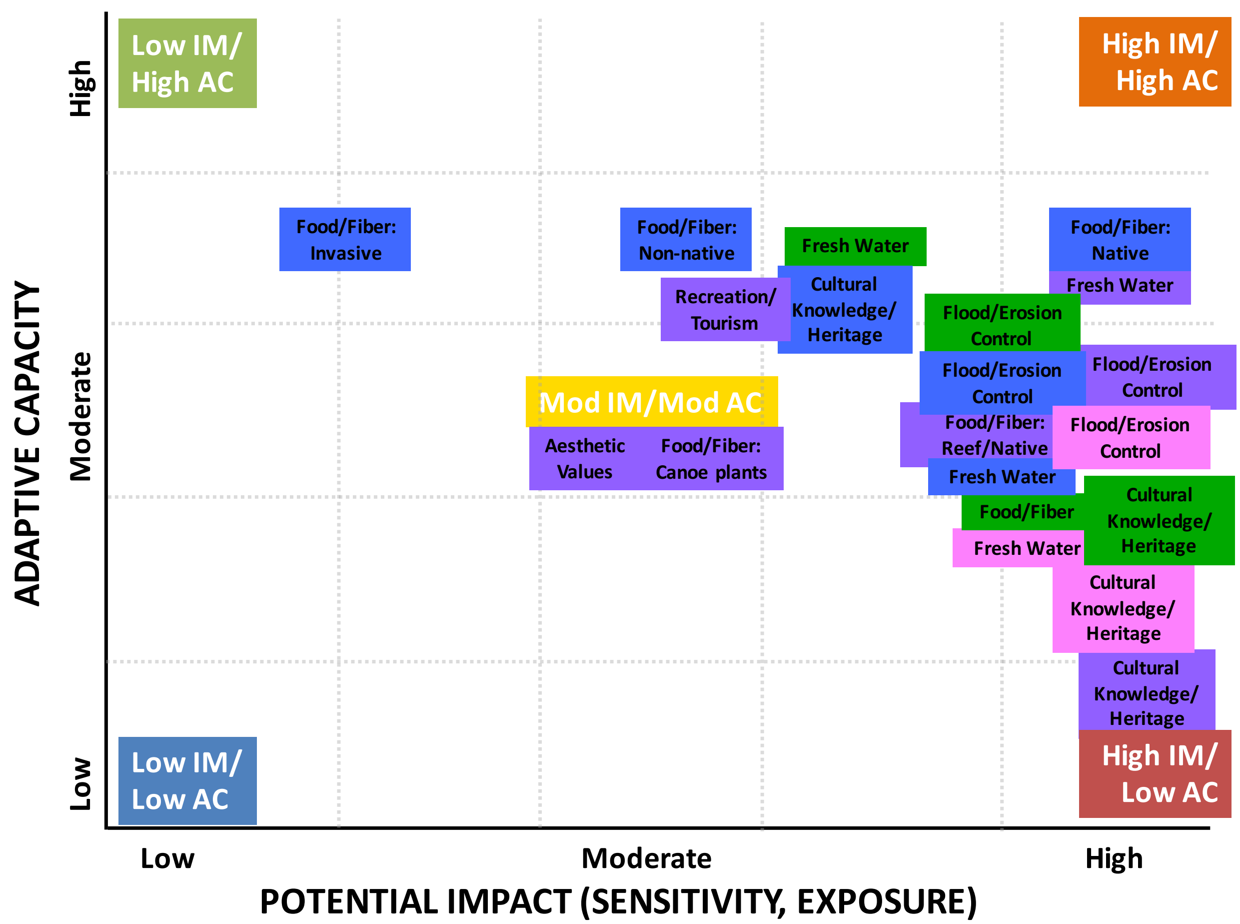

Figure 6. Overall vulnerabilities of 20 ecosystem services based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Services listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. Color code: Maui Nui (purple), O‘ahu (pink), Kaua‘i (blue), Hawai‘i (green).

Overall, cultural knowledge and heritage values were assessed as having moderate-high or high sensitivity to climate and non-climate stressors and low to moderate-high adaptive capacity (Figure 6). Cultural knowledge and heritage values are vulnerable to climatic changes such as sea level rise, coastal erosion, wildfire, and flooding, which impact the health and integrity of ecosystems and/or native species as well as damage or destroy valued cultural assets and heritage sites. Hawaiʻi, Maui Nui, and Oʻahu cultural knowledge and heritage values were scored as having much lower adaptive capacity (i.e. low or low-moderate) compared with Kauaʻi, which scored adaptive capacity as moderate-high due to greater public value and support and the increasing integration of these values into natural resource management decision-making.

In general, flood and erosion control services were evaluated similarly across islands. All islands assessed flood and erosion control as having high sensitivity and exposure to climate and non-climate stressors. Climatic factors such as extreme precipitation and flash flood events can overwhelm this service, while non-climate stressors such as residential and commercial development, roads, and water diversions can exacerbate impacts by altering surface runoff patterns. Adaptive capacity of flood and erosion control was evaluated as moderate or moderate-high across islands, resulting in minor differences in overall vulnerability rankings.

Overall vulnerability rankings for food and fiber were highly variable, ranging from low (Kauaʻi food/fiber: invasive species) to high (Hawaiʻi food/fiber and Kauaʻi food/fiber: native species). Food and fiber ecosystem services are vulnerable to climatic factors that impact water quality and/or supply, as well as non-climate stressors that reduce habitat extent, introduce pollutants, or reduce available water supply (e.g., development, pollution, invasive species). In particular, Hawaiʻi food and fiber appears to exhibit higher vulnerability due to high sensitivity and exposure to climate and non-climate stressors and low-moderate adaptive capacity. Kauaʻi food and fiber, invasive species and non-native species, were both assessed as having lower overall vulnerability, as these species may be less sensitive to disturbances and may actually thrive following a disturbance (e.g., strawberry guava).

Fresh water was evaluated as having moderate-high or high sensitivity and exposure to projected climate changes across islands. Fresh water is primarily sensitive to climate changes that reduce available water supply, including changes in precipitation patterns and drought, air temperature increases, and tropical storms. Similar to other ecosystem services, variations in adaptive capacity scores for fresh water appears to be the primary driver of differences between islands. Both Maui Nui and Hawaiʻi fresh water were assessed as having moderate-high adaptive capacity, whereas Kauaʻi and Oʻahu received moderate and low-moderate rankings, respectively. Lower adaptive capacity evaluations for Kauaʻi and Oʻahu were attributed to a lower likelihood of managing or alleviating climate impacts on fresh water.

Inter-island Comparison

Vulnerability assessment figures for each of the main Hawaiian Islands can be found in the individual island sections that follow. Overall, more Oʻahu habitats received higher vulnerability rankings (63% received moderate-high or high vulnerability rankings) compared with Hawaiʻi (43%), Maui Nui (38%), and Kauaʻi (29%). In general, this trend was due to moderate-high or high rankings of sensitivity and exposure to climate and non-climate stressors and the limited adaptive capacity of Oʻahu habitats. Maui Nui habitats had the widest spread in terms of potential impact (i.e. ranging from low-moderate impact for alpine/subalpine habitats to high potential impact for beaches and shorelines) and the narrowest spread for adaptive capacity (almost all habitats received low-moderate or moderate adaptive capacity rankings), indicating that natural resource managers may want to identify ways in which to bolster adaptive capacity for all habitats. Conversely, Kauaʻi habitats had the narrowest spread in terms of potential impact (all habitats received moderate-high or high rankings) and the widest spread for adaptive capacity (ranging from low adaptive capacity for caves to moderate-high adaptive capacity for upland wetlands), indicating that natural resource managers may want to identify actions that help reduce sensitivity and exposure for all Kauaʻi habitats.

Trends for ecosystem services were slightly different, with Maui Nui services receiving higher vulnerability rankings (83% received moderate-high or high vulnerability rankings) compared with Hawaiʻi (75%), Oʻahu (67%), and Kauaʻi (50%). Interestingly, Maui Nui ecosystem services also had the widest spread for adaptive capacity, ranging from low adaptive capacity (cultural knowledge/heritage values) to moderate-high (fresh water). Oʻahu ecosystem services had the narrowest spread for both potential impact (all services received high rankings) and adaptive capacity (low-moderate to moderate). Similar to Oʻahu, Hawaiʻi ecosystem services also had a narrow spread for potential impact (all services received moderate-high or high rankings). Conversely, Kauaʻi services had the widest spread for potential impact, ranging from low (food/fiber: invasive species) to high (food/fiber: native species).

Adaptation Summary

Adaptation workshop participants were asked to define management goals, strategies, and actions (Figure 7). A *goal* is a desired result for a given resource. An *adaptation strategy* is a general statement of how to reduce vulnerabilities or increase resilience of current management goals. An *adaptation action* is a specific activity that facilitates progress towards achieving an adaptation strategy.

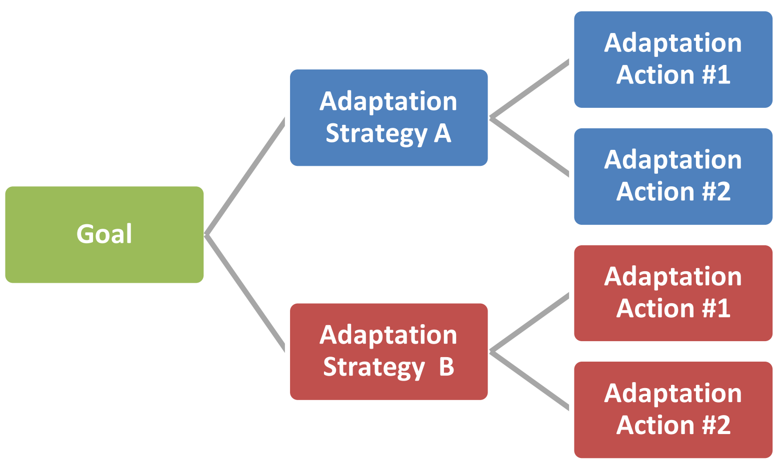

Figure 7. Relationship between adaptation goals, strategies, and actions.

Participants evaluated **current management goals and actions** in light of the results of the vulnerability assessment to determine whether, in their current form, these actions help to reduce identified climate and non-climate vulnerabilities and/or how they can be modified to better address the challenges presented by a changing climate. Participants also explored **potential future management goals and adaptation strategies**, and identified more specific adaptation actions to reduce vulnerabilities. Across the Hawaiian Islands, core conservation goals and activities identified included protecting and restoring **native ecosystems and rare species**; reducing current and future threats posed by **invasive species**; maintaining and improving regional **water resources**; mainstreaming climate change into **land-use**

planning; and preserving and enhancing **cultural resources and practices** under changing climate conditions (Table 7). Several themes emerged from the adaptation strategies designed, such as:

- Restoring and protecting native ecosystem structure and function;
- Reducing non-climate stresses that hinder the ability of habitats and species to resist or recover from climate impacts;
- Identifying and protecting potential habitat migration zones and climate refugia (i.e. areas likely to be less affected by climate change);
- Integrating climate risk and adaptation into decision-making and planning processes;
- Increasing research and monitoring on climatic and non-climatic impacts on habitats, species, and ecosystem services; and
- Increasing community education and engagement on climate-informed biocultural management.

Table 7. Example adaptation strategies and actions grouped by conservation activity.

Conservation Activity	Adaptation Strategies and Actions
Native Ecosystems and Rare Species Conservation	• Identify and protect remnant native habitats • Build fire-resilient native communities (e.g., plant and seed fire-resilient species, remove flammable non-native species, establish fuel breaks) • Develop more efficient technologies for habitat restoration (e.g., improve methods for native species propagation) • Monitor the long-term effectiveness of outplanting and rare species management • Increase research and modeling on potential species range shifts • Identify and promote climate-adapted species compositions • Prioritize planting of native species that thrive under a wide variety of conditions (e.g., generalist species, resilient native/endemic species) • Map transitional areas between dry and mesic habitat to identify and prioritize protection for mesic areas that may convert to dry habitat • Create a digital and physical genetic database to protect remaining native and rare species, using both in situ (outplanting) and ex situ (seed storage) methods
Invasive Species Management	• Create a climate-informed invasive species risk assessment tool • Increase biosecurity measures to address new invasive and non-native species introductions • Research the range of conditions invasive species can tolerate to determine areas vulnerable to potential invasive expansion • Increase public education and outreach about invasive species risk and prevention (e.g., explain the importance of sterilizing recreation equipment) • Prioritize fencing in more pristine areas that currently lack invasive species • Create and manage buffer areas to protect high-value ecosystems from invasive species that pose the greatest threat (e.g., remove mosquito breeding areas, prioritize removal of fire-adapted invasive species) • Increase invasive species control effectiveness (e.g., research on biocontrol methods and applicability, advances in herbicide) • Increase research on any potential benefits that may be obtained from

Conservation Activity	Adaptation Strategies and Actions
	invasive species (e.g., invasive tree tobacco providing food for endangered Blackburn's sphinx moth) • Increase development and implementation of new technology (e.g., drones for invasive detection, genetically modified mosquitos) • Create mechanisms to incentivize private landowner invasive species control (e.g., tax rebates for invasive removal) • Increase public understanding of the difference between native, non-native, and invasive species (e.g., "eat the invasives" campaigns, develop site-specific examples that demonstrate natural vs. invaded vs. climate-impacted conditions)
Water Resources Planning	• Maintain/improve water quantity and quality • Collect data on water withdrawals • Improve water conservation efforts in light of climate change • Increase public understanding of how climate change may affect future water supply and quality • Increase understanding of water quantity, quality, and allocations under changing climate conditions • Improve understanding of drought impacts on water resources • Integrate climate projections into Water Commission planning efforts • Increase water catchments and reservoirs to maintain a resilient water supply • Monitor and control point- and non-point source pollutants (e.g., fertilizers, insecticides) • Reduce stress on water quality by converting cesspools to septic systems • Encourage low-impact development and green infrastructure techniques to reduce the extent of impervious pavement
Land-use Planning	• Engage landowners and decision-makers on projected habitat shifts to inform zoning and development • Protect inland/upland areas for habitat migration in anticipation of sea level rise • Create more nimble planning and zoning processes that promote biocultural landscapes in a changing climate (e.g., shorten land use/general planning timeframe, smart growth, ʻāina-based planning) • Integrate climate change into community planning and zoning • Engage developers, realtors, and insurance companies on climate-related risk and response • Limit development in vulnerable areas (e.g., change permitting rules to prohibit development in coastal areas and floodplains most vulnerable to sea level rise) • Increase biocultural landscape-based planning and management in state and county planning (e.g., create community-defined and practice-based zones; identify and issue permits for all cultural land-use practices)

Conservation Activity	Adaptation Strategies and Actions
Cultural Resources and Practices Preservation	• Reconnect/enhance connections of people to place • Increase cultural participation in tracking environmental and climatic change • Identify cultural community concerns about climate change • Incorporate cultural concerns and community participation into climate adaptation projects • Preserve and/or increase access for cultural stewardship and gathering of important cultural materials • Preserve salt making and kalo production • Increase local food security to build resilient cultural communities • Consider cultural sites, resources, and values in responding to storms, extreme weather events, and climate change • Identify climate-informed processes for conservation practices in vulnerable cultural sites • Incorporate cultural and/or uniquely Hawaiian components into climate change communication products (e.g., cultural voyaging, lei)

Next Steps

Vulnerability assessments and adaptation planning processes help scientists, managers, and planners identify long-term options that will be sustainable in a changing climate. Findings from the state-of-the-science climate impacts and vulnerability assessments and workshops have been peer-reviewed and compiled into this report, as well as habitat and ecosystem service vulnerability syntheses, adaptation summaries, and two-page communication briefs describing key climate and non-climate vulnerabilities and adaptation options. All individual products can be found at www.bitly.com/HawaiiClimate.

These products and the tools within them (i.e. feasibility/effectiveness figures) are designed to be dynamic. Because climate adaptation is an iterative process, it is likely that as more or better information and resources emerge, some vulnerability rankings and adaptation options may change. As a collaborative, the Hawaiian conservation community can use these products as a starting point for conversations on how to effectively integrate climate change into biocultural resources management. For example, some adaptation options designed by workshop participants included planting flood-, drought-, and wind-tolerant species; determining what those species are and in which location (habitat, elevation) and configuration they should be planted will require additional collaboration from the conservation community.

Through this process, workshop participants generated over 400 climate-informed modifications to current management activities and new adaptation approaches (Appendix B). As practitioners move towards implementation, it will be important to carefully think through some best practices in terms of evaluating and prioritizing between adaptation approaches to ensure the consideration of multiple aspects of climate change. These include:

- Ensuring that actions address different components of vulnerability (e.g., reduce sensitivity and exposure, enhance adaptive capacity);

- Selecting actions across different timeframes (near, medium, and long-term);
- Spreading risks and resources across different adaptation approaches;
- Using those actions that are most effective at reducing vulnerabilities and those that will be the most feasible to implement; and
- Paying attention to unintended consequences or effects that a particular action may have on another resource.

The adaptation summaries provide different tools for prioritization. For example, the tables that present adaptation options by approach (i.e. resistance, resilience, response, knowledge, collaboration) give users an idea of the range of actions available for implementation and their applicability over time, and an idea of where additional thought may need to go in developing other climate-informed options. As these adaptation approaches are implemented, monitoring and evaluation will be key. This includes monitoring to document environmental and climatic changes and associated effects on resources to inform decision making, and evaluation to understand how effectively adaptation actions are or are not working so that adjustments can be made.

Additional resources to support your adaptation efforts are the Pacific Islands Regional Climate Assessment (www.PIRCA.org) and the Climate Adaptation Knowledge Exchange (CAKE; www.CAKEx.org).

Maui Nui: Vulnerability Assessment and Adaptation Options

Summary

The following chapter provides a summary of the vulnerability assessment and adaptation planning results for Maui, Lānaʻi, and Kahoʻolawe.[7] Table 8 presents the overall vulnerability and confidence scores for habitats and ecosystem services. Figure 8 presents the overall vulnerabilities of habitats and ecosystem services based on the assessment of climate and non-climate sensitivity and exposure and adaptive capacity.

Table 8. Overall vulnerability and confidence scores for Maui Nui habitats and ecosystem services.

Focal Resource	Vulnerability Score	Confidence Score
Habitats		
Coastal: Beaches and Shorelines	**Moderate-High**	**Moderate**
Coastal: Estuaries, Tidal Wetlands, and Coastal Freshwater Wetlands	**Moderate**	**Moderate**
Coastal: Anchialine Pools	**Moderate-High**	**High**
Aquatic: Streams	**Moderate**	**Moderate**
Aquatic: Groundwater, Seeps, and Springs	**Moderate**	**High**
Dry Forest	**Moderate-High**	**High**
Mesic and Wet Forest	**Moderate**	**High**
Alpine/Subalpine	**Moderate**	**High**
Ecosystem Services		
Cultural Knowledge and Heritage Values	**High**	**High**
Flood and Erosion Control	**High**	**Moderate**
Fresh Water	**High**	**High**
Food and Fiber	**Moderate-High**	**High**
Aesthetic Values	**Moderate**	**High**
Recreation and Tourism	**Moderate-High**	**Moderate**

[7] The vulnerability assessment workshop approach was not applied to Molokaʻi.

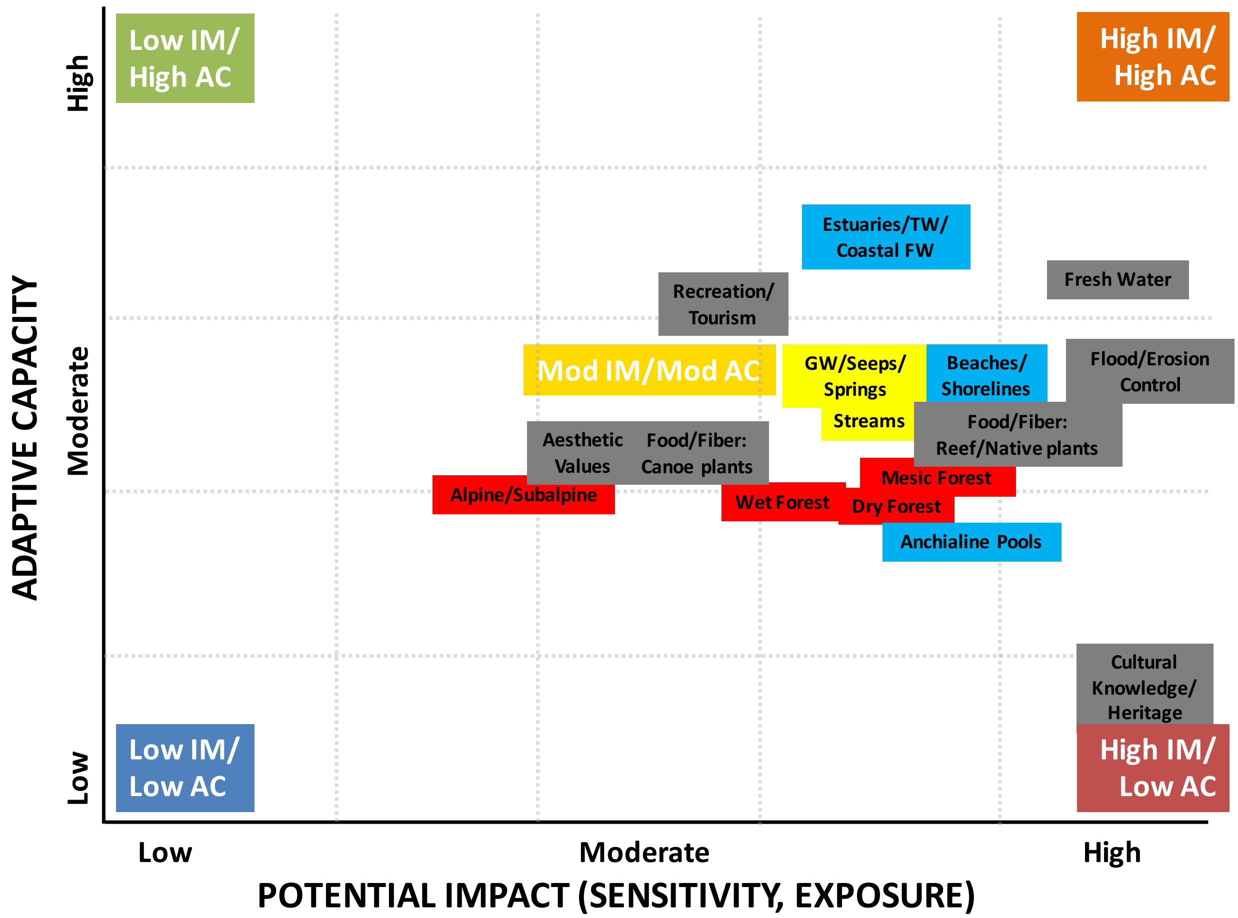

Figure 8. Overall vulnerabilities of Maui Nui habitats and ecosystem services based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. TW: Tidal wetlands, FW: Freshwater, GW: Groundwater Color code: Terrestrial habitats (red), Coastal habitats (blue), Aquatic habitats (yellow), Ecosystem services (grey)

Coastal Habitats

Workshop participants classified coastal habitats on Maui, Lānaʻi, and Kahoʻolawe as beaches and shorelines; estuaries, tidal wetlands, and coastal freshwater wetlands; and anchialine pools. **Beach and shoreline habitats** occur in low-lying coastal areas on Maui Nui and include sandy beaches, boulder/cobblestone/rocky beaches, rocky cliffs and coastal shelves (limestone or lava), dunes, coastal shrubs and strands, and man-made coastal structures. **Estuarine and tidal wetland habitats** are characterized by brackish water conditions resulting from both freshwater and tidal influence. A range of sub-habitats fall into the estuary and tidal wetland classification, including embayments, stream mouths, salt marshes, tidal flats, brackish coastal plain wetlands, and fishponds. **Coastal freshwater wetlands** consist of ponded fresh water derived from precipitation, river and stream runoff, and groundwater inflow. **Anchialine pools** are landlocked pools found on limestone or lava flows, characterized by subsurface hydrological connectivity, but lacking surface connection to the ocean. Maui has many anchialine pools, while Kahoʻolawe has one pool with very high salinity.

Vulnerability Assessment Results

Beaches and Shorelines

Beach and shoreline habitats on Maui Nui were evaluated to have *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Sea level rise, tropical storms, and extreme precipitation events accelerate coastal erosion and increase susceptibility to inundation. Along with drought, wildfire, and flooding, these factors influence vegetative composition, with potential implications for the persistence of native species. Non-climate stressors (e.g., development, agricultural conversion, roads, recreation, invasive ungulates, and invasive vegetation) compound climate-driven habitat reductions and vegetative shifts, and also degrade remnant habitat quality by promoting runoff and erosion and facilitating invasive vegetation establishment. The adaptive capacity of beach and shoreline habitats is bolstered by the fact that they are highly valued, highly managed, and in some areas, have protected status. However, the majority of beach and shoreline habitats have been degraded and fragmented by human activity. Development and other human land uses also prevent landward habitat migration of these habitats in response to sea level rise, and impair the natural resistance and recovery of coastal habitats experiencing disturbance.

Estuaries, Tidal Wetlands, and Coastal Freshwater Wetlands

Estuaries, tidal wetlands, and coastal freshwater wetlands were evaluated to have *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Sea level rise, saltwater intrusion, extreme precipitation events, tropical storms, drought, and coastal and riverine flooding are likely to influence the abundance, distribution, hydrology, salinity, and sediment dynamics of tidal wetlands, estuaries, and freshwater coastal wetlands. These changes, along with shifts in water temperature, pH, wildfire, and disease incidence, will drive shifts in vegetative composition, affecting habitat suitability for a variety of wildlife species. Non-climate stressors (e.g., development, agricultural conversion, roads, recreation, water diversions, invasive ungulates, and invasive vegetation) compound climate-driven habitat reductions and vegetative shifts, and also degrade remnant habitat quality by increasing runoff, erosion, and contaminant delivery. The adaptive capacity of these habitats is bolstered by the fact that they are highly valued, highly managed, and in some areas, have protected status. However, significant estuarine and coastal wetland areas on Maui have been degraded and fragmented by human activity. Development and other human land uses also prevent landward habitat migration in response to sea level rise and impair the natural resistance and recovery of coastal habitats experiencing disturbance. Additionally, societal support for managing and conserving coastal habitats is low, and some current management actions (e.g., water supplementation) may not be possible in a drier climate.

Anchialine Pools

Anchialine pool habitats were evaluated to have *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Anchialine pools are sensitive to climate-driven changes in pool salinity or water depth caused by precipitation changes, storm surge, or saltwater intrusion; salinity and depth changes can be exacerbated by development and water diversions that alter groundwater recharge and withdrawal. Additionally, anchialine pools are sensitive to sea level rise, which may increase pool vulnerability to invasive species, as well as pool distribution, particularly if development blocks landward migration. Anchialine pool shrimp are also sensitive to pollutants and water temperature. The adaptive capacity of anchialine pools may be bolstered by subsurface connectivity, protection through natural area reserves, and knowledge gained through successful restoration efforts on other islands. However, anchialine pools are less valued by the public than other aquatic systems, and face competing interests with development and upstream water uses. Additionally, a lack of knowledge about individual pool aquatic assemblages and hydrodynamics make it difficult to know how each pool will respond to or recover from changes.

Adaptation Planning Results

Table 9 presents a summary of possible adaptation strategies and actions for Maui Nui coastal habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 9 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 9. Summary of possible adaptation strategies and actions for Maui Nui coastal habitats.

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Restore coastal habitats	• Utilize exclusion fencing and restoration in upland areas to enhance erosion control • Remove and control invasive and alien species in wetlands
	Restore and conserve native shoreline habitat	• Nourish beaches in areas where habitat retreat is not an option
	Maintain/improve water quality and quantity	• Investigate and reduce non-point source pollution • Promote and enforce use of best management practices (BMPs) to improve water quality • Manage runoff (stormwater, wastewater, nutrients) in areas affected by human activity
Resilience *Near- to mid-term approach*	Restore coastal habitats	• Restore dune and coastal strand habitats • Outplant native species in current and potential future coastal wetland habitats
	Preserve water supplies by increasing water use efficiency	• Improve rainfall capture to decrease groundwater withdrawals
	Implement climate-informed coastal zoning protections	• Modify the formula for erosion control to incorporate data on climate change • Revise setback requirements to account for projected sea level rise • Incorporate climate change into Special Management Area siting and permitting • Use gap analysis planning to identify areas that need protection based on specific climate-informed criteria
	Enhance habitat and species resilience	• Develop genetic "banks" (e.g., seed banks, captive breeding programs)
Response	Implement climate-informed	• Limit development in most vulnerable sites

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
Long-term approach	coastal zoning protections	
	Protect current and future habitat	• Establish shoreline setbacks • Identify and protect low-lying areas where wetlands and anchialine pools can migrate
	Anticipate and facilitate habitat migration	• Limit development in inland/upland areas where coastal habitats may migrate • Identify and protect currently vulnerable areas and areas of possible habitat migration based on available data, including existing infrastructure lifetime
Knowledge *Near- to long-term approach*	Anticipate and facilitate habitat migration	• Conduct a cost-benefit analysis for a range of alternatives based on climate change vulnerability assessments and prioritization processes
	Protect current and future habitat	• Use gap analysis planning to identify areas that need protection based on specific climate-informed criteria
	Monitor pollutants to protect water quality	• Monitor point- and non-point source pollutants associated with agriculture and development (e.g., fertilizers, insecticides, agricultural byproducts)
Collaboration *Near- to long-term approach*	Build support for coastal habitat protection with climate-informed public education and advocacy	• Engage community groups, develop constituencies, align interest groups, and mobilize people to demand conservation action • Conduct climate-informed public education and outreach about protected areas and habitats at risk

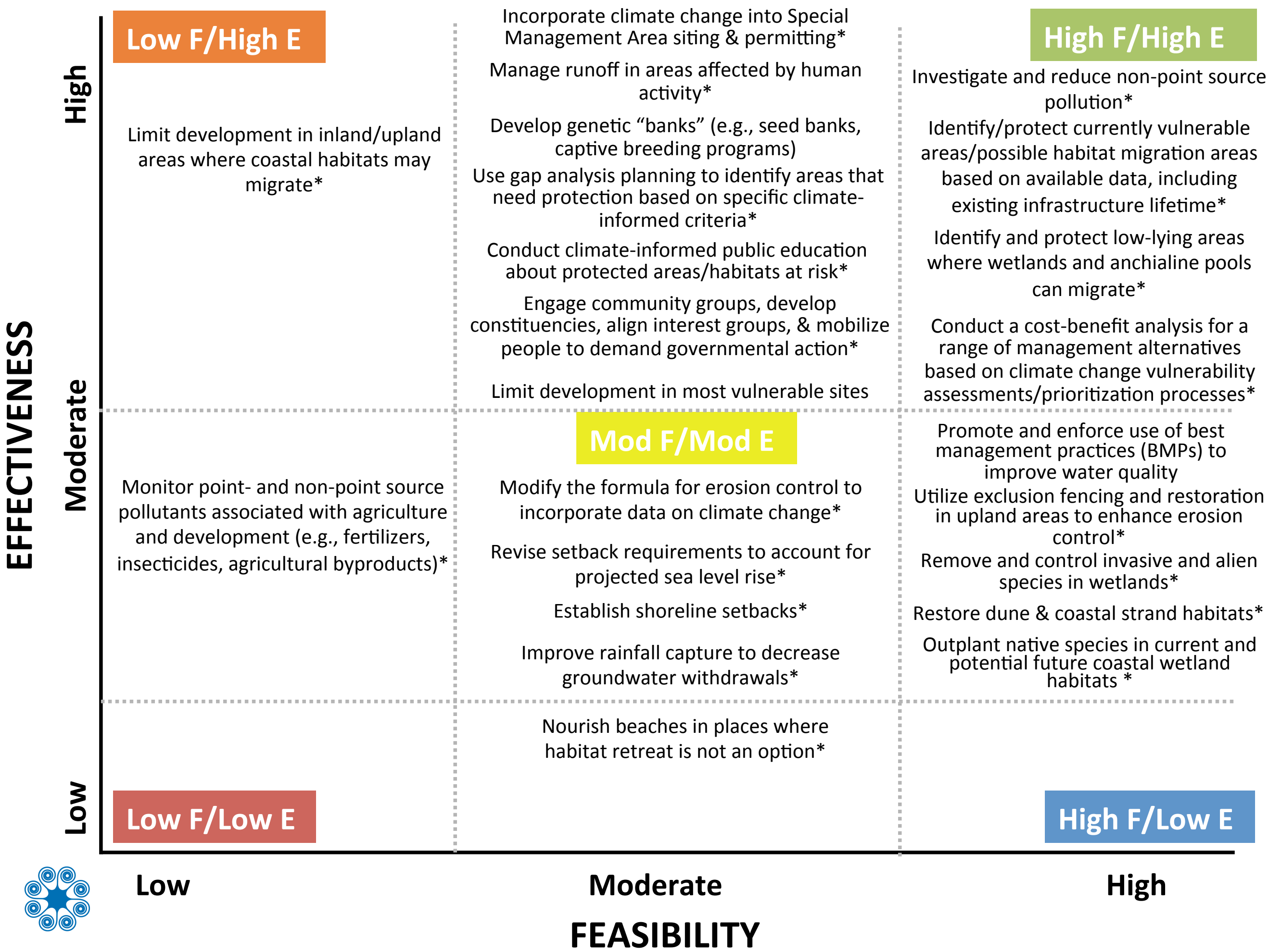

Figure 9. Maui Nui coastal habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants. All other adaptation action evaluations are based on expert opinion.

Aquatic Habitats

Workshop participants classified aquatic habitats on Maui, Lānaʻi, and Kahoʻolawe as streams, groundwater, seeps, and springs. Perennial and intermittent **streams** typically have high flow variability due to small catchment basins, steep slopes, and limited channel storage. **Groundwater systems** include freshwater lenses floating over saltwater on flank lavas and high-level or perched water impounded by low-permeability features such as volcanic dikes. Terrestrial perennial **seeps and springs** can be found along banks of severely incised streams and coastal rock faces. On Maui, springs also emerge from perched aquifers on Keʻanae Point.

Vulnerability Assessment Results

Streams

Stream habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Streams are sensitive to climate changes that reduce water availability or alter streamflow volume, including precipitation amount and timing, drought, tropical storms, flooding, and air temperature. Stream fauna are also sensitive to climatic factors and disturbance regimes that impair water quality, including increased stream temperature and wildfire. Non-climate stressors such as agriculture, pollution and poisons, and development further reduce water quality by introducing contaminants and increasing sediment loads and/or stream temperatures. Additionally, water diversions magnify climate-driven reductions in streamflow, reducing aquatic habitat availability, connectivity, and quality. Despite significant modification, a majority of Maui's perennial streams remain connected to the ocean. Restoration efforts indicate that streams are able to recover from human impacts if streamflow is restored, although highly endemic biota and low biodiversity (relative to mainland systems) make stream fauna vulnerable to climatic or other change. Although streams are valued for a variety of purposes (e.g., public trust uses, recreation opportunities, agricultural and urban uses), offstream uses compete for water needed to support a functioning stream ecosystem, and these conflicts will likely increase in a drier climate.

Groundwater, Seeps, and Springs

Groundwater and seep and spring habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Groundwater, seeps, and springs are sensitive to climate-driven changes and non-climate stressors that affect groundwater recharge, storage, and water quality. Tropical storms promote recharge while shifts in precipitation amount and timing and drought potentially reduce recharge, increasing vulnerability to saltwater intrusion. Groundwater recharge and storage are also negatively impacted by urban water withdrawals and water diversions. Comparatively, agricultural irrigation promotes groundwater recharge, but irrigation contributions have been declining over the past several decades, and the future of large-scale agriculture is uncertain with the recent cessation of sugarcane production. The extent and integrity of groundwater, seep, and spring habitats is threatened by increasing withdrawal rates; the location of a given system, along with current and past management, will affect its ability to resist and recover from impacts. Workshop participants indicated that Maui's groundwater, seeps, and springs are moderately valued by the public. However, these habitats compete for water with a variety of off-stream water uses, and these conflicts may increase in a drier climate.

Adaptation Planning Results

Table 10 presents a summary of possible adaptation strategies and actions for Maui Nui aquatic habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 10 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 10. Summary of possible adaptation strategies and actions for Maui Nui aquatic habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Use fencing in critical watersheds to exclude ungulates from upland forested areas • Remove invasive plants (e.g., Miconia)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Maintain and enhance groundwater quality and quantity	• Adopt well source protection ordinances
	Improve water conservation efforts	• Develop a water budget to account for all water sources, connectivity, uses/withdrawals, and disposal/discharges
Resilience *Near- to mid-term approach*	Increase streamflow to protect habitat and water supply	• Establish and enforce mandated instream flow standards • Encourage non-extractive water uses (e.g., taro farming)
	Protect forests to increase recharge and water retention	• Support healthy native forests through land acquisition and plant restoration
	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	• Modify culverts to accommodate extreme flooding • Modify stream crossings to enhance fish passage and habitat connectivity
	Mandate acquisition of new technologies to maintain and enhance water quality	• Install diversion gates • Extract sodium to increase fresh water supplies
Response *Long-term approach*	Use assisted colonization to restore rare species	• Identify and prioritize suitable habitat based on factors that suggest long-term ecological sustainability
	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
Knowledge *Near- to long-term approach*	Collect data on stream habitats	• Add additional gauges to monitor streamflow, water temperature, and salinity • Create a flexible monitoring system to track water extraction, including who is withdrawing water and for what purpose • Install automatic sensors that monitor streams 24/7
	Monitor pollutants to protect water quality	• Monitor point- and non-point source pollutants associated with agriculture and development (e.g., fertilizers, insecticides, agricultural byproducts) • Monitor and regulate salinity and other indicators of water quality in wells and groundwater
Collaboration *Near- to long-term approach*	Increase collaborative efforts to conserve streams and watersheds	• Expand watershed conservation to lower elevations by enhancing watershed partnerships and seeking legislative changes at the state and local levels • Conduct place-based education to encourage watershed conservation

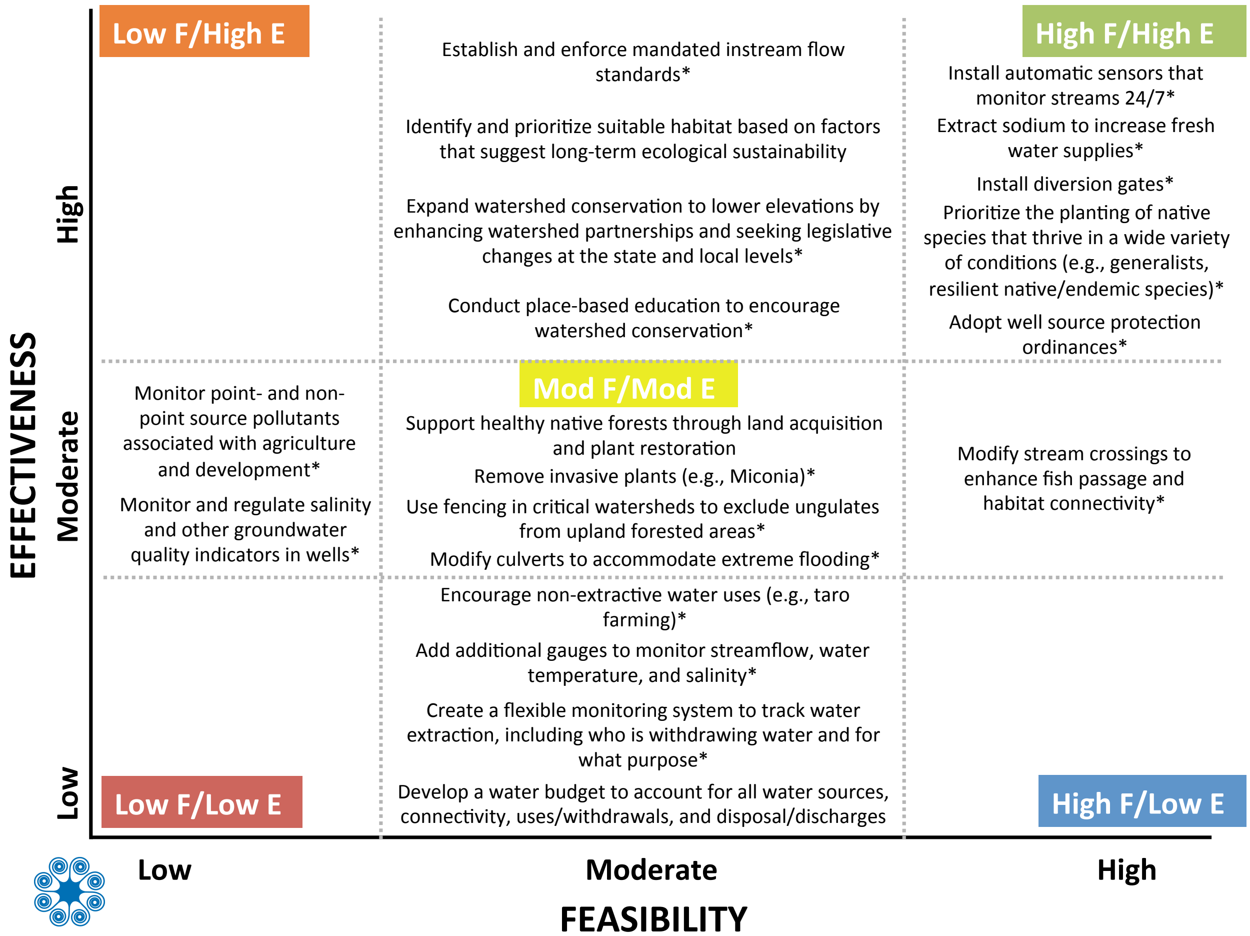

Figure 10. Maui Nui aquatic habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants. All other adaptation action evaluations are based on expert opinion.

Dry Forest

Dry forests and mesic lowland shrublands are typically found in low-elevation areas and on leeward slopes (up to 2,000 m [6,560 ft]), and receive the majority of their moisture from cloud/fog drip and intermittent rain. These habitat types are often associated with younger, shallow substrates comprised of cinder, ash, and lava flows. Dry forests also feature ephemeral streams and wetlands. These habitats are dominated by a variety of species, including lama, ʻōhiʻa, koa, wiliwili, ʻaʻaliʻi, olopua, ʻālaʻa, alaheʻe, ʻōlapa, lovegrass, and pili grass.

Vulnerability Assessment Results

Dry forest habitats were evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Because dry forests are already limited by moisture, they are most sensitive to climatic factors that increase water stress, such as increased drought, warmer air and soil temperatures, reduced soil moisture, and changes in the timing of precipitation; these changes are likely to impact species recruitment, community composition, and forest distribution. Disturbance events (e.g., wildfire, floods, wind, insects, disease) may also damage forest areas, reducing forest cover and canopy integrity and increasing vulnerability to invasion, while non-climate stressors, such as residential and commercial development, agriculture, and pollution, further reduce habitat extent, integrity, and continuity, limiting species dispersal and recruitment. Invasive species (e.g., ungulates, mammalian predators, trees/shrubs, flammable grasses, social insects, and pathogens/parasites) also impair dry forest recruitment and recovery by competing with and displacing vegetation, altering ecosystem processes (e.g., water infiltration, pollination), and/or causing direct plant damage or mortality.

Over 90% of historical dry forest area in Hawaiʻi has already been lost, and the remaining area is highly fragmented and vulnerable to conversion to agriculture or other uses. Although dry forests are diverse and have high numbers of endemic species, many native species are endangered. Although intensive restoration efforts have led to the successful reestablishment of native species in some areas, degraded dry forests are largely unable to recover without active management.

Adaptation Planning Results

Table 11 presents a summary of possible adaptation strategies and actions for Maui Nui dry forest habitat, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 11 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 11. Summary of possible adaptation strategies and actions for Maui Nui dry forest habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Expand the use of fencing in and remove invasive ungulates and plants from remnant native habitats and corridors between protected habitats
	Maintain and protect existing dry forest habitat	• Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals
	Improve fire prevention and response	• Maintain fuel breaks below power lines and on road sides • Use managed grazing and fuel treatments to limit potential fire spread and severity
Resilience *Near- to mid-term approach*	Maintain and restore existing dry forest habitat	• Collect and propagate native seeds for revegetation in disturbed areas • Consider climate projections in the timing and seasonality of planting to promote natural recruitment
	Improve resilience of key dry forest species/communities	• Identify and prioritize existing dry forest biomes and create a strategy to expand protection and restoration • Create a digital and physical genetic database to protect remaining species, using both in situ

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		(outplanting) and ex situ (seed storage) methods • Explore genetic engineering for increased resilience (e.g., drought tolerance)
Response *Long-term approach*	Improve resilience of key dry forest species/communities	• Identify key species that are most adapted to future climate conditions
	Identify and promote climate-adapted species composition	• Map transitional areas between dry and mesic habitat to identify and prioritize protection for areas of mesic habitat that may transition to dry habitat • Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions
	Use assisted colonization to restore rare species (e.g., corals, turtles, birds)	• Identify and prioritize suitable habitat for release of rare species • Protect and prepare habitat for rare species introduction by increasing habitat quality and reducing threats (e.g., predators, invasive species, human disturbance) • Release rare species into suitable habitat and monitor survival, dispersal, reproductive success, abundance, and genetic diversity
Knowledge *Near- to long-term approach*	Increase knowledge to improve dry forest restoration	• Identify gaps in cultural and technical knowledge to prioritize research needs • Develop new technologies to increase survival and long-term restoration success (e.g., fog drip capture, irrigation, invasive species, biomimicry, nanobots)
Collaboration *Near- to long-term approach*	Increase capacity for dry forest restoration	• Create a community workforce to implement restoration in historic dry forest and high-priority sites in a timely manner
	Raise public awareness and community support for dry forest protection	• Conduct a comprehensive public media campaign to highlight the importance of dry forest habitats and what is at risk from climate change (e.g., culture, economy, ecosystem services) • Engage community (i.e. cultural woodworkers, agricultural producers) in addressing knowledge gaps and restoration work • Celebrate success to keep the community involved

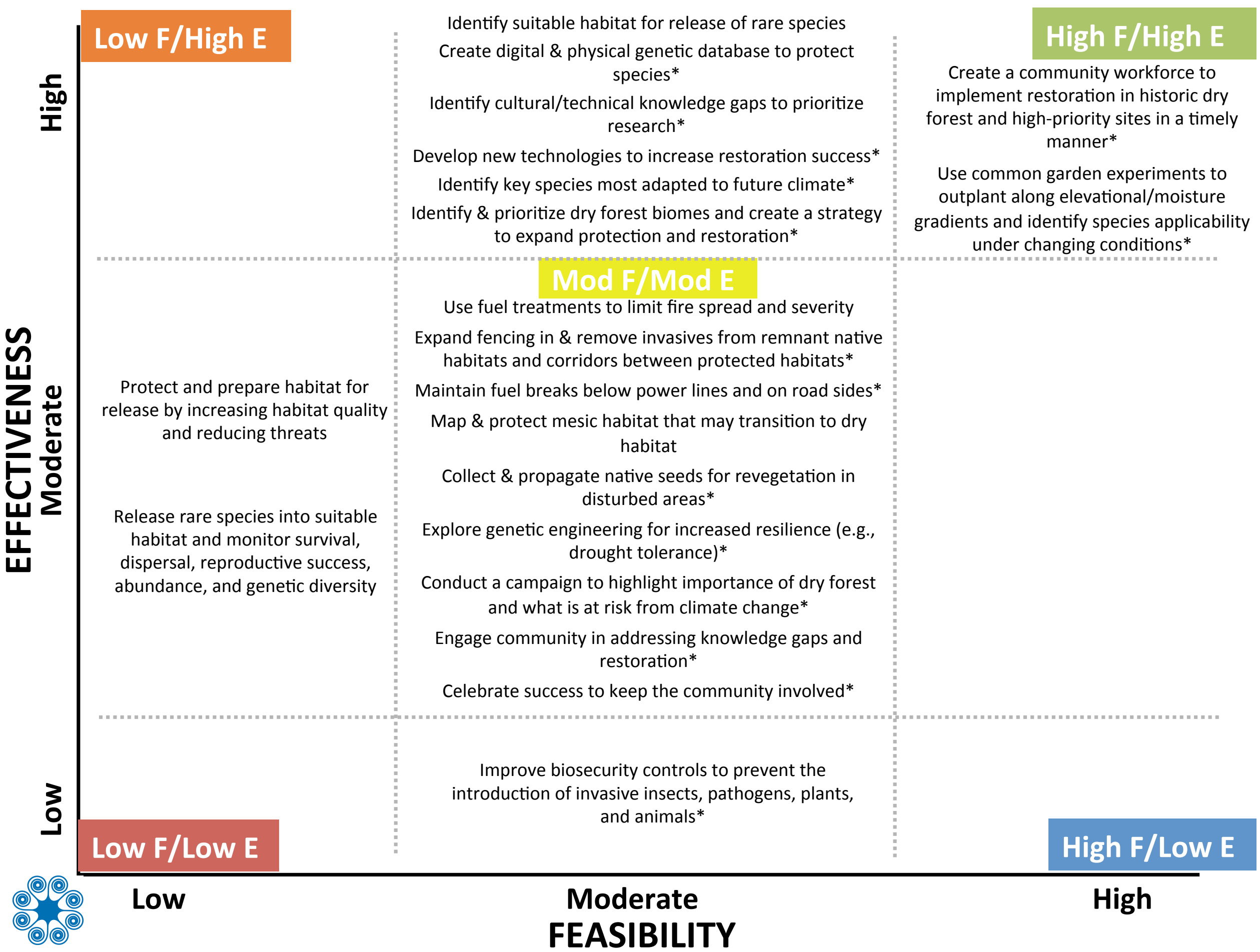

Figure 11. Maui Nui dry forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants. All other adaptation action evaluations are based on expert opinion.

Mesic and Wet Forest

Mesic and wet forest habitats are typically found on windward lowland areas and montane slopes up to elevations of 2,194 m (7,200 ft). These mesic/wet bands are created in areas that lie at or below the mean height of the TWI, and receive up to 7,620 mm (300 in) of rainfall per year. Mesic and wet forest habitat types range from mesic forests to tropical montane cloud forests, and are typically dominated by ʻōhiʻa and koa trees with dense understories comprised of shrubs, ferns, and sedges. Mesic and wet forest habitats can be found on east Maui from Makawao clockwise to Kipahulu and Kahikinui, and on the upland, windward slopes of west Maui. On Lānaʻi, mesic forest habitats are distributed on the windward slopes and extend down to the ocean. Kahoʻolawe lies in the rain shadow of Maui and does not contain mesic or wet forest habitat.

Vulnerability Assessment Results

Mesic and wet forest habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Mesic and wet forests are sensitive to factors that alter moisture gradients, such as drought, precipitation amount and timing, storms, and air temperature. Disturbance events, such as disease, wind, and insect outbreaks can damage large habitat areas, potentially allowing invasive plants to become established. Invasive ungulates, mammalian predators, trees/shrubs, flammable grasses, and pathogens/parasites are the primary non-climate stressors for mesic and wet forest types, and have led to the rapid decline of many native and endemic species over the past several hundred years. High-elevation wet forests remain relatively intact, but lowland areas and mesic forests experience development pressure and conversion to agriculture, ranching, or other uses. Forest species diversity and endemism is very high, and many species are able to recover rapidly from wildfire and other disturbances. Management and restoration efforts are likely to be relatively successful at alleviating the impacts of climate change, though public value and societal support for mesic and wet forest habitats is low.

Adaptation Planning Results

Table 12 presents a summary of possible adaptation strategies and actions for Maui Nui mesic and wet forest habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 12 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 12. Summary of possible adaptation strategies and actions for Maui Nui mesic/wet forest habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Expand fencing to lower elevations, focusing on incipient sites or most vulnerable areas throughout the forest • Increase upfront investment in ungulate and mammalian predator removal through hunting/shooting and snares • Remove invasive plants through biological, chemical, or mechanical treatments • Prevent introduction of new insects and diseases by increasing biosecurity controls (e.g., quarantines, intra-island policies, optional vs. mandatory restrictions)
	Improve fire prevention and response	• Prevent off-road vehicle and pedestrian activity in high recharge areas, sensitive watersheds, and core native habitats through education and access limits
Resilience *Near- to mid-term approach*	Maintain intact, native-dominated ecosystems	• Outplant native species to create habitat and facilitate biome shifts • Augment native habitat through outplanting and seeding of temperature- and drought-tolerant species in post-disturbance sites and buffer zones
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Response	Facilitate transition of	• Create test plots to determine where habitat may shift

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Long-term approach	species into new areas as climate regimes shift	along ecotone boundaries and identify potential unintended consequences • Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
	Manage invasive species	• Erect fences across biome and habitat borders to allow for potential habitat and species range shifts
Knowledge *Near- to long-term approach*	Develop more efficient technologies/tools for habitat restoration and invasive species control	• Increase technical capacity and decrease regulations of invasive species removal (e.g., herbicide delivery) • Develop biocontrol methods for invasive species • Improve methods for native species propagation (all taxa) in high-quality core habitat
	Increase education and outreach to instill a community conservation ethic	• Increase awareness of biocultural and ecosystem services
	Collect data on existing non-climate stressors	• Monitor abundance of native and invasive forest species as temperature rises and precipitation changes
Collaboration *Near- to long-term approach*	Increase direct community restoration	• Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change impacts
	Create new/improve partnerships to increase capacity	• Collaborate with universities to conduct research on invasive species management • Improve data sharing within and between agencies

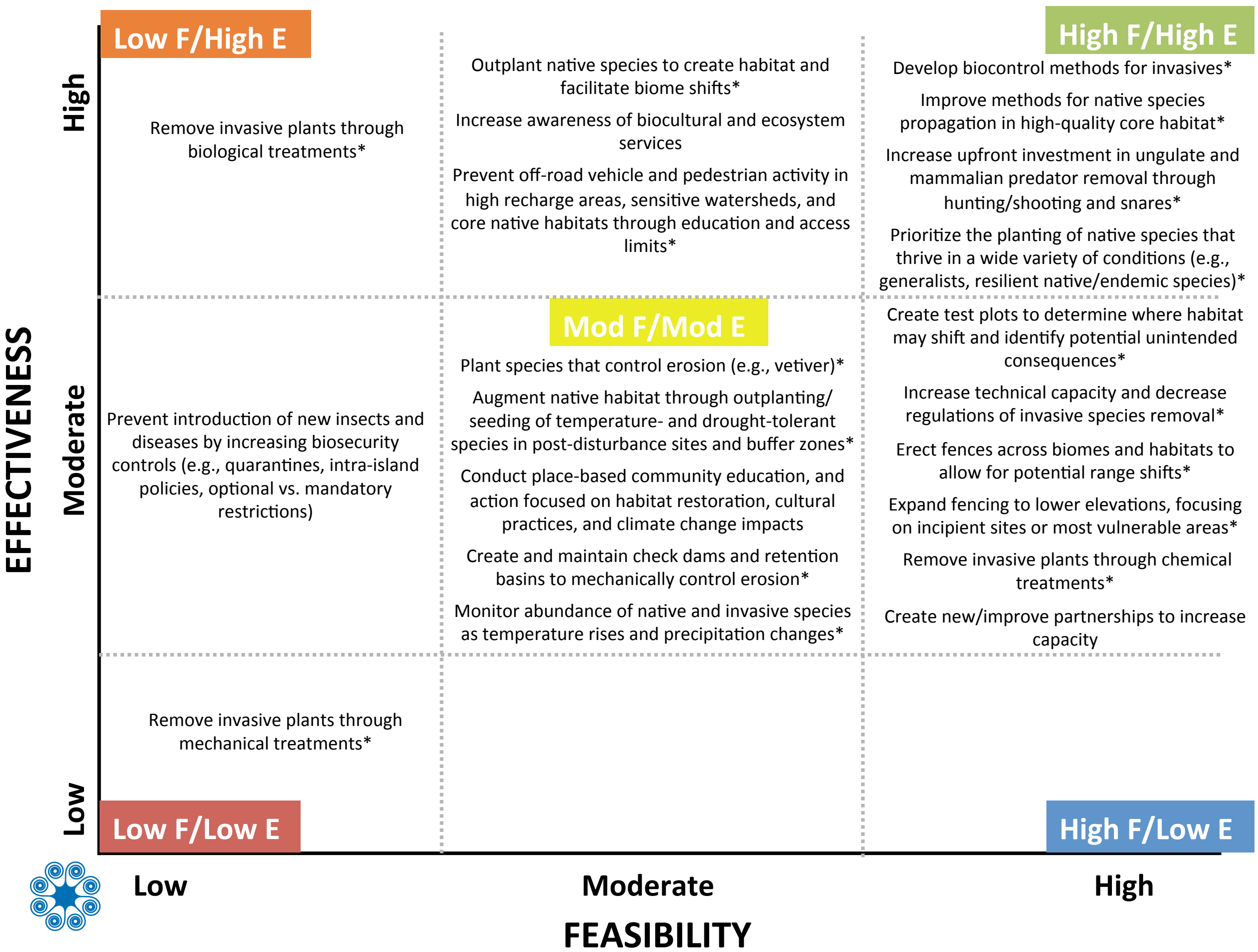

Figure 12. Maui Nui mesic and wet forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants. All other adaptation action evaluations are based on expert opinion.

Alpine/Subalpine

Alpine and subalpine habitats are found in high-elevation areas of Haleakalā on Maui. These habitats mostly lie above the mean height of the TWI, and are arid with very little precipitation or fog. Unlike many areas of the world, high-elevation vegetation is most likely limited by moisture rather than by temperature. Alpine communities are found above the tree line up to the summit of Haleakalā at 3,055 m (10,023 ft). Alpine habitats are dry and semi-barren, with sparse, highly specialized vegetation including the Haleakalā silversword. Subalpine communities lie between 2,000 and 3,000 m (6,560 to 10,000 ft) in elevation, and may consist of forests, shrublands, and grasslands. Dominant vegetation includes māmane, naio, and ʻōhiʻa trees; ʻōhelo, pūkiawe, and pilo shrubs; bracken fern; and alpine hairgrass. These communities are primarily found on windward east Maui, where subalpine shrublands transition into wet forest, and on leeward east Maui, where subalpine forests transition into remnant dry and mesic forest and and non-native habitats dominated by introduced forest and grassland species.

Vulnerability Assessment Results

Alpine and subalpine habitats in Maui were evaluated as having *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Alpine and subalpine habitats are sensitive to factors that contribute to water stress, including changes in the amount and timing of precipitation, drought, air temperature, soil moisture, and changes in the frequency of the TWI. Disturbance events, such as wildfire, may allow invasive plants to become established, as native vegetation is slow to recover. Although non-climate stressors have a low impact on these habitats, invasive/problematic species and recreation can degrade habitats and alter native species composition. These habitat types are protected but very limited in extent, with little ability to shift upslope into higher-elevation areas. Although these habitats are highly valued, increasing water stress and the eventual loss of refugia may make it difficult for many endemic and highly specialized species to survive.

Adaptation Planning Results

Table 13 presents a summary of possible adaptation strategies and actions for Maui alpine and subalpine habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 13 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 13. Summary of possible adaptation strategies and actions for Maui alpine/subalpine habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Remove small mammals inside fences, as well as within a buffer around the fence • Erect fencing to protect subalpine areas from feral ungulates • Remove feral ungulates through aerial eradication, ground hunting, or snares • Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion • Increase fuel reduction efforts in common ignition sites and areas of high conservation value
Resilience *Near- to mid-term approach*	Manage invasive species	• Prioritize invasive plant removal, focusing on areas with high diversity or rare species
	Maintain and augment native species populations	• Identify a good existing seed bank and allow for natural regeneration • Actively restore high-priority sites inside the fence, considering surrogate species that may be tolerant of future climate conditions
Response	Use assisted colonization to	• Identify and prioritize suitable habitat for release of

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Long-term approach	restore rare species (e.g., birds)	rare species • Protect and prepare habitat for rare species introduction by increasing habitat quality and reducing threats (e.g., predators, invasive species, human disturbance) • Release rare species into suitable habitat and monitor survival, dispersal, reproductive success, abundance, and genetic diversity
	Facilitate transition of species into new areas as climate regimes shift	• Create assessment/test plots to determine where habitat will be and whether there may be unintended consequences
Knowledge *Near- to long-term approach*	Improve silvicultural practices for priority species	• Improve seed storage capacity • Improve methodology for seed propagation • Improve silvicultural planting methods (i.e. seed collection, composition, spacing)
	Conduct research to support adaptive policies and technology that increase landscape-level protection and restoration	• Research and develop new/improved methods of small predator control • Research and develop new/improved methods of weed control
Collaboration *Near- to long-term approach*	Increase direct community restoration	• Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change impacts

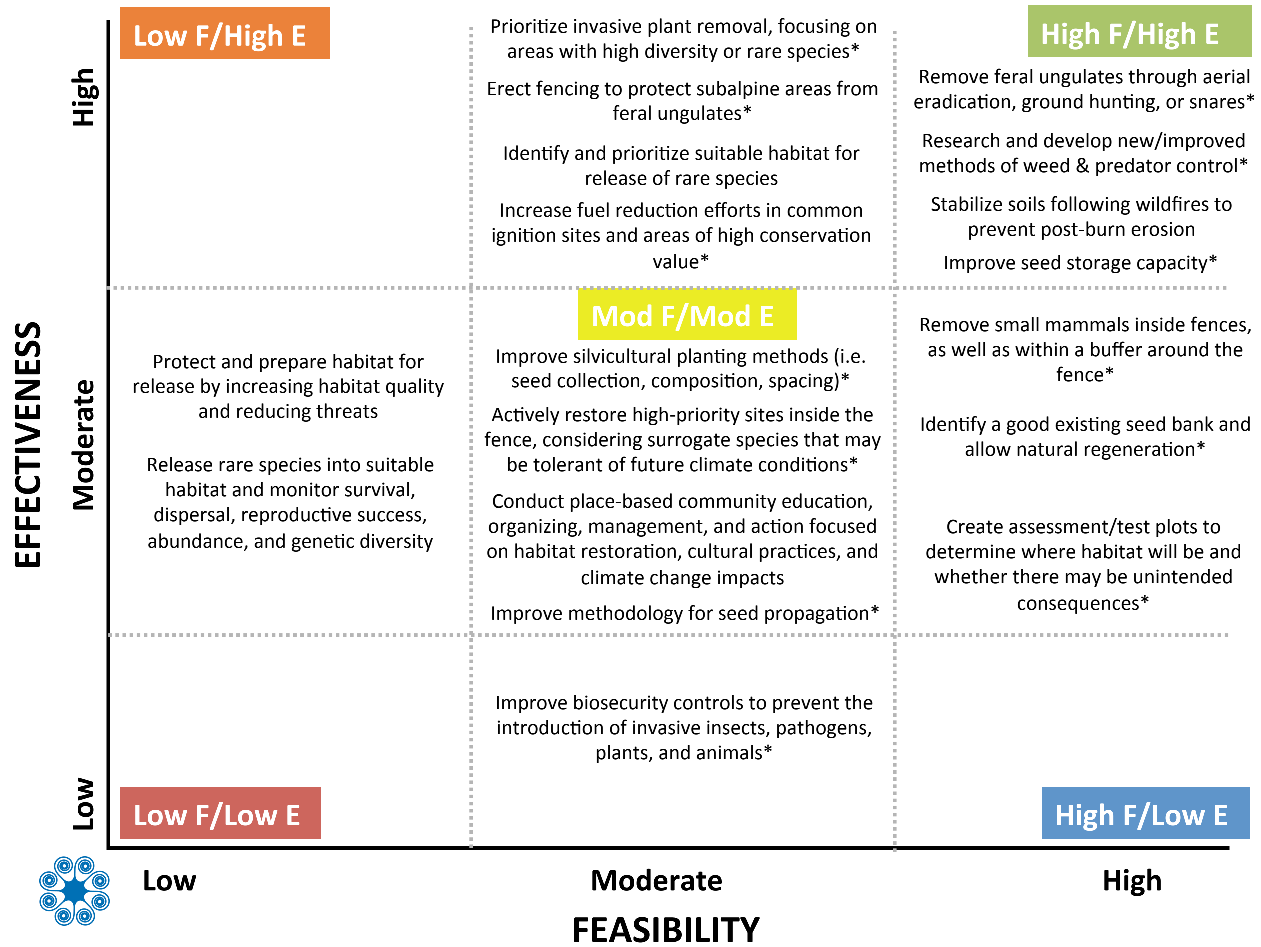

Figure 13. Maui Nui alpine and subalpine habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Cultural Knowledge and Heritage Values

Natural resources and Native Hawaiian culture are closely interwoven. Cultural knowledge is closely tied to the provisioning of food, clothing, and shelter, crop cultivation, plant propagation, and general stewardship of natural resources. Cultural heritage incorporates past legacies that relate to ecosystems and a sense of place, and includes many aspects of identity and spirituality. Many cultural practices are dependent on natural ecosystems, such as the gathering of native plant and animal species for food, medicine, carving, tools, weaving, jewelry, hula or traditional dance, and ceremonial practices.

Vulnerability Assessment Results

Cultural knowledge and heritage values on Maui Nui were evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low* adaptive capacity. This ecosystem service is vulnerable to climate changes that impact the health and integrity of ecosystems and/or native species, and changes that damage or destroy valued cultural assets and heritage sites; these include changes in precipitation and drought, air and water temperatures, sea level rise, coastal erosion, and disturbance events such as wildfire, flooding, insects, and disease. Disturbance events can affect large areas and cause extensive damage or loss of living things and landscapes of cultural importance, and they can also limit access to traditional gathering areas or the ability to carry out traditional practices. Many non-climate stressors are linked to increasing human populations and associated impacts of changes in land use and the overuse of natural resources (e.g., residential and commercial development, pollution and poisons, water diversions, recreation, etc.), which have fragmented and degraded natural habitats, exacerbating the negative effects of climate change. The introduction and establishment of invasive species, including plants, wildlife, insects, fish, and pathogens/parasites, have had an especially large impact on cultural knowledge and heritage by altering ecosystem functions and driving the loss of native species and habitats.

Native Hawaiian knowledge and heritage is still affected by colonialism, and these values receive relatively little public and societal recognition and support. However, the importance of cultural knowledge, as well as the benefits it offers to ecosystems and other ecosystem services, is starting to be incorporated into natural resource management and decision-making processes to a greater degree.

Adaptation Planning Results

Table 14 presents a summary of possible adaptation strategies and actions for Maui Nui cultural knowledge and heritage values, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 14 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 14. Summary of possible adaptation strategies and actions for Maui Nui cultural knowledge and heritage values.

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Protect cultural practices (e.g., fishing, gathering, farming, fiber collection and processing)	• Protect/create dedicated spaces for cultural practices • Protect water rights and public access to the shoreline and forest
Resilience *Near- to mid-term approach*	Prioritize and pair habitat restoration with cultural resource management	• Restore culturally significant habitats from mauka to makai (e.g., loʻi, forests, beaches) • Implement ahupuaʻa practices to encourage geographically based restoration and a sustainability mindset • Articulate the value of culturally significant habitats (especially for cultural resource improvement)
	Increase biocultural landscape-based planning and management	• Create policies that maintain public access to coastal, forest, and wetland areas • Enforce existing conservation zoning laws (e.g., Haleakalā) • Revise planning documents (e.g., Maui Island Plan) based on climate change data • Revise the coastal erosion formula and setback

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
		requirements in Special Management Areas to account for projected sea level rise
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Acquire land for mauka migration in anticipation of sea level rise, increasing temperatures, and precipitation changes
Knowledge *Near- to long-term approach*	Increase understanding of cultural resources in need of protection	• Collect data from the community in order to better protect cultural resources
	Ensure community-wide intergenerational transmission of knowledge	• Facilitate mentorship and knowledge exchange among and between practitioners
Collaboration *Near- to long-term approach*	Increase direct community restoration	• Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change impacts
	Create healthy communities	• Increase cultural community input on water use decisions • Create/build relationships within the community, non-profit, and government sectors • Break plantation mentality and strengthen ancestral connections

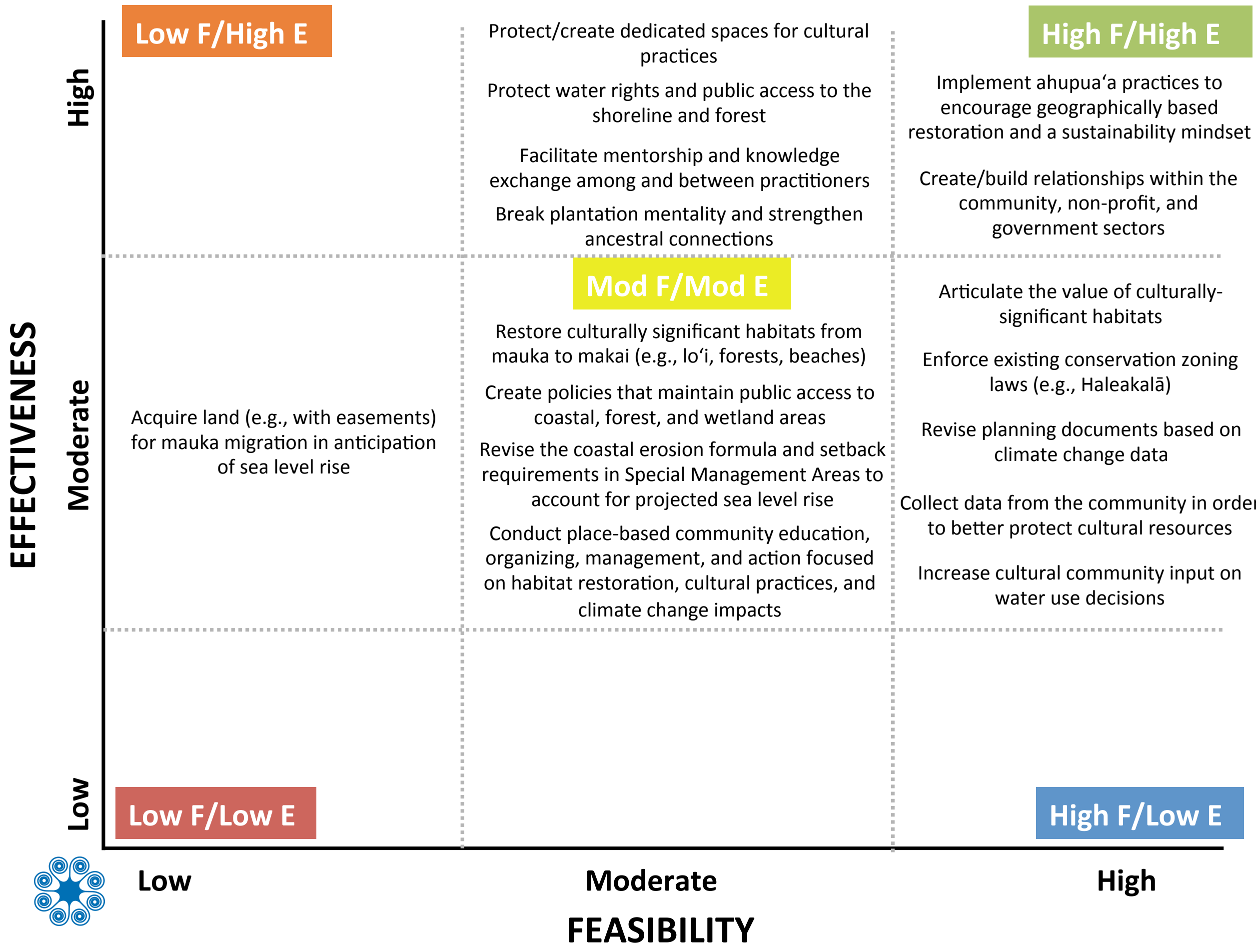

Figure 14. Maui Nui cultural knowledge and heritage values adaptation actions plotted according to implementation feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability). Those actions having high feasibility and effectiveness appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Flood and Erosion Control

Native terrestrial and aquatic ecosystems help regulate flooding and erosion by regulating surface and subsurface flow, storing and reducing rates of water discharge to water bodies, and anchoring and retaining sediment. For example, wetlands help slow floodwater velocity and attenuate sediment, and native forest landscapes intercept rain, slow runoff, and anchor sediment.

Vulnerability Assessment Results

The flood and erosion control ecosystem service on Maui Nui was evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic changes such as extreme precipitation and flash flood events can overwhelm this service, while drought and wildfire impair or alter native ecosystems, affecting their ability to provide flood and erosion control. Non-climate stressors such as residential and commercial development, roads, highways, trails, recreation, and water diversions increase sheet flow and alter surface runoff patterns, typically increasing streamflow volumes and velocity. These stressors, along with agricultural land use and invasive species (e.g., grasses, ungulates, trees), also increase bare ground and reduce native vegetative cover, increasing erosion potential. Workshop participants indicated that best management practices in urban, agricultural, and natural landscapes may help maintain flood and erosion control into the future, but also indicated that political will and public support for enhanced management will be needed.

Adaptation Planning Results

Table 15 presents a summary of possible adaptation strategies and actions for Maui Nui flood and erosion control, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 15 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 15. Summary of possible adaptation strategies and actions for Maui Nui flood and erosion control.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Use fencing in critical watersheds to exclude ungulates from upland forested areas • Remove invasive plants (e.g., Miconia)
	Increase education and outreach to increase public engagement and stewardship in conservation	• Increase education and outreach on invasive species risks and specific actions the public can take to reduce introduction and spread (e.g., sterilize recreation equipment)
	Improve fire prevention and response	• Use managed grazing and fuel treatments to limit potential fire spread and severity • Maintain fuel breaks below power lines and on road sides
	Decrease erosion and sediment delivery to improve water quality and protect municipal water supplies	• Design and construct roads to minimize erosion and sediment production • Increase and/or relocate road cross drains to decrease hydrologic connectivity between roads and streams
	Reduce non-climate stressors that affect water quality	• Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)
Resilience *Near- to mid-term approach*	Protect forests to increase recharge and water retention	• Support healthy native forests through land acquisition and plant restoration
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Provide sustainable recreation opportunities in response to changing supply and demand	• Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing climate conditions
Knowledge *Near- to long-term approach*	Anticipate and facilitate habitat migration	• Conduct a cost-benefit analysis for a range of management alternatives based on climate change vulnerability assessments and prioritization processes
Collaboration *Near- to long-term approach*	Increase collaborative efforts to conserve streams and watersheds	• Expand watershed conservation to lower elevations by enhancing watershed partnerships and seeking legislative changes at the state and local levels

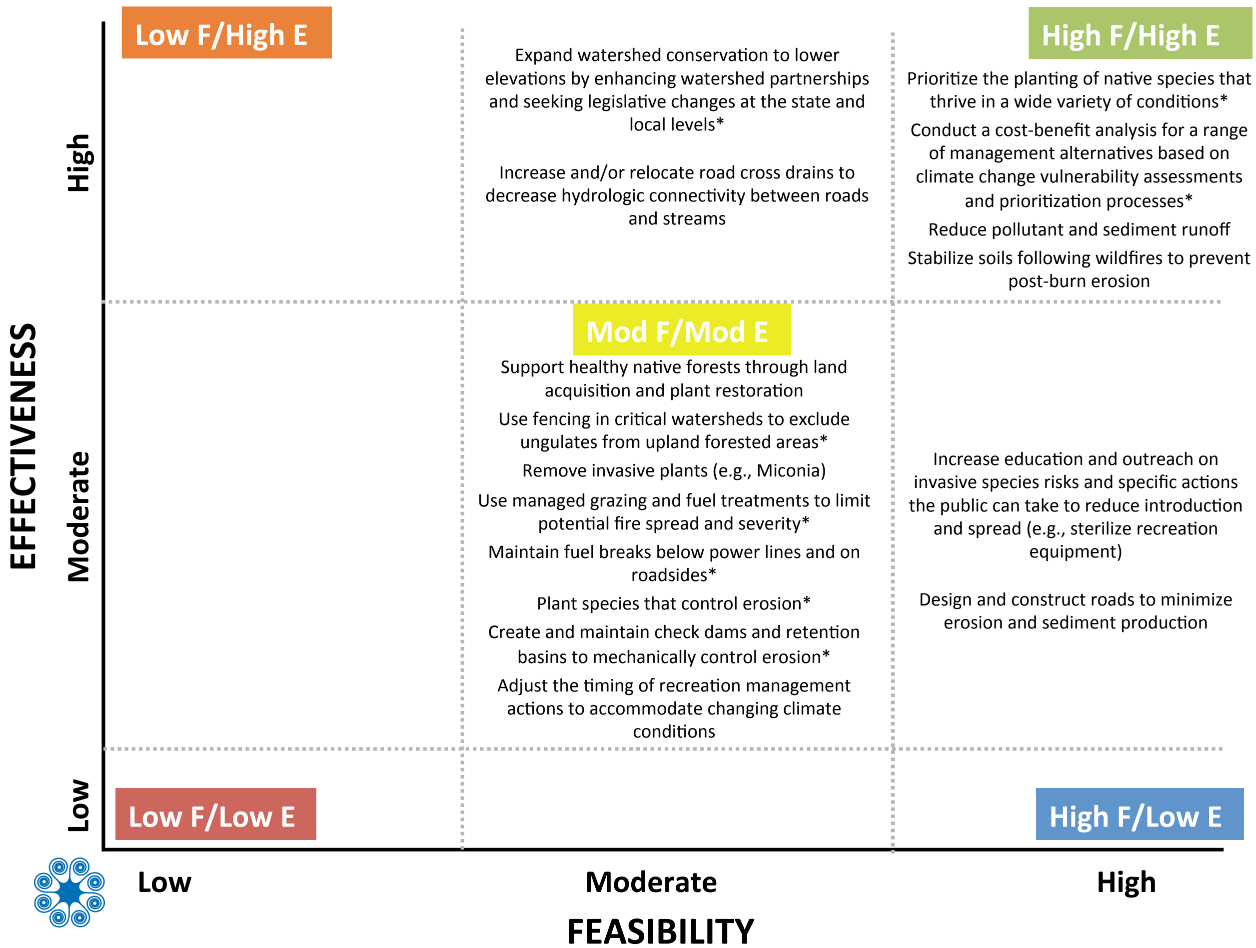

Figure 15. Maui Nui flood and erosion control adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Fresh Water

Fresh water is classified as a provisioning ecosystem service because it supplies both consumptive (e.g., drinking water, agricultural and industrial use) and non-consumptive human uses (e.g., power generation). Fresh water also supports other natural systems and processes that provide additional ecosystem services. For example, it supports aquatic habitats, which in turn provide ecosystem services such as food production, flood control, aesthetic values, and tourism and recreation. Native forests, wetlands, and other habitats help maintain fresh water supply by intercepting, slowing, and storing water. Native habitats also enhance water quality by anchoring and filtering sediment and filtering pollutants. Groundwater, surface water, and rainwater catchments represent the primary sources of fresh water on the Hawaiian Islands, including Maui Nui. On Maui, groundwater is the primary fresh water source for public supply (e.g., drinking water), while surface water has historically been predominantly used for irrigation. Overall, Maui had the highest fresh water use of all Hawaiian Islands from 1980–2010, largely due to irrigation.

Vulnerability Assessment Results

Fresh water was evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Climatic changes such as increasing drought frequency and severity, increasing precipitation variability, and warmer air temperatures are likely to reduce fresh water supply, and sea level rise may impair water quality. Shifting wind patterns may exacerbate changes in precipitation by altering orographic precipitation regimes, and changes in atmospheric circulation will likely increase TWI frequency, resulting in decreased rainfall. Other disturbance regimes such as wildfire and disease may reduce or alter native vegetation cover, impairing water capture and filtration. Non-climate stressors — including residential and commercial development, agriculture, energy development, water diversions, and groundwater development — alter water use and delivery, potentially exacerbating future climate-driven reductions in water availability. At a minimum, these stressors increase competition among water uses, which may become more problematic under drier climate conditions. Human land uses (e.g., roads, urban areas) and activities (e.g., recreation) can also impair water quality by introducing contaminants and alter water capture by increasing runoff and introducing invasive species. These invasive species — including invasive parasites/pathogens (e.g., ‘ō‘hia rust), trees (e.g., strawberry guava, miconia, and kiawe), and ungulates (e.g., feral pigs, deer, goats, and cattle) — undermine watershed health and integrity, reducing water storage and degrading water quality.

The diverse uses of fresh water increase management challenges, particularly in the face of drier climate conditions. However, workshop participants indicated that fresh water is highly valued, which may support ecosystem service stewardship. Additionally, native landscape protection and restoration may help sustain fresh water quality and supply under variable climate conditions, although changes in societal water management, politics, and economics will also influence management opportunities.

Adaptation Planning Results

Table 16 presents a summary of possible adaptation strategies and actions for Maui Nui fresh water, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 16 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 16. Summary of possible adaptation strategies and actions for Maui Nui fresh water.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Improve water conservation efforts	• Develop a water budget to account for all water sources, connectivity, uses/withdrawals, and disposal/discharge • Increase agricultural water conservation (i.e. promote soil moisture management, capture rain water) • Increase public and private water system conservation (i.e. alter rate structure, use low-flow fixtures, detect and fix leaks)
	Manage invasive species	• Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Prevent introduction of new diseases and pathogens by increasing biosecurity controls (e.g., quarantines, intraisland policies, optional vs. mandatory restrictions)
	Maintain/improve water quantity and quality	• Alter well drill depths and practice optimal well placement to minimize vulnerability to saltwater intrusion • Investigate and reduce non-point source pollution
	Reduce non-climate stressors	• Increase public education to minimize disturbance and/or degradation of vulnerable habitats or species
Resilience *Near- to mid-term approach*	Protect forests to increase recharge and water retention	• Support healthy native forests through land acquisition and plant restoration
	Mandate acquisition of new technologies to maintain and enhance water quality	• Extract sodium to increase fresh water supplies • Install diversion gates
	Increase ecosystem resilience, connectivity, and integrity	• Restore hydrologic function (i.e. reduce/remove diversions, convert ditches to pipes)
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion
Response *Long-term approach*	Increase ecosystem resilience, connectivity, and integrity	• Acquire land for mauka migration in anticipation of sea level rise, increasing temperatures, and precipitation changes
	Maintain/improve water quantity and quality	• Integrate climate projections into Water Commission planning efforts
Knowledge *Near- to long-term approach*	Monitor pollutants to protect water quality	• Monitor and regulate salinity and other indicators of water quality in wells and groundwater • Monitor point- and non-point source pollutants associated with agriculture and development (e.g.,

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		fertilizers, insecticides, agricultural byproducts)
Collaboration *Near- to long-term approach*	Increase collaborative efforts to conserve streams and watersheds	• Expand watershed conservation to lower elevations by enhancing watershed partnerships and seeking legislative changes at the state and local levels

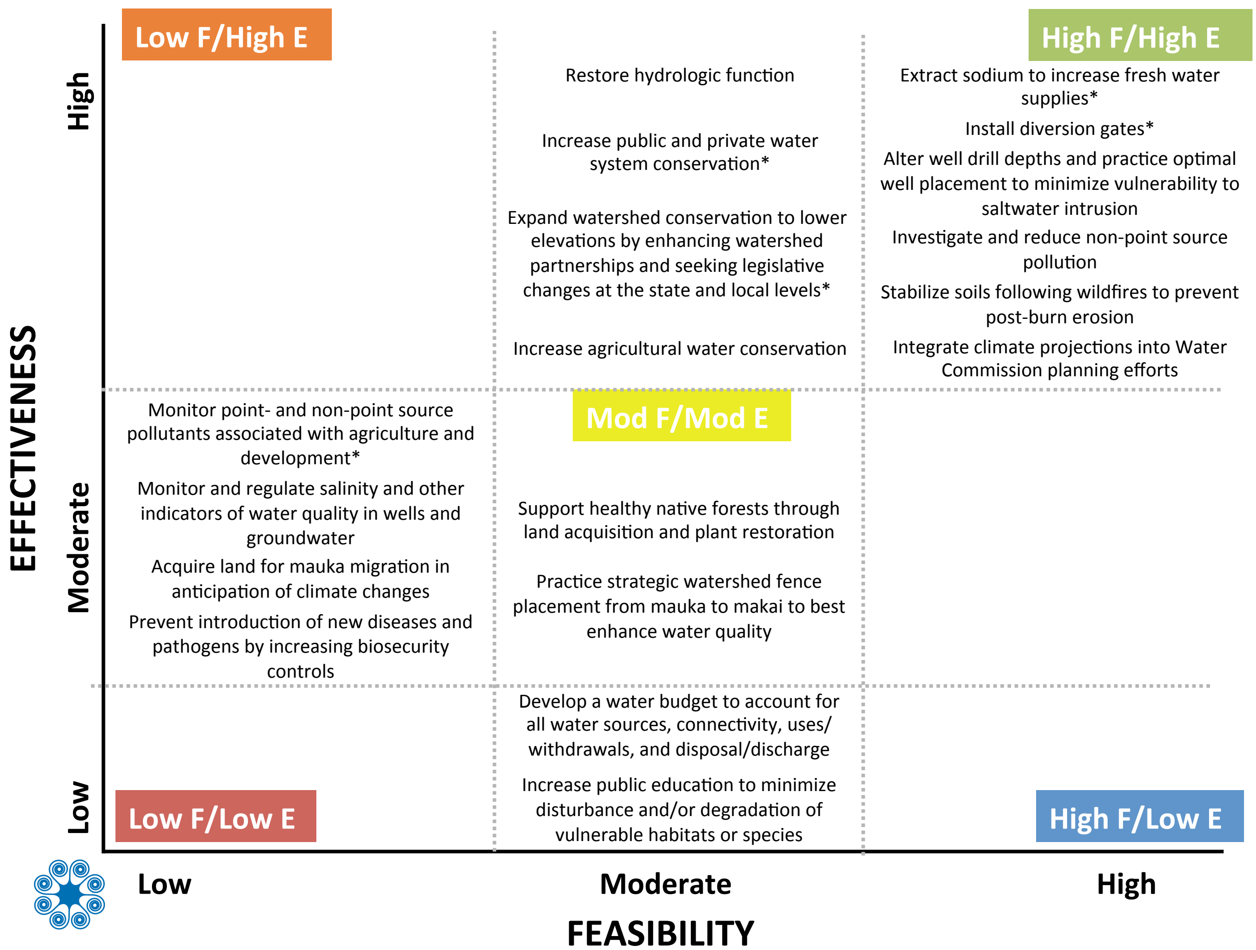

Figure 16. Maui Nui fresh water adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Food and Fiber

Agriculture, aquaculture, hunting, fishing, and gathering are used to obtain food and fiber resources, and these include many traditional cultural practices such as pig hunting, taro cultivation, fishpond aquaculture, and forest, marine, and shoreline gathering. Native species historically and currently harvested for these purposes are critical links to bridge past and present Hawaiian culture. Many food and fiber products are derived from canoe plants, a group of species that were transported to the Hawaiian Islands by early Polynesian voyagers several thousand years ago, and then carefully propagated and cultivated for use as food and fibers. Notable canoe plants used for fiber include the hala tree, wauke, olonā, and hau bush; canoe plants used for food include ʻolena (turmeric), niu (coconut palm), ko (sugarcane), and maiʻa (banana).

Native Hawaiians also historically constructed and utilized coastal fishponds (loko iʻa) for aquaculture, although fishpond use and distribution has declined over time (Maui has 44 remnant fishponds). Remnant loko iʻa in Hawaiʻi are used to raise and harvest the following traditional native species: ʻamaʻama (mullet), awa (milkfish), āholehole (Hawaiian flagtail), moi (threadfin), pāpio (jack), ʻōʻio (bonefish), awaʻaua (ladyfish), and limu (edible seaweeds). Additionally, fishponds are used to raise some harvestable non-native species, including ogo (seaweed), rainbow trout, tilapia, and ornamental carp.

Vulnerability Assessment Results

Overall, food and fiber ecosystem services were evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic changes such as water temperature, ocean acidification, and drought are likely to impact water supply and quality, increasing stress in cultivated and native species. These species may also be directly impacted by extreme events (e.g., storms) or disturbances (e.g., wildfire, insects, disease), which can impact water resources and damage infrastructure. Non-climate stressors introduce pollutants and diminish surface- and groundwater sources, degrading habitat quality and availability for harvestable species. Additionally, invasive plants and wildlife alter native ecosystems harboring species harvested for food, fiber, and other materials, in many cases out-competing native species for resources or leading to the damage or decline of cultivated and/or wild plants and animals. Although food and fiber ecosystem services are highly valued by the public, societal support for management is relatively low, and little funding is available to accomplish this. Food security in the Hawaiian Islands is low, but some efforts to restore fishponds and increase traditional taro cultivation have been successful.

Adaptation Planning Results

Table 17 presents a summary of possible adaptation strategies and actions for Maui Nui food and fiber, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 17 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 17. Summary of possible adaptation strategies and actions for Maui Nui food and fiber.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Provide erosion control by using fencing to exclude invasive species from upland habitats
	Increase food security to build resilient cultural communities	• Preserve cultural foods
Resilience *Near- to mid-*	Protect cultural practices (e.g., fishing, gathering, farming, fiber	• Create policies that maintain public access to coastal, forest, and wetland areas

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
term approach	collection and processing)	• Protect and restore culturally appropriate taro farming areas and fishponds
	Increase food security to build resilient cultural communities	• Use community gardens as pilot sites to test resilient crops
	Preserve water supplies by increasing water use efficiency	• Investigate alternative agricultural crops that have economic benefit and capture water • Improve rainfall capture to decrease groundwater withdrawals
Response *Long-term approach*	Increase ecosystem resilience, connectivity, and integrity	• Acquire land for mauka migration in anticipation of sea level rise, increasing temperatures, and precipitation changes
	Promote climate-adapted agricultural practices	• Investigate alternative agricultural crop varieties and mixes with economic value
Knowledge *Near- to long-term approach*	Increase understanding of water quantity, quality, and allocations under changing climate conditions	• Research options for water allocations under changing climate conditions • Identify, map, and quantify groundwater and surface water conditions
Collaboration *Near- to long-term approach*	Increase direct community restoration	• Conduct place-based community education, organizing, management, and action focused on native habitat restoration, cultural practices, and climate change impacts
	Create healthy communities	• Increase cultural community input on water use decisions • Create/build relationships within the community, non-profit, and government sectors

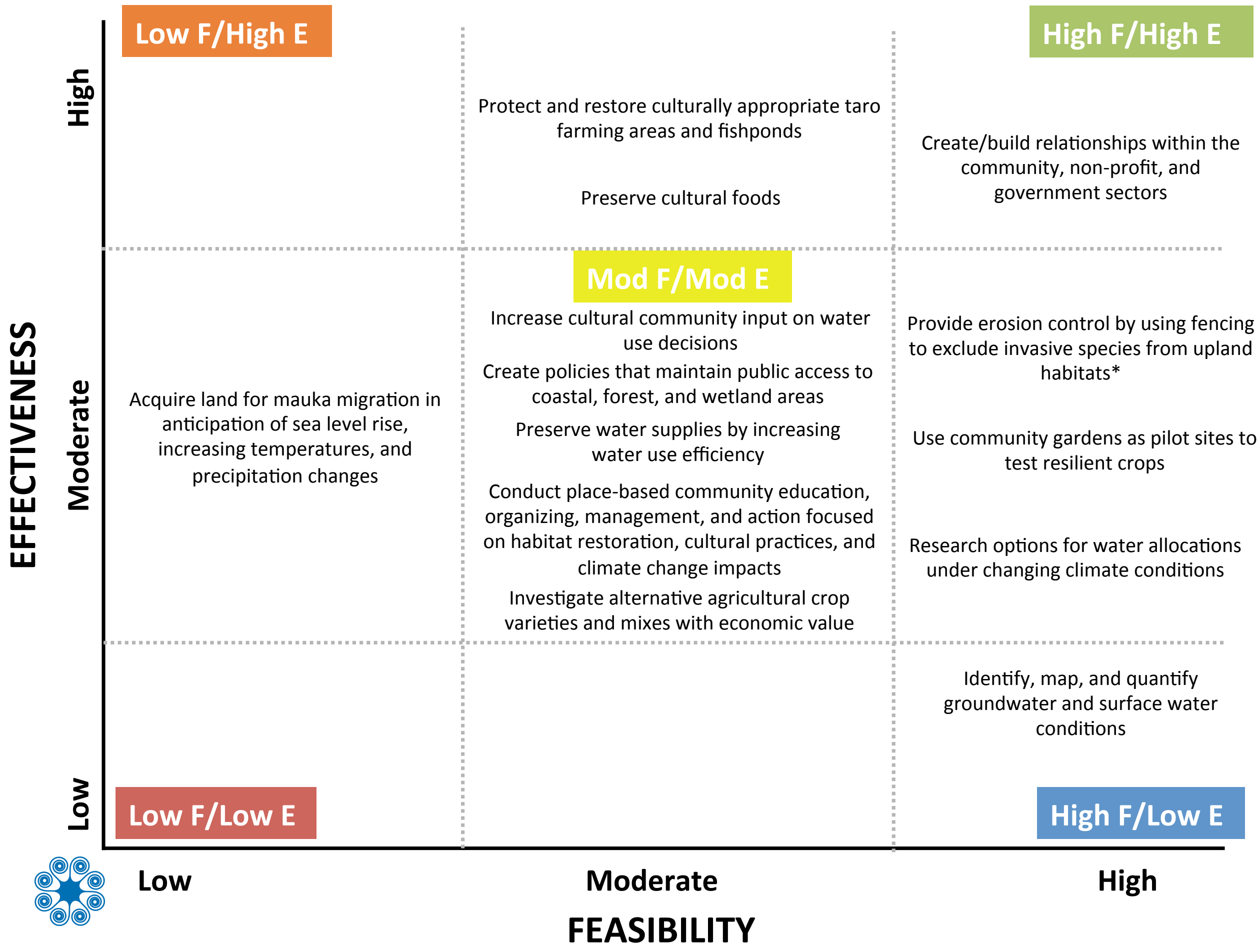

Figure 17. Maui Nui food and fiber adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Aesthetic Values

Aesthetic ecosystem services include the value of visual scenery, emotional response, and appreciation of the natural environment experienced by humans (e.g., sand between toes, smell of a plant, joy of a sunset). The perception of visual aesthetic value increases with perceived naturalness, well-preserved man-made cultural elements, percentage of plant cover, presence of water or mountains, and landscape heterogeneity.

Vulnerability Assessment Results

Aesthetic value ecosystem services on Maui Nui were evaluated as having *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. This ecosystem service is sensitive to factors that impact or alter iconic or highly valued natural areas (e.g., beaches, waterfalls), including sea level rise, coastal erosion, and changes in the amount of precipitation. Disturbances, such as wildfire, tropical storms/hurricanes, and insect outbreaks, may cause noticeable damage to these natural areas, affecting people's enjoyment of natural and cultural features. Additionally, development and agriculture/aquaculture activities can also cause damage or exacerbate the impact of climate stressors. Tourism is a large contributor to the economy of Maui Nui, which is known for its beautiful landscapes, so public support for aesthetic values is relatively high. However, this service receives little support as a management priority.

Adaptation Planning Results

Table 18 presents a summary of possible adaptation strategies and actions for Maui Nui aesthetic values, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 18 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 18. Summary of possible adaptation strategies and actions for Maui Nui aesthetic values.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Improve fire prevention and response	• Maintain fuel breaks below power lines and on road sides • Use managed grazing and fuel treatments to limit potential fire spread and severity
	Manage invasive species	• Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals
	Improve water conservation efforts	• Increase agricultural water conservation (i.e. promote soil moisture management, capture rain water)
Resilience *Near- to mid-term approach*	Maintain intact, native-dominated ecosystems	• Support healthy native forests through land acquisition and plant restoration • Consider climate projections in the timing and seasonality of planting to promote natural recruitment
Response *Long-term approach*	Implement climate-informed coastal zoning protections	• Revise setback requirements to account for projected sea level rise • Incorporate climate change into Special Management Area siting and permitting
	Anticipate and facilitate habitat migration	• Implement living shorelines and green infrastructure • Limit development in inland/upland areas where coastal habitats may migrate
Knowledge *Near- to long-term approach*	Conduct research to support adaptive policies and technology	• Identify gaps in cultural and technical knowledge to prioritize research needs • Research and develop new/improved methods of small predator and weed control
Collaboration *Near- to long-*	Build support through public education and advocacy	• Conduct climate-informed public education and outreach about protected areas and habitats at risk

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
term approach		• Conduct place-based education to encourage watershed conservation • Create remote sites and viewpoints and post public signage about the natural and cultural importance of habitats

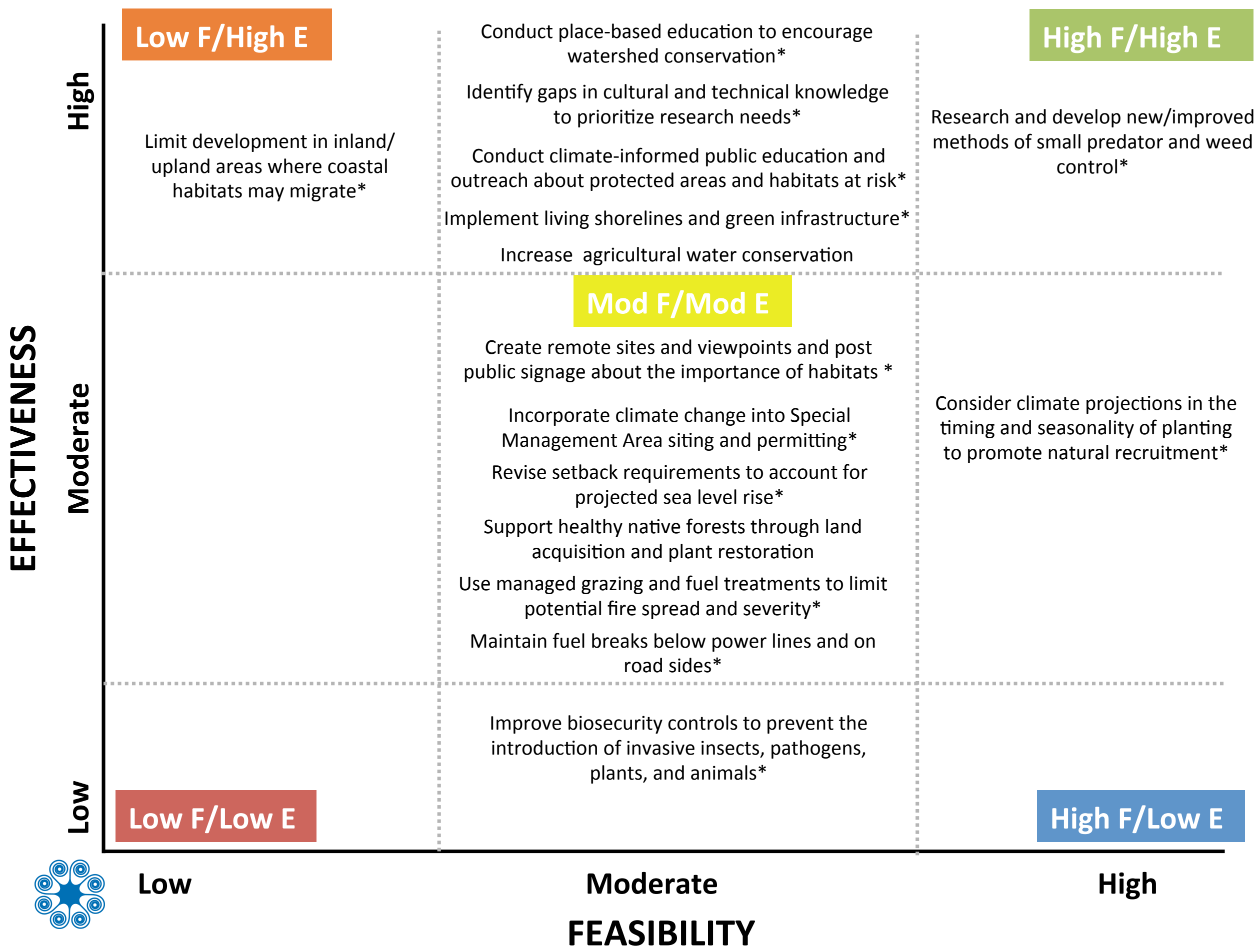

Figure 18. Maui Nui aesthetic values adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Recreation and Tourism

Maui Nui's native ecosystems and cultural landscapes provide a diversity of recreation and tourism opportunities. Mauka activities include hiking, camping, bird watching, and sport hunting; makai activities include hiking, wildlife viewing, beach access, sport fishing, snorkeling and scuba diving, whale watching, and other water-based activities. Cultural tourism (e.g., visiting historic sites), ecotourism (e.g., enjoying scenic views/forested landscapes), and geotourism (e.g., visiting volcanic areas) occur across the mauka to makai continuum.

Vulnerability Assessment Results

Maui Nui recreation and tourism was evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Recreation and tourism are sensitive to climatic factors that reduce the integrity or naturalness of native systems or affect the health and behavioral patterns of wildlife, including drought, low streamflow, sea surface temperature changes, and increasing air temperatures. Recreation and tourism are also sensitive to factors such as sea level rise, flooding, tropical storms, extreme precipitation events, and wildfire, which contribute to loss of recreation and tourism opportunities (e.g., physical loss of beaches, loss of access in burned or flooded areas). Insects and disease also degrade tourism and recreation experiences by negatively impacting Hawaiian landscapes and wildlife, and posing a health hazard to visitors. A variety of non-climate stressors threaten recreation and tourism by affecting natural landscape integrity and access and degrading water quality via elevated runoff. Land-use changes (e.g., urban development, agriculture, roads/highways/trails, water diversions, energy development) eliminate natural areas and alter ecosystem processes, impacting valued wildlife and native plant species characteristic of Hawaiʻi and exacerbating some impacts of climate change (e.g., flooding, erosion). Similarly, invasive species (e.g., ungulates, flammable grasses, trees, reptiles/amphibians, parasites/pathogens, social insects) displace native species and alter regional forest and watershed processes, affecting tourism and recreation access, quality, and safety.

As a main component of Maui Nui's economy, recreation and tourism are highly valued and management for these ecosystem services has moderate-high societal support. However, management can be challenging because recreation and tourism can potentially degrade other ecosystem services (e.g., fresh water, food production, aesthetic values, cultural services), though recreation and tourism can benefit some services as well (e.g., provide support for biodiversity and conservation).

Adaptation Planning Results

Table 19 presents a summary of possible adaptation strategies and actions for Maui Nui recreation and tourism, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 19 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 19. Summary of possible adaptation strategies and actions for Maui Nui recreation and tourism.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Improve fire prevention and response	• Enhance public awareness of the risks and consequences of wildfire to native plant ecosystems • Increase funding for support of fire response agencies and Community Wildland Protection Plans
	Improve water conservation efforts	• Increase public and private water system conservation (i.e. alter rate structure, use low-flow fixtures, detect and fix leaks) • Increase agricultural water conservation (i.e.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		promote soil moisture management, capture rain water)
	Reduce non-climate stressors	• Increase public education to minimize disturbance and/or degradation of vulnerable habitats or species
	Manage invasive species	• Prevent introduction of new diseases and pathogens by increasing biosecurity controls (e.g., quarantines, interisland policies, optional vs. mandatory restrictions)
	Maintain/improve water quality and quantity	• Investigate and reduce non-point source pollution
Resilience *Near- to mid-term approach*	Ensure no new development occurs in areas that will likely be inundated in the future	• Change permitting rules to limit development along the shoreline and floodplain to higher elevations above the 100-year sea level rise projections
	Provide sustainable recreation opportunities in response to changing supply and demand	• Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing climate conditions
	Enhance habitat and species resilience	• Identify and protect refugia (e.g., temperature-tolerant coral areas)
	Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities	• Modify existing infrastructure to better withstand future climate conditions • Adjust infrastructure maintenance schedule as needed to accommodate changing climate conditions • Relocate at-risk infrastructure
Response *Long-term approach*	Implement climate-informed coastal zoning protections	• Revise setback requirements to account for projected sea level rise • Modify the formula for erosion control to incorporate data on climate change • Limit development in most vulnerable sites
	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
Knowledge *Near- to long-term approach*	Monitor pollutants to protect water quality	• Monitor point- and non-point source pollutants associated with agriculture and development (e.g., fertilizers, insecticides, agricultural byproducts)
Collaboration *Near- to long-term approach*	Increase direct community restoration	• Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change impacts

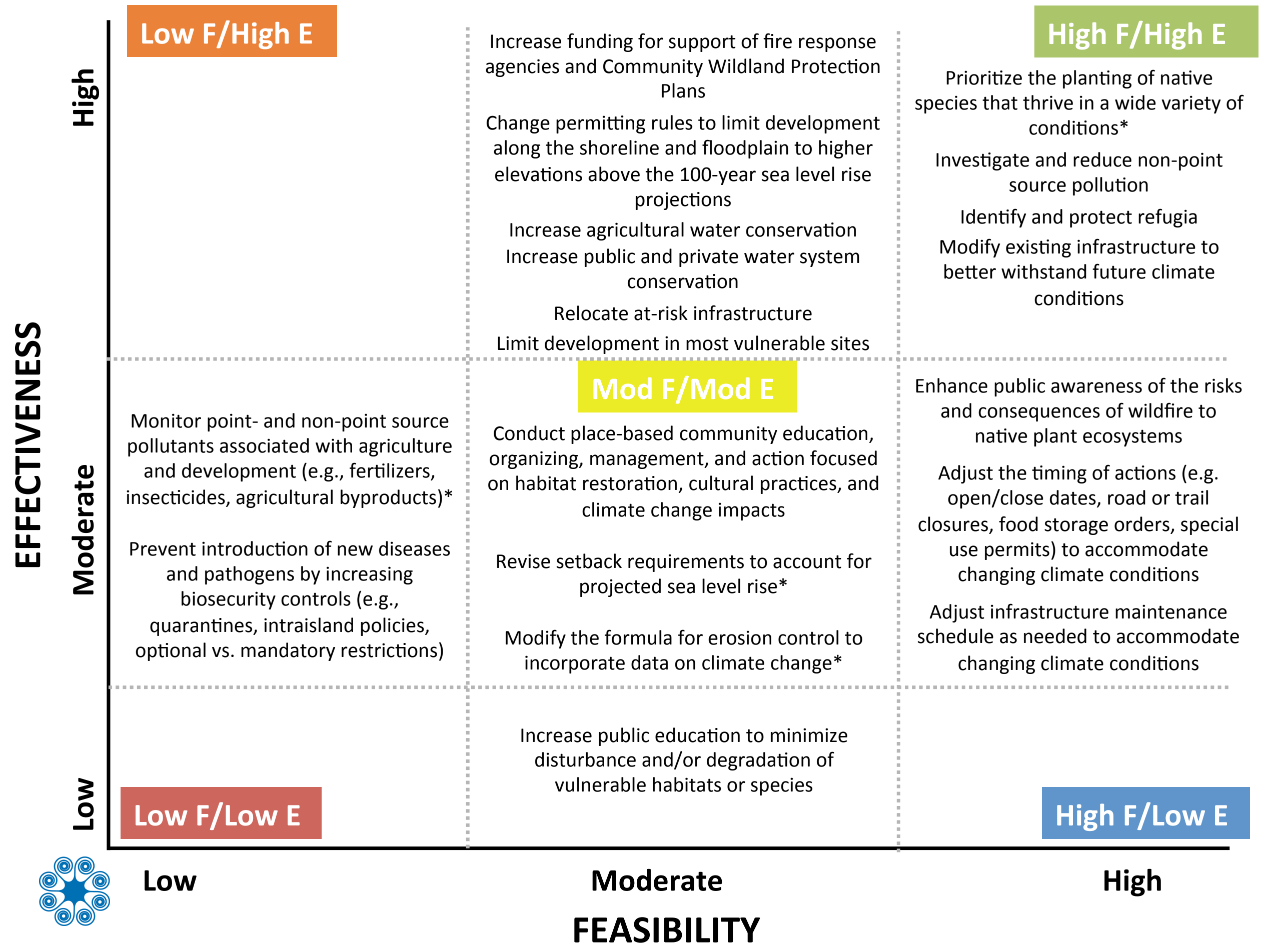

Figure 19. Maui Nui recreation and tourism adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Adaptation Planning: Molokaʻi

EcoAdapt and the PICCC were invited to participate in a discussion with the Molokaʻi Climate Change Network in April 2017. During the conversation, participants brainstormed a potential adaptation project. The overarching goal identified was to *increase connectivity between important biocultural upland and aquatic ecosystems (e.g., forest, springs, wetlands, nearshore habitats).* Participants discussed the importance of choosing a teaching/training site to test innovative approaches, refine restoration techniques, and incorporate community participation and engagement in conservation efforts. Members of the network are continuing to meet to discuss potential next steps, including developing an implementation and funding plan.

Oʻahu: Vulnerability Assessment and Adaptation Options

Summary

The following chapter provides a summary of the vulnerability assessment and adaptation planning results for Oʻahu. Table 20 presents the overall vulnerability and confidence scores for habitats and ecosystem services. Figure 20 presents the overall vulnerabilities of habitats and ecosystem services based on the assessment of climate and non-climate sensitivity and exposure and adaptive capacity.

Table 20. Overall vulnerability and confidence scores for Oʻahu habitats and ecosystem services.

Focal Resource	Vulnerability Score	Confidence Score
Habitats		
Coastal: Sandy Shorelines	**High**	**High**
Coastal: Rocky Shorelines	**Moderate**	**Moderate**
Coastal: Estuaries	**Moderate-High**	**High**
Aquatic: Lowland Wetlands	**Moderate-High**	**Moderate**
Aquatic: Upland Wetlands	**Moderate**	**Moderate**
Aquatic: Streams	**Moderate**	**Moderate**
Dry Forest	**Moderate-High**	**Moderate**
Mesic and Wet Forest	**Moderate-High**	**High**
Ecosystem Services		
Cultural Knowledge and Heritage Values	**High**	**Moderate**
Flood and Erosion Control	**Moderate**	**High**
Fresh Water	**High**	**High**

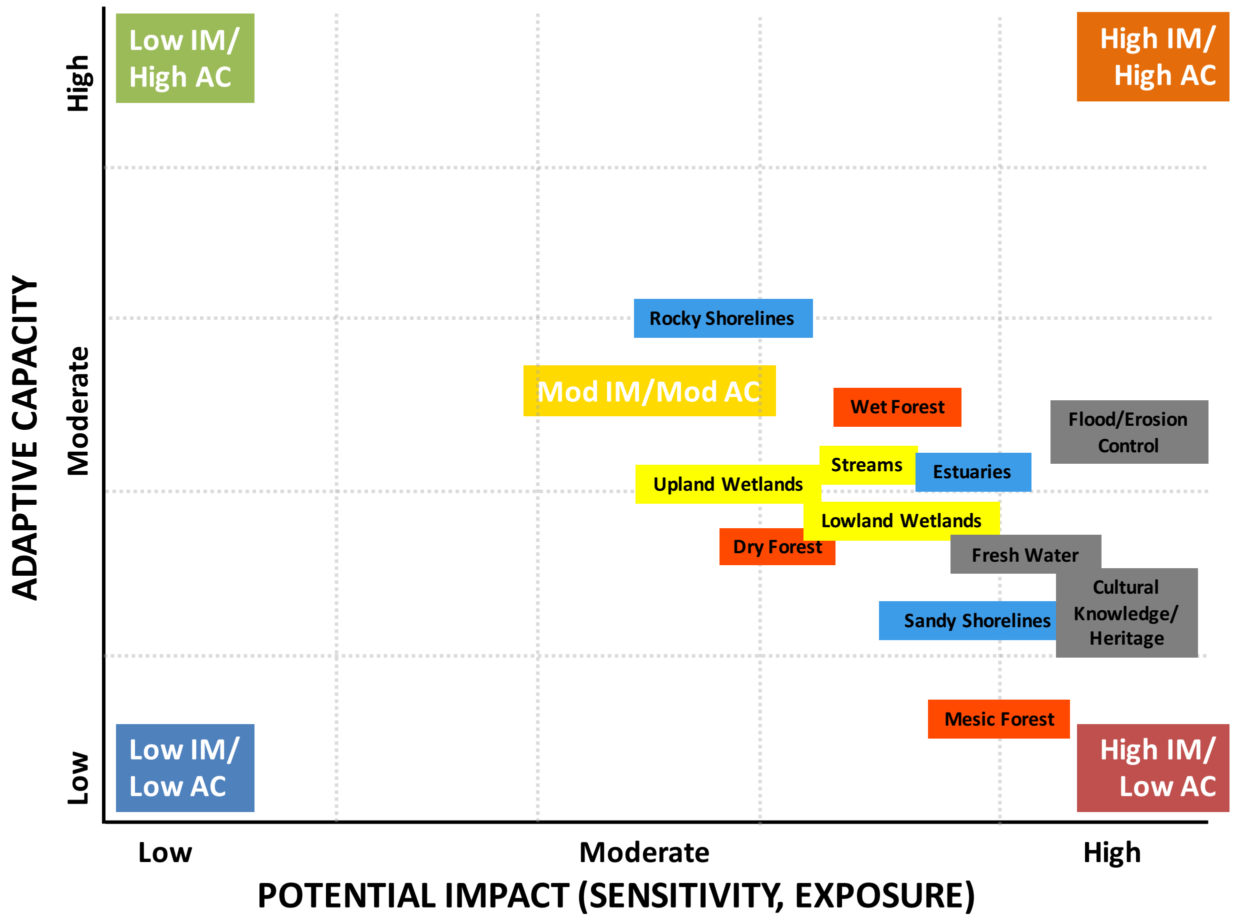

Figure 20. Overall vulnerabilities of O'ahu habitats and ecosystem services based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. Color code: Terrestrial habitats (red), Coastal habitats (blue), Aquatic habitats (yellow), Ecosystem services (grey)

Coastal Habitats

Workshop participants classified coastal habitats as sandy shorelines, rocky shorelines, and estuaries. Oʻahu has approximately 107 km (66 miles) of **sandy shorelines**, including dunes, continuous beach stretches spanning multiple kilometers, and pocket beaches between rocky headlands. **Rocky shoreline** habitats include low-lying rocky shorelines (e.g., beachrock, boulder beach basalt, limestone, perched rocky platforms), bluffs and rocky headlands often with boulder beach at the base, and tidepools. **Estuarine habitats** include lowland/coastal saline wetlands, stream mouths, and anchialine pools. Example estuarine habitats on Oʻahu include Kahana, Pearl Harbor National Wildlife Refuge, Heʻeia Natural Estuarine Research Reserve, Nuʻupia, Kāneʻohe, Pouhala Marsh, and Haleʻiwa.

Vulnerability Assessment Results

Sandy Shorelines

Sandy shoreline habitats on Oʻahu were evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Sandy shorelines are likely to be affected by climatic factors and disturbance regimes that increase erosion and inundation, including sea level rise, storm-related swell, and trade winds. These factors are largely projected to contribute to continued loss of sandy beach habitat on Oʻahu over time. Non-climate stressors such as residential and commercial development, shoreline armoring, roads, and highways exacerbate erosion issues by preventing habitat migration and restricting terrestrial sediment supply. Sandy shorelines are also sensitive to other non-climate stressors such as under-managed recreation and pollution and poisons, which degrade habitat suitability for vegetation and wildlife. Sandy shoreline habitats are highly valued by the public and provide several critical ecosystem services. However, funding for conservation is limited, and conservation practices are sometimes at odds with development and shoreline property owner interests. Additionally, many of Oʻahu's sandy shoreline habitats are degraded by development and armoring. These shoreline alterations make it difficult for sandy shoreline habitats to resist or recover from climate impacts such as sea level rise and erosion.

Rocky Shorelines

Rocky shoreline habitats on Oʻahu were evaluated to have *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Rocky shorelines are sensitive to increased erosion, inundation, and altered wave energy as a result of sea level rise and tropical storms. These climatic factors may also affect community structure. Non-climate stressors, such as pollution and development, further alter rocky shoreline biotic communities by degrading habitat quality and availability, although shoreline hardening may provide connectivity (i.e. hard substrate) between isolated rocky shoreline areas. In general, roads and development can destroy or displace rocky shoreline habitats, and prevent landward migration in response to sea level rise and coastal erosion. Rocky shorelines have a high geographic extent on Oʻahu, but habitat integrity is affected by human activities. Rocky shorelines are fairly resilient to disturbance and climatic changes due to hard substrates that help resist erosion, quick colonization and recruitment within disturbed areas, and the high tolerance of component organisms to stressful conditions. Rocky shoreline habitats have a moderate-high value to the public, but conservation funding is limited, and conservation practices may be at odds with development interests.

Estuaries

Estuarine habitats on Oʻahu were evaluated as having *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Climatic factors such as sea level rise, saltwater intrusion, and streamflow affect estuarine salinity, hydrology, water quality, and water temperature. Hydrological, salinity, and water quality changes affect overall habitat distribution, availability, and species composition. Higher estuarine water temperatures as a result of increasing stream and sea surface temperatures may alter native species assemblages. Non-climate stressors such as invasive marine and terrestrial species and pollution and poisons will also contribute to loss of native species and increased exotic dominance. Stressors such as agriculture, development, and roads eliminate or alter estuarine habitat, and may compound climate-driven changes by affecting hydrology, sedimentation, and available space for habitat migration. Projected population growth on Oʻahu will likely exacerbate existing non-climate stressors. Estuarine habitats on Oʻahu are abundant but vary in ecological integrity. Development, roads, agriculture, and alien species degrade these habitats, and also inhibit habitat migration in response to climatic changes. Estuarine habitats exhibit a moderate-high ability to resist and recover from changes, particularly when supported by restoration. Native estuarine species also exhibit a high tolerance for extreme conditions, which enhances habitat resilience. However, estuarine habitats are less resilient to invasive species and human-driven modifications. Estuarine management and conservation is supported by regulatory protection, constituency support, and recognition of the critical ecosystem services estuaries provide.

Adaptation Planning Results

Table 21 presents a summary of possible adaptation strategies and actions for Oʻahu coastal habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 21 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 21. Summary of possible adaptation strategies and actions for Oʻahu coastal habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Restore and conserve native shoreline and estuarine habitat	• Remove mangroves and other invasive vegetation • Nourish beaches in areas where habitat retreat is not an option
	Reduce non-climate stressors	• Reduce litter and marine debris • Remove existing debris from coastal habitats • Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)
Resilience *Near- to mid-term approach*	Restore and conserve native shoreline and estuarine habitat	• Restore native species • Restore dune and coastal strand habitats
	Practice climate-informed habitat restoration	• Maintain and/or increase coastal habitat restoration efforts that incorporate climate information • Remove hard structures that exacerbate climate impacts
	Increase resilience to changes in temperatures	• Use vegetation to increase shading of wetlands and microhabitats
	Implement climate-informed coastal zoning protections	• Incorporate climate change into Special Management Area siting and permitting • Modify the formula for erosion control to incorporate data on climate change • Revise setback requirements to account for projected sea level rise
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Identify critical infrastructure that needs to be protected or relocated • Acquire property with high future ecosystem value (i.e. less developed, less exposed/vulnerable sites) • Limit development in inland/upland areas where coastal habitats may migrate • Implement living shorelines and green infrastructure • Establish shoreline setbacks

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Knowledge *Near- to long-term approach*	Coordinate and amplify public education and outreach messages	• Conduct a needs assessment of agencies/organizations doing outreach, education, and on-the-ground stewardship/engagement service projects
	Develop more efficient technologies/tools for habitat restoration and invasive species control	• Develop alternative removal technologies that the public can do themselves
	Increase environmental and climate literacy across all ages	• Create a suite of products to educate decision-makers about likely impacts of climate change
Collaboration *Near- to long-term approach*	Improve science-management communication and partnerships	• Share new climate models and tools to increase accessibility to information
	Develop more efficient technologies/tools for habitat restoration and invasive species control	• Enhance interagency coordination between groups working in same landscape area (e.g., collaboratively identify priority areas and high risk invasive species, collaborate on monitoring and surveys)

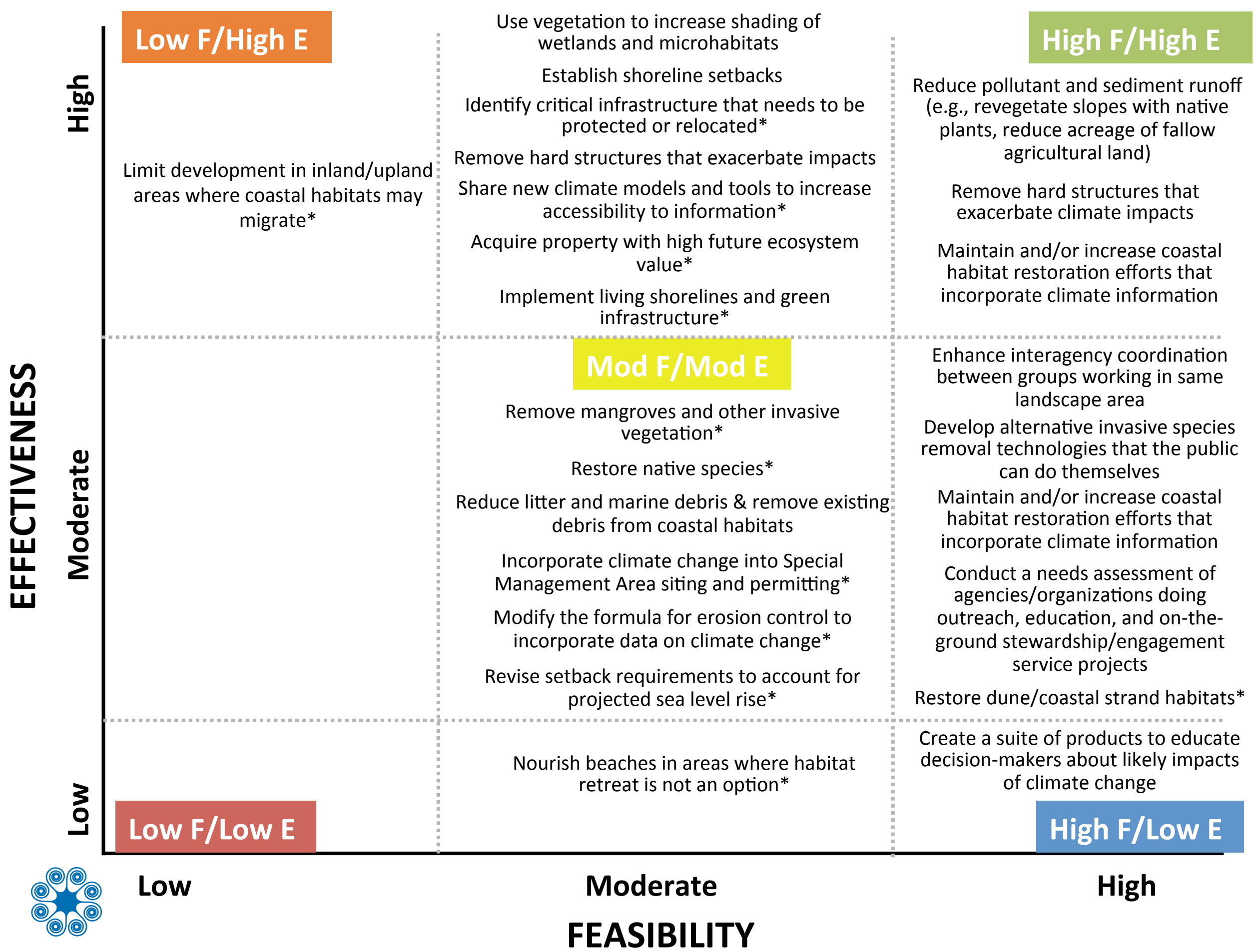

Figure 21. O'ahu coastal habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right

corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Aquatic Habitats

Workshop participants classified aquatic habitats as lowland wetlands, upland wetlands, and streams. **Lowland wetlands** are coastal freshwater marshes that occur below 100 m (328 ft), and feature perennial or seasonal ponded fresh water derived from precipitation, river and stream runoff, and groundwater inflow. Significant lowland wetland habitats on Oʻahu occur at James Campbell National Wildlife Refuge, Pearl Harbor National Wildlife Refuge, Kawai Nui and Hamakua Marsh Complex, the Nuʻupia Pond Wildlife Management Areas, Pouhala Marsh, Kaelepulu Wetland, and lowland areas within the windward ahupuaʻa of Heʻeia, Kahaluʻu, Waiheʻe, Waiāhole, Waikane, and Hakipuʻu. **Upland wetland habitats** are comprised of bogs, swamps, and marshes that occur above 100 m (328 ft). Oʻahu has two significant upland wetland habitats: Kaʻala Bog on the leeward side of Oʻahu on the summit plateau of Mount Kaʻala, and Kaʻau Crater on the windward, southern Koʻolau Mountains. **Streams** are defined as continuous perennial streams and naturally interrupted streams that maintain some type of perennial flow; intermittent streams were not considered. Oʻahu streams originate in the Waiʻanae and Koʻolau Mountain Ranges. Oʻahu has 57 perennial streams, 29 of which flow continuously across their entire course.

Vulnerability Assessment Results

Lowland Wetlands

Lowland wetland habitats on Oʻahu were evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Climatic factors such as sea level rise, saltwater intrusion, precipitation, and drought are likely to affect lowland wetland hydroperiod (i.e. seasonal pattern of wetland water levels), salinity, and geographic extent, which can drive changes in vegetative composition and/or affect habitat suitability for wildlife (e.g., endangered waterbirds). Warmer air temperatures are also likely to affect wetland plant germination, increase avian disease risk, and alter waterbird nesting success. Non-climate stressors such as development, pollution and poisons, and invasive vegetation and ungulates compound potential reductions in lowland wetland habitat availability and quality by affecting overall habitat extent, water quality, and hydrological and sediment regimes. Invasive amphibians, fish, and mammalian predators prey on and compete with native wetland species. Oʻahu has lost roughly 71% of its lowland wetland area since human settlement, with development contributing to a majority of habitat losses and degraded habitat function. Development — along with commercial agriculture, infrastructure, invasive species, and geologic/atmospheric/water features — also limits habitat migration in response to climate stressors such as sea level rise. Lowland wetlands are not very resistant to non-climate stressors (e.g., invasive species, hydrological and sediment changes due to upland watershed changes), although wetland waterbirds appear to be able to use artificial wetland habitats. Lowland wetland diversity has been impacted by invasive species, and may be further threatened by salinity changes. Overall, lowland wetland habitats on Oʻahu rely on a high degree of management to maintain function. Lowland wetland management is supported by regulatory protection, interest in preserving endangered and endemic waterbirds, the critical ecosystem services wetlands provide, and for some wetlands, high grassroots and constituency support. Future management may be challenged by shifts in water availability, which could increase competition with other water uses and affect some current management actions (e.g., water supplementation).

Upland Wetlands

Upland wetland habitats on Oʻahu were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors including precipitation, soil moisture, condensation levels, and drought affect water availability in upland wetlands, which along with air temperature, affects vegetation survival, composition, and peat formation. Tropical storms, wildfire, and disease may also affect water delivery to upland wetlands by affecting the condition of the broader water catchment; wildfire and tropical storms also affect wetland sediment input via erosion. Non-climate stressors such as invasive species (e.g., ungulates, flammable grasses, trees, and shrubs) can further alter upland wetland vegetative composition by displacing native species. Invasive vegetation also alters ecological processes, such as fire. Upland wetlands occupy only a small area on Oʻahu and are structurally degraded by invasive species. Upland wetlands have limited room to migrate in response to climate change due to their location at high elevations, and the restricted range of component specialist and endemic species undermines overall habitat adaptive capacity. Vegetation appears to be somewhat resistant to invasives in the absence of disturbance, and able to recover from prior disturbance once disturbances (e.g., pigs) are removed. Additionally, vegetation seems somewhat adapted to seasonal variations in water availability, although large shifts in precipitation would likely lead to community composition changes. Management potential in the face of climate change is bolstered by high societal value, regulatory protection, and location of one wetland area within Natural Area Reserve boundaries.

Streams

Stream habitats on Oʻahu were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors such as precipitation, drought, extreme precipitation events, tropical storms, soil moisture, and flooding affect water availability and streamflow regimes, influencing stream habitat availability, quality, and connectivity to the ocean, as well as aquatic community assemblages. Tropical storms, extreme precipitation events, flooding, and wildfire also affect water quality by delivering sediment, nutrients, and contaminants. Stream hydrological changes are exacerbated by many non-climate stressors, including water diversions, groundwater development, residential and commercial development, agriculture, roads, and invasive trees and shrubs. Development, agriculture, aquaculture, and roads also degrade stream water quality, along with invasive ungulates and pollution and poisons. The adaptive capacity of Oʻahu streams is undermined by low native biodiversity and significant alteration and degradation of streams at lower elevations and in areas adjacent to agriculture and urban land uses. However, even with alteration, streams typically support some type of biotic community, and restoration efforts on other Hawaiian islands indicate that stream algal and invertebrate biomass can recover rapidly following natural flow restoration. Workshop participants identified several non-climate stressors that can be managed to reduce overall habitat impacts (e.g., invasive species, channelization). However, stream habitat management will continue to be affected by competing water interests, especially in a drier climate.

Adaptation Planning Results

Table 22 presents a summary of possible adaptation strategies and actions for Oʻahu aquatic habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 22 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 22. Summary of possible adaptation strategies and actions for Oʻahu aquatic habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Reduce non-climate stressors that affect water quality	• Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land) • Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Retrofit existing infrastructure to reduce water losses and improve water conservation (e.g., fix leaks)
Resilience *Near- to mid-term approach*	Maintain and augment native species populations	• Control and remove invasive plants and predators • Use native outplantings to relocate and/or increase native plant and animal populations
	Restore "mauka to makai" streamflows to restore connectivity, stream quality, and native species movement and re-establishment	• Modify diversions to allow flow passage, particularly on high-use streams under development pressure • Modify culverts to accommodate extreme flooding • Modify stream crossings to enhance fish passage and habitat connectivity • Establish and enforce instream flow standards in streams with multiple diversions and existing conflicts/competition • Practice holistic management by eliminating watershed transfers and restoring traditional decision-making
Response *Long-term approach*	Maintain and augment native species populations	• Plant a variety of species adapted to different salinities
	Facilitate transition of species into new areas as climate regimes shift	• Identify and protect possible refugia based on precipitation modeling • Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
	Use assisted colonization to restore rare species	• Identify and prioritize suitable habitat based on factors that suggest long-term ecological sustainability
	Create new wetlands to buffer climate-related habitat change	• Factor in climate changes in wetland acquisition planning and examine risk involved in managing new wetlands
Knowledge *Near- to long-term approach*	Improve water conservation efforts	• Increase outreach and education on water conservation in light of climate change (e.g., mauka to makai event at aquarium)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		• Use ENSO Climate Outlooks to facilitate public understanding of potential climate impacts on water resources
	Increase restoration capacity	• Increase in-state capacity to conduct research on pests and pathogens
Collaboration *Near- to long-term approach*	Improve science-management communication and partnerships	• Facilitate community events where public can visit wetlands as a first step to increasing action, awareness, and education

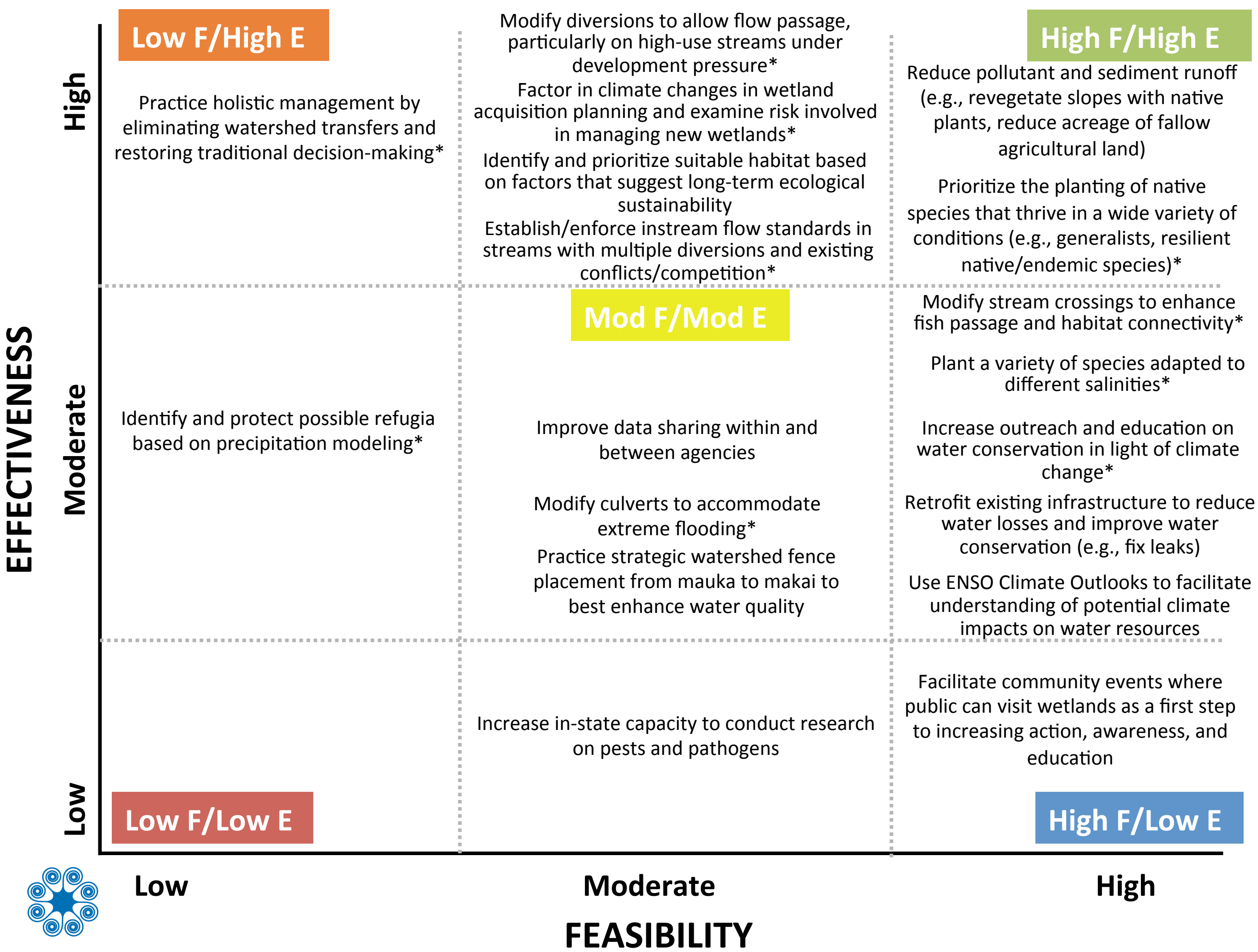

Figure 22. O'ahu aquatic habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Dry Forest

Dry forests on Oʻahu have extremely limited distribution; they occur in leeward lowland areas and are commonly limited to steep slopes that have experienced less exposure to development and invasive species. These habitat types are often associated with younger, shallow substrates comprised of cinder, ash, and lava flows, and plant succession corresponds to substrate age. Dry forests typically receive less than 1,270 mm (50 in) of annual rainfall and are characterized by warm to hot conditions and a seasonal dry period. Dominant dry forest canopy species include lama, ʻōhiʻa, koa, and wiliwili.

Vulnerability Assessment Results

Dry forest habitats on Oʻahu were evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Because dry forests are already limited by moisture, they are most sensitive to climatic factors that increase water stress, such as drought, soil moisture, precipitation changes, extreme precipitation events, and air temperature. These changes are likely to impact species recruitment, community composition, and forest distribution. Disturbance events (e.g., wildfire, wind, insects, disease) may also affect dry forest cover and canopy integrity by increasing vulnerability to invasion by flammable grasses and causing tree damage or mortality. Several invasive species (e.g., flammable grasses, trees and shrubs, mammalian predators) also impair dry forest recruitment and recovery either by competing with and displacing native vegetation or consuming seeds and fruit needed for recruitment. Invasive ungulates also elevate disturbance and increase vulnerability to non-native plant establishment. Additional non-climate stressors, including development, agriculture, and roads/highways, threaten remnant dry forest habitat by competing for space and increasing disturbance. Only a small area of dry forest habitat remains on Oʻahu, and remnant habitat patches are severely degraded by invasive species. Habitat fragmentation, a high number of endangered species, and slow recovery rates of native species make it difficult for dry forests to recover from disturbances and respond to climate change. Dry forest management and conservation is supported by successful restoration efforts, regulatory and legal protection, and some public value for ecosystem services associated with dry forest. However, existing degraded habitat conditions make management under a changing climate difficult, particularly with limited funding.

Adaptation Planning Results

Table 23 presents a summary of possible adaptation strategies and actions for Oʻahu dry forest habitat, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 23 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 23. Summary of possible adaptation strategies and actions for Oʻahu dry forest habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain and protect existing dry forest habitat	• Increase fencing and invasive plant and ungulate removal at high elevations to increase continuity between dry and mesic/wet forest habitats • Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals • Widen firebreaks and change placement if necessary to improve fire prevention • Develop tree fall protocols for storm damage to fences (i.e. strategic removal of trees pre-storm) and increase funding for repairs
	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	• Integrate climate change into Wildland-Urban Interface designations and future landscape development, particularly for areas that are dry or projected to become drier
Resilience *Near- to mid-term approach*	Restore degraded dry forest habitat	• Improve seed collection and storage by creating common native seed orchards • Revegetate dry forests by outplanting native species (i.e. along dry forest edges, Wildland-Urban Interface, higher elevations to increase survival) • Consider climate projections in the timing and seasonality of planting to promote natural recruitment
	Improve resilience of key dry forest species/communities	• Identify and prioritize existing dry forest biomes and create a strategy to expand protection and restoration • Explore genetic engineering for increased resilience (e.g., drought tolerance)
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Identify, prioritize, and protect areas that may transition to dry forest in the future
	Identify and promote climate-adapted species composition	• Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing climate conditions
Knowledge *Near- to long-term approach*	Increase research efforts to improve capacity and management tools in dry forest	• Conduct controlled fuel break trial burns in previously burned and low-risk sites to identify fuel break characteristics and other measures that may minimize wildfire risk • Identify limiting factors and develop forestry tools to improve management • Explore use of goat grazing to minimize fuel loads on a small scale • Increase research on strategic firebreak placement
Collaboration	Improve public education on the	• Increase layperson knowledge of dry-forest related

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Near- to long-term approach	importance of dry forest habitats	ecosystem services and linkages between dry forests and coral reefs • Host outreach events (e.g., Wiliwili Festival, Biocultural Blitz, Run for the Dry Forest, hunting tournaments) and integrate climate change (e.g., lei competition with different climate-adapted species)

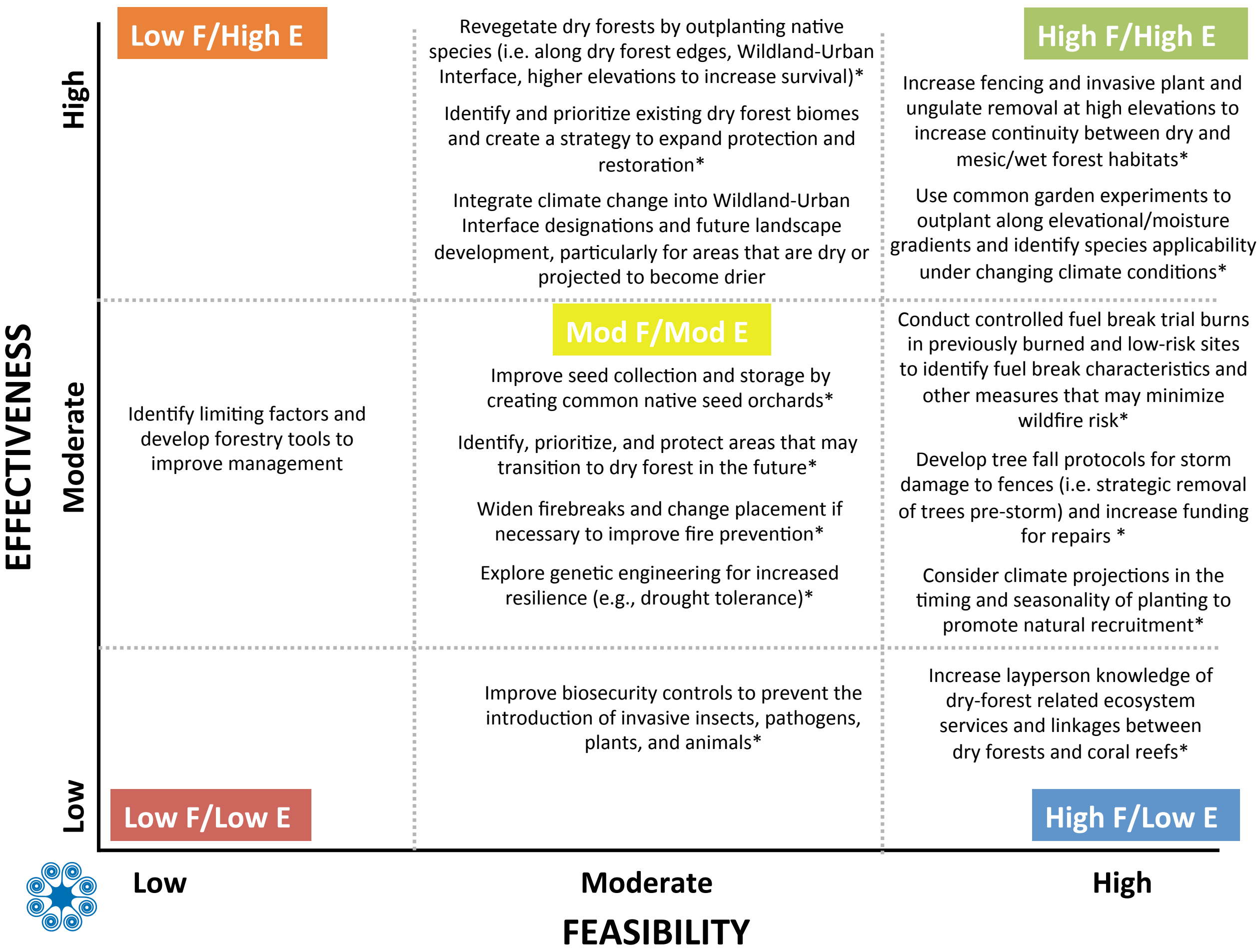

Figure 23. Oʻahu dry forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Mesic and Wet Forest

On Oʻahu, mesic forests exist at mid-elevations below the wet forest band, ranging from 573–792 m (1,880–2,600 ft) in the leeward Waiʻanae Range and from 243–518 m (797–1,700 ft) in the windward Koʻolau Range. There are two primary sub-habitats — koa-dominated ridges and diverse gulches — that support a variety of plant species, including koa, ʻōhiʻa, lama, ēlama, alaheʻe, ʻiliahi, kōpiko, and olopua trees, as well as ʻaʻaliʻi, kaulu, *Pritchardia* palms, hame, and many lobeliads and ferns. Wet forests represent the highest-elevation vegetation communities on Oʻahu. Wet forests on Oʻahu exist at elevations above 518 m (1,700 ft) in the windward Koʻolau Range and at greater than 792 m (2,600 ft; i.e. summit areas) in the leeward Waiʻanae Range. They support a variety of sub-habitats (e.g., bog, semi-bog, lowland wet forests, cloud forests, and wet cliffs) and species (e.g., koa, ʻōhiʻa, *Cheirodendron* spp., lobeliads, uluhe, lapalapa, kamakahala [endemic to Oʻahu], and olomea).

Vulnerability Assessment Results

Mesic and wet forest habitats on Oʻahu were evaluated as having *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Climatic factors such as precipitation, soil moisture, drought, air temperature, and trade winds affect water availability in mesic and wet forests. Reduced water availability can alter vegetative distribution and composition, and may increase invasive species dominance. Mesic and wet forests are also affected by disturbance regimes such as wildfire, storms, high winds, disease, and insects. Wildfire, storms, and winds alter forest structure and composition by removing vegetation and resetting succession, while diseases and insects undermine health and survival of native species. Mesic and wet forests are additionally sensitive to a variety of invasive species, including ungulates, trees, shrubs, flammable grasses, social insects, mammalian predators, and alien birds. Invasive species can alter ecosystem processes, directly compete with native taxa, and contribute to elevated native species' mortality and impaired recruitment, undermining the ecological integrity and persistence of native forests. Invasive vegetation may also be better able to accommodate changing climatic conditions; range expansions of invasive vegetation are promoted by recreation, ungulates, and disturbance of native canopies. Many of these non-climate stressors also contribute to the reduction of native pollinator populations, which can impair native forest persistence and recovery from disturbance.

The adaptive capacity of mesic forests on Oʻahu is reduced because significant forest area has been lost to human land uses, and remnant forest habitat is highly invaded. In comparison, wet forests are isolated at higher elevations on Oʻahu, but are less degraded than mesic systems. Mesic and wet forests have limited opportunity to disperse in the face of climate change because native vegetation struggles to outcompete invasive vegetation, and native species have limited regeneration capacity due to reduced mature plant abundance and the loss of key pollinators and dispersers. Much remnant mesic and wet forest habitat exists within protected land areas, which may promote resilience, but a lack of funding and issues with existing regulatory frameworks and enforcement may undermine management opportunities. Despite strong support for mesic and wet forest management amongst a few constituency groups, overall there is low public value and societal support for managing these forest habitats.

Adaptation Planning Results

Table 24 presents a summary of possible adaptation strategies and actions for Oʻahu mesic and wet forest habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 24 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 24. Summary of possible adaptation strategies and actions for O'ahu mesic and wet forest habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Increase invasive species eradication efforts through manual removal and/or biocontrol of ungulates, predators, and plants with a high rate of spread • Fence priority areas to exclude invasive species within intact forest
Resilience *Near- to mid-term approach*	Maintain and restore native mesic and wet forest habitat	• Restore forests with resilient common species, as well as rare species • Augment native habitat through outplanting and seeding of temperature- and drought-tolerant species in post-disturbance sites and buffer zones
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Identify and protect potential refugia based on precipitation modeling • Create test plots to determine where habitat may shift along ecotone boundaries and identify potential unintended consequences • Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species) • Erect fences across biome and habitat borders to allow for potential habitat and species range shifts
Knowledge *Near- to long-term approach*	Increase capacity for mesic/wet forest restoration	• Increase in-state capacity to conduct research on pests and pathogens
	Increase education and outreach to instill a community conservation ethic	• Increase awareness of biocultural and ecosystem services
Collaboration *Near- to long-term approach*	Increase outreach and education to support forest restoration and management	• Increase education of the legislature, as well as public engagement with natural resource decisions made by the legislature
	Create new partnerships to increase capacity	• Increase state leadership, coordination, and engagement with organizations and stakeholders (e.g., watershed partnerships) • Collaborate with universities to conduct research on invasive species management • Improve data sharing within and between agencies

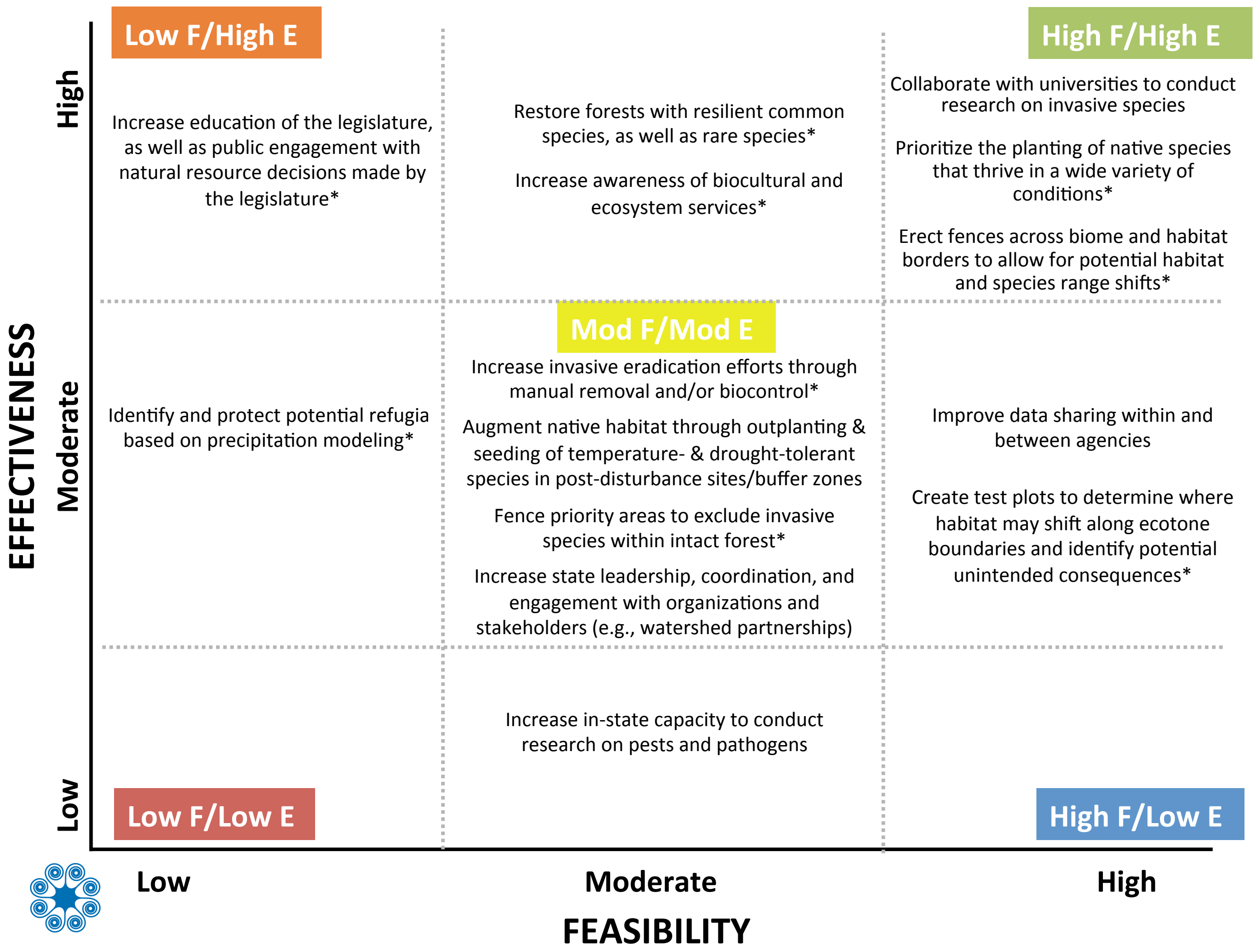

Figure 24. Oʻahu mesic and wet forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Cultural Knowledge and Heritage Values

Native Hawaiian cultural and heritage values are inextricably tied to the surrounding environment and ecosystem health, and a strong connection to place is maintained through stories of family and collective Hawaiian heritage, place names that hold cultural significance, and management of ecosystems and resources. Native Hawaiians place great value on mālama ʻāina (care for the land), and great cultural importance is placed on native species and management of ecosystems and resources. Many cultural practices utilize natural resources, such as the gathering of native plant and animal species for food, medicine, carving, tools, weaving, jewelry, hula or traditional dance, and ceremonial practices.

Vulnerability Assessment Results

Cultural knowledge and heritage values on Oʻahu were evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. This ecosystem service is vulnerable to climatic changes that impact the health and integrity of ecosystems and/or native species, as well as to impacts that damage or destroy valued cultural assets and heritage sites. These include changes in precipitation, air and water temperatures, sea level rise, ocean pH and sea surface temperature, and wind/circulation patterns. Disturbance events, such as wildfire, floods, insect outbreaks, and disease, can affect large areas and cause extensive damage or loss of living things and landscapes of cultural importance. Many non-climate stressors are linked to increasing human populations and associated impacts of changes in land use and the overuse of natural resources (e.g., residential and commercial development, pollution and poisons, water diversions, recreation), which have fragmented and degraded natural habitats, exacerbating the negative effects of climate change. The introduction and establishment of invasive species, including plants, wildlife, insects, fish, and pathogens/parasites, have had a large impact on cultural knowledge and heritage by altering ecosystem functions and driving the loss of native species and habitats.

Native Hawaiian knowledge and heritage is still affected by colonialism, and these values receive relatively little public and societal recognition and support. However, the importance of cultural knowledge, as well as the adaptability of historical cultural practices, is increasingly being recognized and incorporated into natural resource management.

Adaptation Planning Results

Table 25 presents a summary of possible adaptation strategies and actions for Oʻahu cultural knowledge and heritage values, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 25 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 25. Summary of possible adaptation strategies and actions for Oʻahu cultural knowledge and heritage values.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Protect natural cultural resources and native ecosystems	• Work with cultural groups to identify the best way to protect cultural sites (e.g., to use or not use signs to mark places)
	Improve fire prevention and response	• Increase funding for support of fire response agencies and Community Wildland Protection Plans
	Manage invasive species	• Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals
	Reduce non-climate stressors that affect water quality	• Practice strategic watershed fence placement from mauka to makai to reduce pollutant and sediment runoff
Resilience *Near- to mid-term approach*	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	• Maintain water availability for cultural groups to sustain traditional practices (e.g., loʻi and spring use)
	Reduce non-climate stressors	• Protect seagrasses and corals that may help buffer the

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	that affect water quality	effects of ocean acidification
	Encourage local participation in preserving cultural resources	• Streamline permitting system for practitioners and partners (e.g., one permit for a fishpond system instead of several)
	Integrate cultural knowledge into resource management	• Consider cultural values, resources, and sites in responding to extreme weather events, climate change, and storms
Response *Long-term approach*	Plan for managed retreat of coastal habitats	• Limit development in inland/upland areas where coastal habitats may migrate • Limit development in most vulnerable sites • Acquire land for mauka migration in anticipation of sea level rise, increasing temperatures, and precipitation changes
Knowledge *Near- to long-term approach*	Identify community concerns about climate change and variability to help direct research	• Work with communities and cultural practitioners to identify the cultural resources most at risk
	Increase collaboration between researchers and the community	• Foster research from Native Hawaiian communities and knowledge systems to increase access to traditional ecological knowledge
	Incorporate cultural concerns and community relations into climate adaptation projects	• Research community priorities to avoid adversely affecting cultural resources • Ensure projects are consistent with cultural resource protection
Collaboration *Near- to long-term approach*	Increase collaboration between researchers and the community	• Require researchers outside the Native Hawaiian community to take cultural components into account (e.g. within permitting processes) • Provide background cultural material to support research in order to avoid putting the education burden on communities • Incorporate community engagement protocols into funding requirements and research permits and they are sustained throughout the lifetime of the project
	Integrate cultural knowledge into resource management	• Work with cultural practitioners during development of management plans
	Refine communication strategies to increase buy-in and engagement	• Incorporate cultural and/or uniquely Hawaiian components into climate change communication products (e.g., cultural voyaging, lei) • Identify and cultivate community leaders to help share messages about cultural resilience and adaptation • Develop materials and methods to communicate climate impacts in empowering ways (e.g., promote collaborative conversations vs. outsiders coming in)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Increase local food security	• Create rating system for public to emphasize and promote local foods grown through Native Hawaiian practices
	Encourage local participation in preserving cultural resources	• Identify partners that could provide additional space for cultural activities and resources (e.g., schools, botanical gardens, unused lots) • Identify community roadblocks for local conservation/preservation and cultural resources most at risk • Increase availability of cultural education and apprenticeships

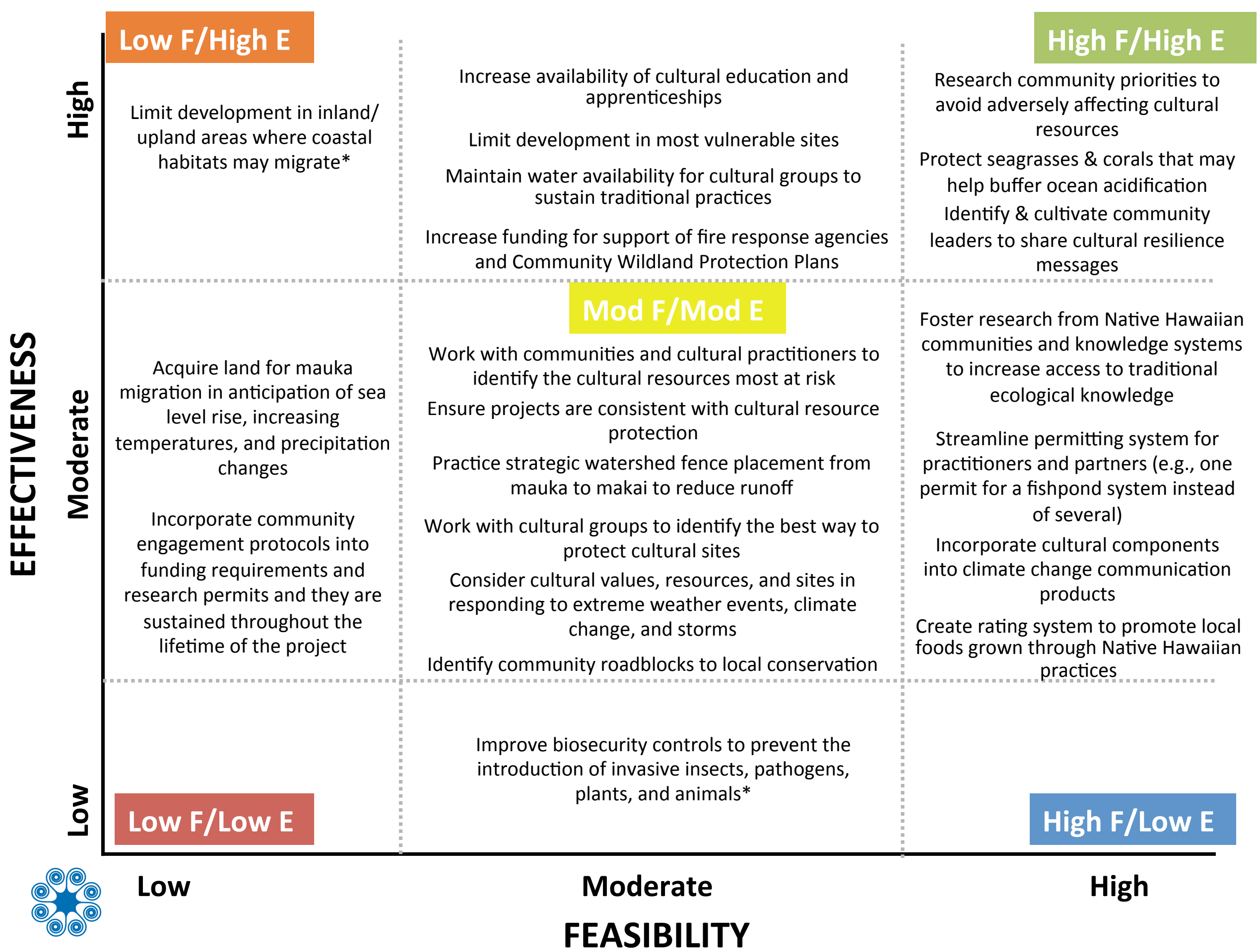

Figure 25. Oʻahu cultural knowledge and heritage values adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Flood and Erosion Control

Native terrestrial and aquatic ecosystems help regulate flooding and erosion by regulating surface and subsurface flow, storing and reducing rates of water discharge, and anchoring and retaining sediment. Vegetation and functioning habitats from mountain to sea maintain the ability of natural systems to absorb "shocks" and control floods and erosion to manageable levels. For example, Oʻahu's wetlands help slow floodwater velocity and attenuate sediment, decreasing erosion. Coastal ecosystems also help mitigate flooding and erosion by anchoring coastal sediment and altering wave dynamics, and native forests intercept rain, slow runoff, and anchor forest sediment.

Vulnerability Assessment Results

The flood and erosion control ecosystem service on Oʻahu was evaluated as having *moderate* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *moderate* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors such as extreme precipitation events and sea level rise can overwhelm the natural capacity of this ecosystem service, while other factors such as drought, disease, and wildfire affect the ability of natural systems to provide flood and erosion control by altering vegetative cover and composition. Non-climate stressors such as development, agriculture, roads, highways, and trails often alter sheet flow and surface runoff patterns, increasing flood volumes. Along with stressors such as invasive plants, animals, and pathogens, these non-climate stressors can also reduce native vegetative cover and increase bare ground, increasing erosion potential. Some non-climate stressors (e.g., water diversions, groundwater withdrawals) may benefit flood control to a small degree. Continued protection and advocacy for natural habitats, as well as best management practices in agricultural and urban areas, will help maintain flood and erosion control ecosystem services in the future. Additionally, sustaining flood and erosion control provides mutual benefits for other valued ecosystem services (e.g., fresh water) and habitats (e.g., streams, coral reefs). However, limited funding may affect manager capacity to mitigate climate impacts on this service.

Adaptation Planning Results

Table 26 presents a summary of possible adaptation strategies and actions for Oʻahu flood and erosion control, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 26 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 26. Summary of possible adaptation strategies and actions for Oʻahu flood and erosion control.

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Fence priority areas to exclude invasive species within intact forest • Increase biosecurity
	Decrease erosion and sediment delivery to improve water quality and protect municipal water supplies	• Design and construct roads to minimize erosion and sediment production • Increase and/or relocate road cross drains to decrease hydrologic connectivity between roads and

Adaptation Category	Adaptation Strategy	Specific Adaptation Actions
		streams
	Reduce non-climate stressors that affect water quality	• Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)
Resilience *Near- to mid-term approach*	Manage invasive species	• Increase invasive species eradication efforts through manual removal and/or biocontrol of ungulates, predators, and plants with a high rate of spread
	Engage developers, real estate, and insurance companies on climate-related risk and response for coastlines	• Integrate design and engineered solutions into development (e.g., resilient shorelines, xeriscaping, floodable development)
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
	Prepare for sea level rise impacts	• Plant salt- and flood-tolerant vegetation • Redesign development guidelines to account for sea level rise and other climate change impacts
Knowledge *Near- to long-term approach*	Anticipate potential shifts in invasive species distributions	• Research range of conditions invasive species can tolerate to determine where invasive species may expand
Collaboration *Near- to long-term approach*	Increase environmental and climate literacy across all ages	• Engage communities that have experienced weather/climate disturbances in the past to help amplify climate change messages

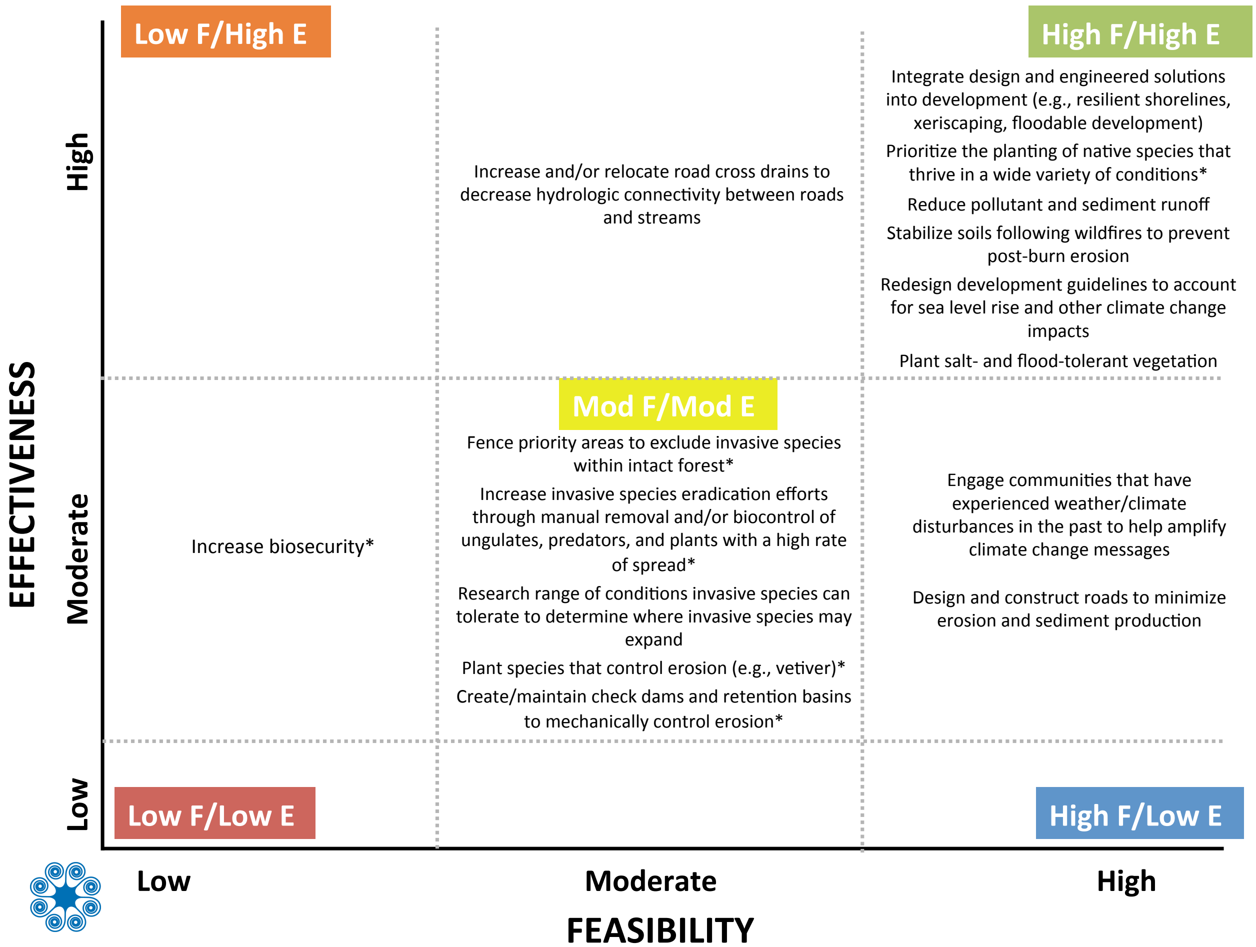

Figure 26. Oʻahu flood and erosion control adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Fresh Water

Fresh water is classified as a provisioning ecosystem service because it supplies both consumptive (e.g., drinking water, agricultural and industrial use) and non-consumptive human uses (e.g., power generation). Fresh water also supports other natural systems and processes that provide additional ecosystem services. For example, it supports aquatic habitats, which in turn provide ecosystem services such as food production, flood control, aesthetic values, and tourism and recreation. Native forests, wetlands, and other habitats help maintain fresh water supply by intercepting, slowing, and storing water. Native habitats also enhance water quality by anchoring and filtering sediment and filtering pollutants. Oʻahu's fresh water resources include both groundwater and surface water. Waiʻanae and Koʻolau are Oʻahu's primary aquifers, with central Oʻahu providing a majority of the island's groundwater resources. Oʻahu has both confined and unconfined aquifers; extensive confined caprock aquifers prevent water discharge to the ocean, meaning Oʻahu has more abundant groundwater resources than other Hawaiian Islands. Oʻahu also has extensive surface water resources in the form of perennial and intermittent streams and freshwater wetlands. Groundwater primarily provides drinking water and supports aquatic habitat via discharge to streams, seeps, and springs, while surface water supplies aquatic habitats and irrigation needs.

Vulnerability Assessment Results

The fresh water ecosystem service on Oʻahu was evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Climatic factors such as drought, air temperature, and altered storm and extreme precipitation events have the potential to reduce fresh water supply, and along with sea level rise, may impair water quality. Flooding can temporarily impair water quality, while wind, wildfire, insects, and disease have the potential to alter groundwater infiltration and surface runoff quality by affecting the health and composition of regional forests. Non-climate stressors, including residential and commercial development, agriculture and aquaculture, energy development, water diversions, and groundwater development, alter water use and delivery, potentially compounding future climate-driven reductions in water availability. Human land uses (e.g., roads, urban areas, agriculture) and activities (e.g., recreation) can also impair water quality by introducing contaminants, and affect water capture by increasing runoff and introducing invasive species. Invasive species undermine watershed health and integrity, reducing water storage and degrading water quality.

Fresh water is highly valued by the public and there are several statewide and island-based efforts focused on promoting water conservation and watershed health and function, helping enhance the adaptive capacity of this service in the face of climate change. However, increasing human populations and variable enforcement of laws and policies will challenge management of this ecosystem service. Additionally, fresh water provisioning and quality will largely depend on climate impacts to native forests.

Adaptation Planning Results

Table 27 presents a summary of possible adaptation strategies and actions for Oʻahu fresh water, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 27 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 27. Summary of possible adaptation strategies and actions for Oʻahu fresh water.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Reduce non-climate stressors that limit water supply	• Continue fencing to maintain water yields of one million gallons per day • Remove water diversions • Improve water conservation efforts (e.g., fix leaks) • Incentivize rainwater capture for local irrigation • Use gray water for irrigation by implementing wastewater and rain water recycling
	Reduce non-climate stressors that affect water quality	• Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		of fallow agricultural land) • Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Convert cesspools to septic systems • Increase public education to minimize disturbance and/or degradation of vulnerable habitats or species
	Maintain/improve water quantity and quality	• Alter well drill depths and practice optimal well placement to minimize vulnerability to saltwater intrusion
	Manage invasive species	• Prevent introduction of new diseases and pathogens by increasing biosecurity controls (e.g., quarantines, intraisland policies, optional vs. mandatory restrictions)
Resilience *Near- to mid-term approach*	Maintain/improve water quantity and quality	• Develop a stormwater residential tax, and use revenue to fund water capture and reuse projects • Encourage low-impact development and green infrastructure to reduce the extent of impervious pavement • Increase water catchments and reservoirs • Integrate climate projections into forest and watershed restoration and protection efforts • Retrofit and improve water infrastructure
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion
Response *Long-term approach*	Maintain a resilient water supply	• Integrate climate projections into Water Commission planning efforts
Knowledge *Near- to long-term approach*	Reduce non-climate stressors that limit water supply	• Increase public education (industries, agriculture, residents, tourists) on water conservation in light of climate change (i.e. integrate messaging into water bills)
Collaboration *Near- to long-term approach*	Create new/improve existing partnerships to increase capacity	• Increase state leadership, coordination, and engagement with organizations and stakeholders (e.g., watershed partnerships)

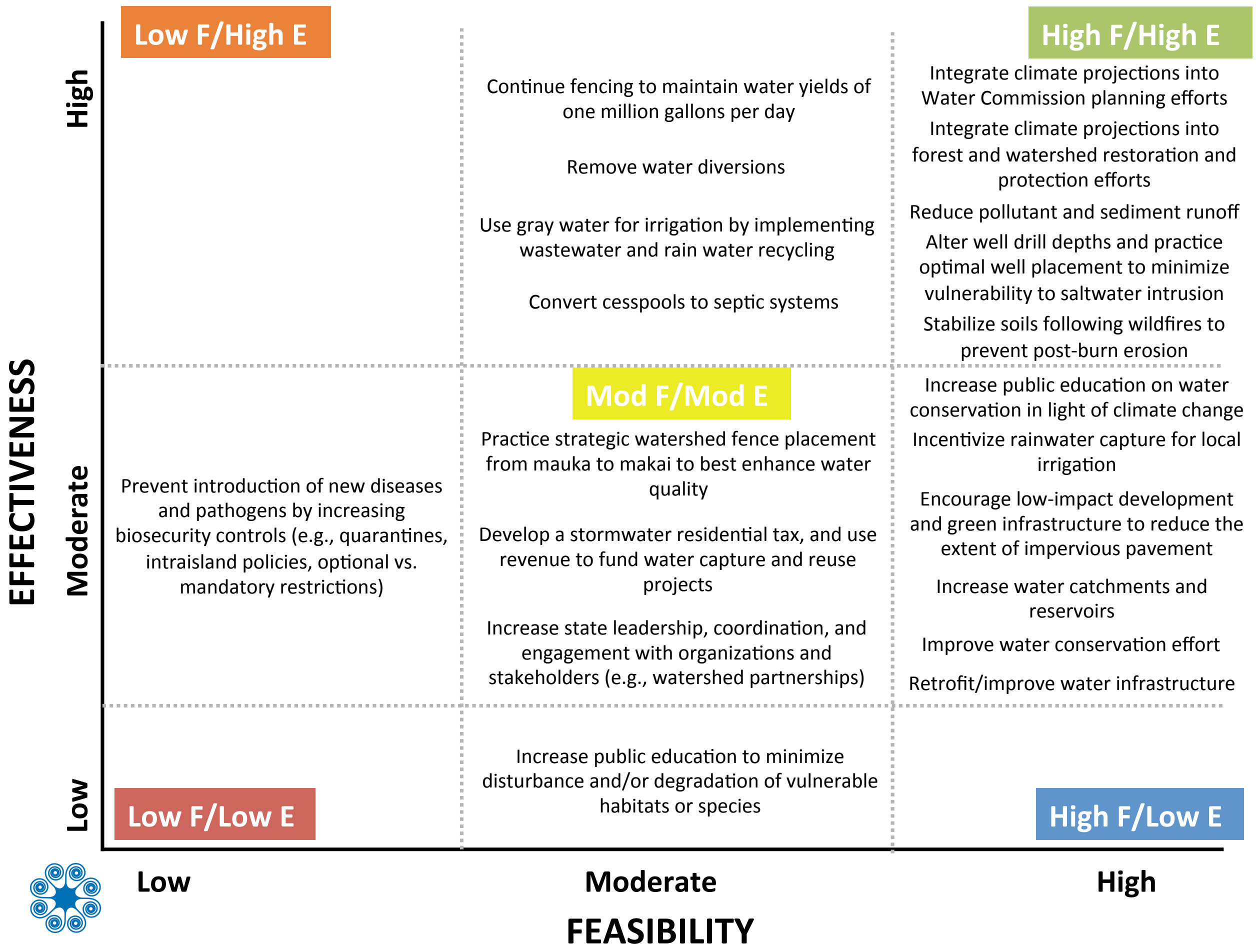

Figure 27. Oʻahu fresh water adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Hawaiʻi: Vulnerability Assessment and Adaptation Options

Summary

The following chapter provides a summary of the vulnerability assessment and adaptation planning results for Hawaiʻi. Table 28 presents the overall vulnerability and confidence scores for habitats and ecosystem services. Figure 28 presents the overall vulnerabilities of habitats and ecosystem services based on the assessment of climate and non-climate sensitivity and exposure and adaptive capacity.

Table 28. Overall vulnerability and confidence scores for Hawaiʻi habitats and ecosystem services.

Focal Resource	Vulnerability Score	Confidence Score
Habitats		
Coastal: Beaches and Cliffs	**Moderate**	**High**
Coastal: Estuaries and Fishponds	**Moderate**	**High**
Coastal: Anchialine Pools	**Moderate-High**	**High**
Aquatic	**Moderate**	**Moderate**
Dry Forest	**Moderate-High**	**High**
Mesic and Wet Forest	**Moderate**	**Moderate**
Alpine/Subalpine	**Moderate-High**	**Moderate**
Ecosystem Services		
Cultural Knowledge and Heritage Values	**Moderate-High**	**High**
Flood and Erosion Control	**Moderate-High**	**Moderate**
Fresh Water	**Moderate**	**High**
Food and Fiber	**High**	**Moderate**

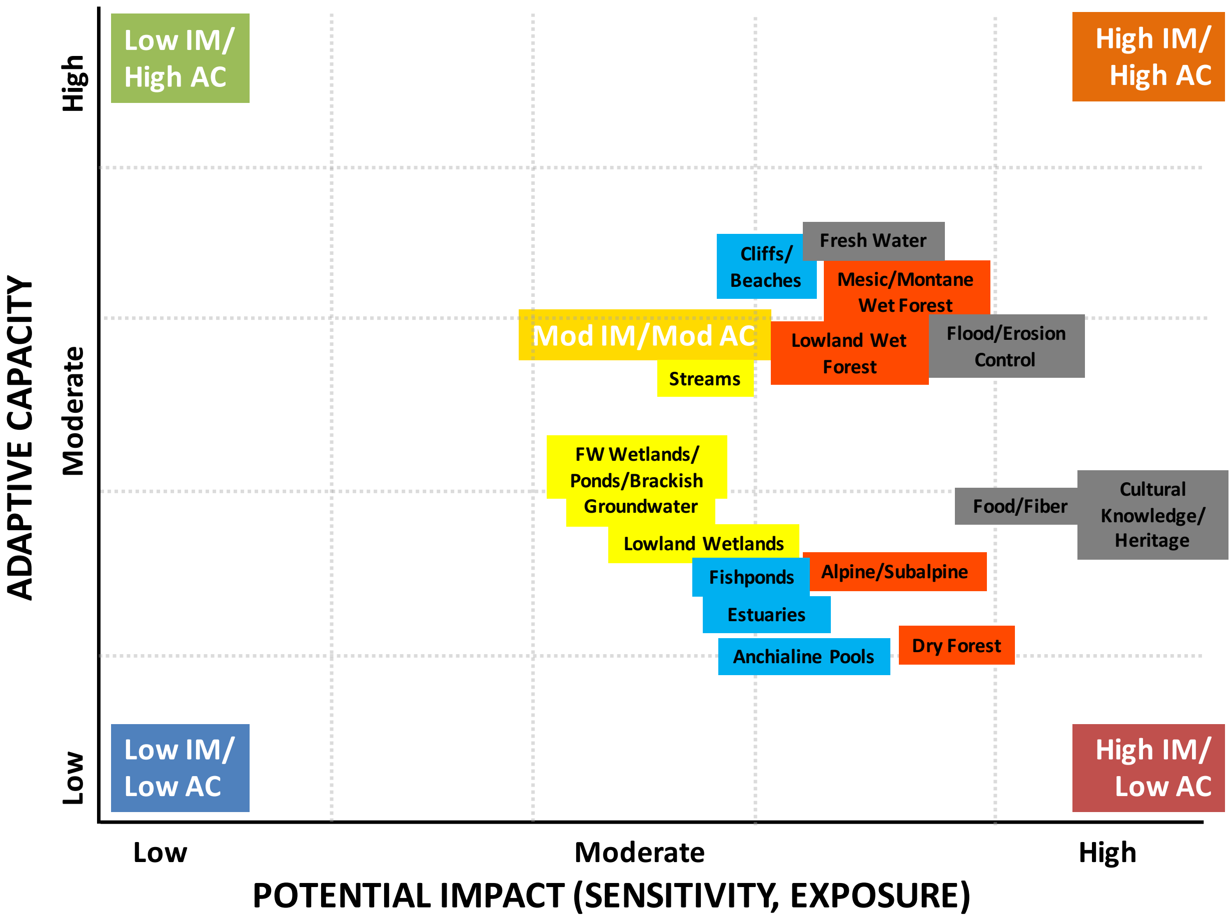

Figure 28. Overall vulnerabilities of Hawai'i habitats and ecosystem services based on the climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. FW: Freshwater Color code: Terrestrial habitats (red), Coastal habitats (blue), Aquatic habitats (yellow), Ecosystem services (grey)

Coastal Habitats

Workshop participants classified coastal habitats as beaches and cliffs, estuaries and fishponds, and anchialine pools. As the biggest island in the Hawaiian archipelago, Hawaiʻi has the longest shoreline consisting of **beaches and cliffs**. **Estuarine** habitats occur at the fresh and saltwater interface, and are characterized by deep-water habitat and brackish water conditions. Hawaiian **fishpond systems** (loko iʻa) are natural or artificial enclosures used to cultivate fish, plants, and other freshwater and saltwater food sources. **Anchialine pools** are landlocked pools found on limestone or lava flows, characterized by subsurface hydrological connectivity, but lacking surface connection to the ocean. The island of Hawaiʻi supports 80% of the world's known anchialine pools.

Vulnerability Assessment Results

Beaches and Cliffs

Beach and cliff habitats in Hawaiʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Climatic factors, including tropical storms, sea level rise, riverine flooding, and altered streamflows, affect beach and cliff erosion rates, sediment delivery dynamics, and vulnerability to inundation, reducing habitat availability or altering community composition. Non-climate stressors such as development, agriculture, and energy production reduce existing coastal habitat area and elevate disturbance, which can endanger or eliminate component native vegetative and faunal communities. Native fauna and vegetation are also vulnerable to increased mortality, predation, and competition as a result of invasive mammalian predators, invasive vegetation, and marine debris. The adaptive capacity of Hawaiʻi's beach and cliff habitats is supported by a high habitat extent, high public value, the existence of constituency groups that promote habitat conservation and management, and the location of some beach and cliff habitat within protected land areas. Additionally, beach and cliff habitats provide many valued ecosystem services. However, many existing habitats have been modified by human activity and invasive species, and beaches and cliffs face continued use conflicts with coastal development.

Estuaries and Fishponds

Estuarine habitats on Hawaiʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low* adaptive capacity. Fishpond habitats on Hawaiʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity.

Climatic factors and disturbance regimes such as drought, precipitation and soil moisture changes, tropical storms, and extreme precipitation events affect freshwater delivery, streamflow, and sediment, and nutrient and contaminant delivery to estuarine and fishpond habitats. Changes in these factors will influence species composition, integrity, and overall habitat extent. Habitat and community shifts will be further magnified by increasing salinity and ocean connectivity as a result of sea level rise and coastal flooding, increasing sea surface and stream temperatures, and elevated wildfire and disease risk. Non-climate stressors may exacerbate some climate-driven impacts. For example, a variety of non-climate stressors reduce or alter freshwater inflow, including development, groundwater development, water diversions, invasive species, and roads, highways, and trails. Other stressors degrade water quality by increasing pollutant and sediment delivery (e.g., development, pollution and poisons, roads, invasive ungulates). Additionally, stressors such as recreation and invasive species can impact native species by elevating competition, predation, or disturbance.

The adaptive capacity of estuarine and fishpond habitats is bolstered by high habitat extent, constituency group support, public value, and component species' tolerance of variable conditions. However, current degradation of these habitats as a result of invasive species and human activity undermines their ability to resist and recover from climate change and other disturbances. Additionally, high endemism, low functional group diversity, and high occurrence of species particularly vulnerable to climate change reduces overall habitat resilience. Management also faces challenges related to funding, protecting these habitats from development pressure, and regulatory and permitting issues for restoration projects.

Anchialine Pools

Anchialine pool habitats on Hawaiʻi were evaluated to have *moderate-high* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low* adaptive capacity. Climatic factors such as precipitation changes, drought, extreme precipitation events, and tropical storms affect groundwater levels and direct runoff to pools, impacting pool depth and salinity. Sea level rise and saltwater intrusion also affect pool size and salinity, and will ultimately influence pond distribution and abundance on the landscape. Anchialine pool fauna are likely sensitive to shifts in pool salinity, depth, and distribution, and will also be exposed to increasing sea surface and pool temperatures. Non-climate stressors such as invasive aquatic species, pollution and poisons, and recreation further affect anchialine pool biotic communities and structure by affecting water quality, competition and predation, and elevating disturbance. Development and roads destroy and degrade existing habitat, and will likely reduce opportunities for new pool formation as sea levels rise. Additionally, groundwater withdrawals and water diversions impact pool water depth, affecting habitat availability.

Anchialine pools are abundant on Hawaiʻi, areas of pristine habitat still remain, and studies indicate that component species can colonize new habitat areas as they form. However, new pool formation may be affected by a variety of landscape barriers (e.g., development, roads). The adaptive capacity of anchialine pools is also undermined by low biodiversity, a high number of rare and endemic species, and the current endangered status of several. Although anchialine pools have moderate-high public value, and significant pool habitat occurs within protected land areas, managers have limited funding, and remnant pools will continue to compete with coastal development pressure.

Adaptation Planning Results

Table 29 presents a summary of possible adaptation strategies and actions for Hawaiʻi coastal habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 29 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 29. Summary of possible adaptation strategies and actions for Hawaiʻi coastal habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain/improve water quantity and quality	• Provide incentives for Hawaiian field systems to not be developed or grazed by cattle • Investigate and reduce non-point source pollution • Promote and enforce use of best management practices (BMPs) to improve water quality • Manage runoff (stormwater, wastewater, nutrients) in areas affected by human activity
	Preserve water supplies by increasing water use efficiency	• Maintain aquifers by ensuring native forest cover
	Reduce non-climate stressors that limit water supply	• Remove water diversions

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Restore and conserve native shoreline and estuary habitat	• Remove mangroves and other invasive vegetation
Resilience *Near- to mid-term approach*	Preserve water supplies by increasing water use efficiency	• Use Hawaiian field system to slow water, increase recharge, and use as a model for other places • Improve rainfall capture to decrease groundwater withdrawals
	Reconnect/enhance connections of people to place	• Build the local economy to support ecosystem conservation and protection and enhance sustainability (e.g., create jobs, preserve human needs, preserve natural and cultural heritage)
	Create more nimble planning and zoning processes that promote natural landscapes and community values and are adaptable to climate change	• Identify island carrying capacity and examine novel ways to manage growth (e.g., Florida Keys)
	Enhance habitat and species resilience	• Develop genetic "banks" (e.g., seed banks, captive breeding programs)
Response *Long-term approach*	Protect current and future habitat	• Establish shoreline setbacks • Identify and protect low-lying areas where wetlands and anchialine pools can migrate
	Anticipate and facilitate habitat migration	• Protect upland areas for mauka migration in anticipation of sea level rise • Identify and protect currently vulnerable areas and areas of possible habitat migration based on available data, including existing infrastructure lifetime
Knowledge *Near- to long-term approach*	Increase understanding of water resources and their value	• Increase monitoring of groundwater and surface water resources • Increase understanding of groundwater influence on anchialine pools • Increase knowledge of water needs of native ecosystems and species and the impact of water withdrawals on these resources
	Change laws/policies to protect and promote community response to climatic changes and impacts	• Expand Ecological Effects of Sea Level Rise (EESLR) model to cover the whole island
	Build adaptation and resilience in local communities through education, engagement, and outreach	• Increase citizen science efforts to gather data to support climate-informed decision making
	Reconnect/enhance connections of people to place	• Build local experience of landscapes and seascapes into science

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Create more nimble planning and zoning processes that promote natural landscapes and community values and are adaptable to climate change	• Increase ʻāina-based education and use of ahupuaʻa considerations
Collaboration *Near- to long-term approach*	Reconnect/enhance connections of people to place	• Build the capacity of local communities through restoration projects, on-the-ground action, involvement in policy decisions, and genealogy exercises
	Build adaptation and resilience in local communities through education, engagement, and outreach	• Increase education and involvement of students (K-12, college) in conservation work through hands-on teaching and learning experiences
	Change laws/policies to protect and promote community response to climatic changes and impacts	• Create a network of expertise (e.g., natural and cultural resource managers, students) to be a resource for local communities • Create strategic communications campaign to implement policy changes • Engage the larger community to discuss climate impacts and co-develop climate-informed policies and plans
	Create new/improve existing partnerships to increase capacity	• Review existing monitoring programs across jurisdictions to identify overlaps and avoid duplication of effort • Build off of existing programs by creating/enhancing networks with other agencies and organizations

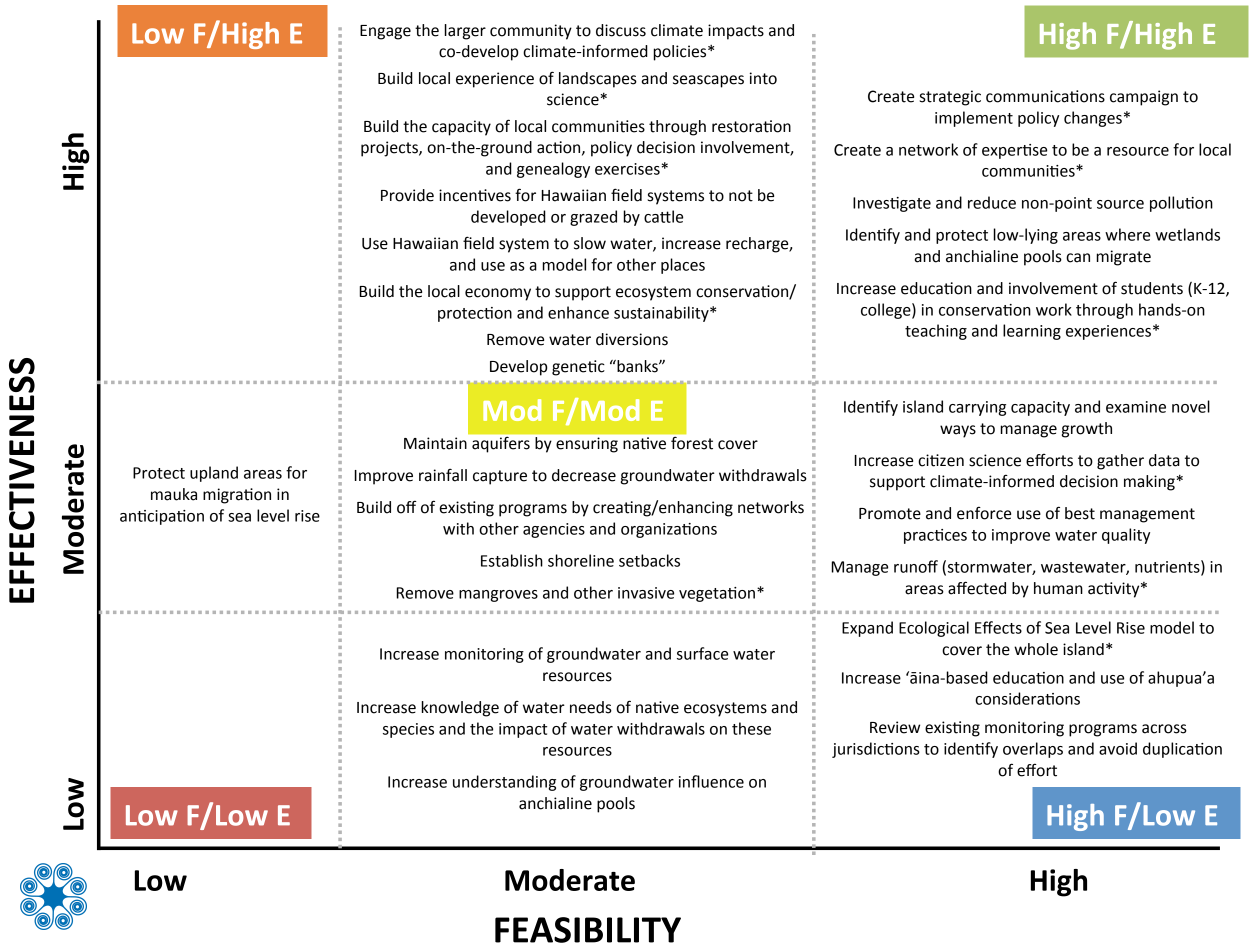

Figure 29. Hawaiʻi coastal habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Aquatic Habitats

Aquatic habitats on Hawaiʻi include perennial and intermittent streams, freshwater wetlands (e.g., bogs and seeps), lowland-specific freshwater habitats (e.g., wetlands, floodplains), brackish/saline wetlands, and groundwater systems. Aquatic systems support a variety of native flora and fauna, including native sedges, migratory shorebirds, and endemic ʻoʻopu (gobies), ʻōpae (shrimps), snails, and waterbirds. Streams on Hawaiʻi may be perennial or intermittent, and native aquatic fauna are adapted to high flow variability, frequent flooding, and large fluctuations in stream temperature and turbidity due to small catchment basins, steep slopes, and limited channel storage. Hawaiʻi has 132 perennial streams, 70 of which are continous to the ocean. Upland wetlands typically occur in openings of the surrounding rainforest, are small in size, and feature a mixture of mud, standing water pockets, and highly endemic and specialized species, including mosses, lichen, and dwarfed woody plants.

Lowland-specific freshwater habitats include wetlands, valley bottoms, and floodplains. Lowland wetlands feature perennial or seasonal ponded fresh water derived from precipitation, stream runoff, and groundwater inflow. Manmade wetlands include irrigated agricultural areas (e.g., taro, lotus, watercress), loko iʻa kalo (freshwater taro fishponds) and loko wai (natural freshwater fishponds). Brackish/saline wetlands that lack tidal influence include Kapoho Crater and Punaluʻu on the island of Hawaiʻi, as well as loko puʻuone (brackish fishponds); vegetation is often dominated by the non-native pickleweed. Groundwater systems include freshwater lenses floating over saltwater on flank lavas, and high-level or perched water impounded by low-permeability features, such as volcanic dikes. Terrestrial perennial seeps and springs can be found along banks of severely incised streams and along coastal rock faces.

Vulnerability Assessment Results

Aquatic habitats on Hawaiʻi were evaluated within five distinct groups: streams (both perennial and intermittent), freshwater wetlands and ponds (at all elevations), lowland-specific wetlands (e.g., valley bottoms and floodplains), brackish/saline wetlands (without tidal influence), and groundwater systems (e.g., aquifers). Overall, aquatic habitats in Hawaiʻi were evaluated as having *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity, although individual rankings varied between groups.

Climatic factors such as changes in precipitation (including extreme events) and increased drought alter surface and groundwater availability for aquatic habitats. Warmer water temperatures, saltwater intrusion, tropical storms, extreme precipitation events, flooding, and lava flows reduce water quality (by increasing salinity, reducing dissolved oxygen, and introducing contaminants) and can cause physical and/or structural changes in habitat characteristics. These impacts can significantly reduce aquatic habitat extent and connectivity, affecting the health, recruitment, and survival of associated flora and fauna. Non-climate stressors cause additional impacts on aquatic habitats, often affecting water availability and quality, flow variability, and habitat extent. Invasive trees/shrubs contribute to lower groundwater recharge and streamflow, and can reduce areas of open water, limiting habitat availability. Residential and commercial development, water diversions, groundwater development, agriculture, and aquaculture are associated with stream channel alterations, wetland loss, increased invasive species, and reduced water availability and quality. Finally, invasive ungulates disturb upland forests and wetlands, reducing native plant cover, facilitating the spread of invasive plants, and increasing erosion and sedimentation that impacts downstream habitats.

Aquatic habitats on Hawaiʻi are still relatively intact, although wetlands and stream channels in low-elevation areas have been degraded, altered, and/or lost. Because aquatic systems are generally adapted to frequent disturbances and extreme conditions, these habitat types are often able to recover from non-climate stressors. High species diversity also bolsters adaptive capacity, although high levels of endemism within aquatic fauna and the restricted distributions of rare species may increase vulnerability to climate change impacts. Aquatic habitats have relatively low public and societal support for management, but some restoration activities have been successful, and these may help mitigate the impacts of climate change.

Adaptation Planning Results

Table 30 presents a summary of possible adaptation strategies and actions for Hawaiʻi aquatic habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 30 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 30. Summary of possible adaptation strategies and actions for Hawaiʻi aquatic habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain/improve water quantity and quality	• Provide incentives for Hawaiian field systems to not be developed or grazed by cattle • Investigate and reduce non-point source pollution
	Preserve water supplies by increasing water use efficiency	• Maintain aquifers by ensuring native forest cover
Resilience *Near- to mid-term approach*	Preserve water supplies by increasing water use efficiency	• Use Hawaiian field system to slow water, increase recharge, and use as a model for other places • Improve rainfall capture to decrease groundwater withdrawals
	Reconnect/enhance connections of people to place	• Build the local economy to support ecosystem conservation and protection and enhance sustainability (e.g., create jobs, preserve human needs, preserve natural and cultural heritage)
	Increase ecosystem resilience, connectivity, and integrity	• Restore hydrologic function (i.e. reduce/remove diversions, convert ditches to pipes)
	Maintain/enhance riparian vegetation to shade aquatic systems and buffer warming water temperatures	• Restore native riparian vegetation in degraded areas • Adjust which plants are used for riparian restoration to favor species that are better suited for future climate conditions
Response *Long-term approach*	Protect current and future habitat	• Establish shoreline setbacks • Identify and protect low-lying areas where wetlands can migrate
Knowledge *Near- to long-term approach*	Increase understanding of water resources and their value	• Increase monitoring of groundwater and surface water resources • Increase knowledge of water needs of native ecosystems and species and the impact of water withdrawals on these resources
	Change laws/policies to protect and promote community response to climatic changes and impacts	• Expand Ecological Effects of Sea Level Rise (EESLR) model to cover the whole island

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Build adaptation and resilience in local communities through education, engagement, and outreach	• Increase citizen science efforts to gather data to support climate-informed decision making
	Reconnect/enhance connections of people to place	• Build local experience of landscapes and seascapes into science
Collaboration *Near- to long-term approach*	Reconnect/enhance connections of people to place	• Build the capacity of local communities through restoration projects, on-the-ground action, involvement in policy decisions, and genealogy exercises
	Build adaptation and resilience in local communities through education, engagement, and outreach	• Increase education and involvement of students (K-12, college) in conservation work through hands-on teaching and learning experiences
	Change laws/policies to protect and promote community response to climatic changes and impacts	• Create a network of expertise (e.g., natural and cultural resource managers, students) to be a resource for local communities • Create strategic communications campaign to implement policy changes • Engage the larger community to discuss climate impacts and co-develop climate-informed policies and plans
	Create new/improve existing partnerships to increase capacity	• Review existing monitoring programs across jurisdictions to identify overlaps and avoid duplication of effort

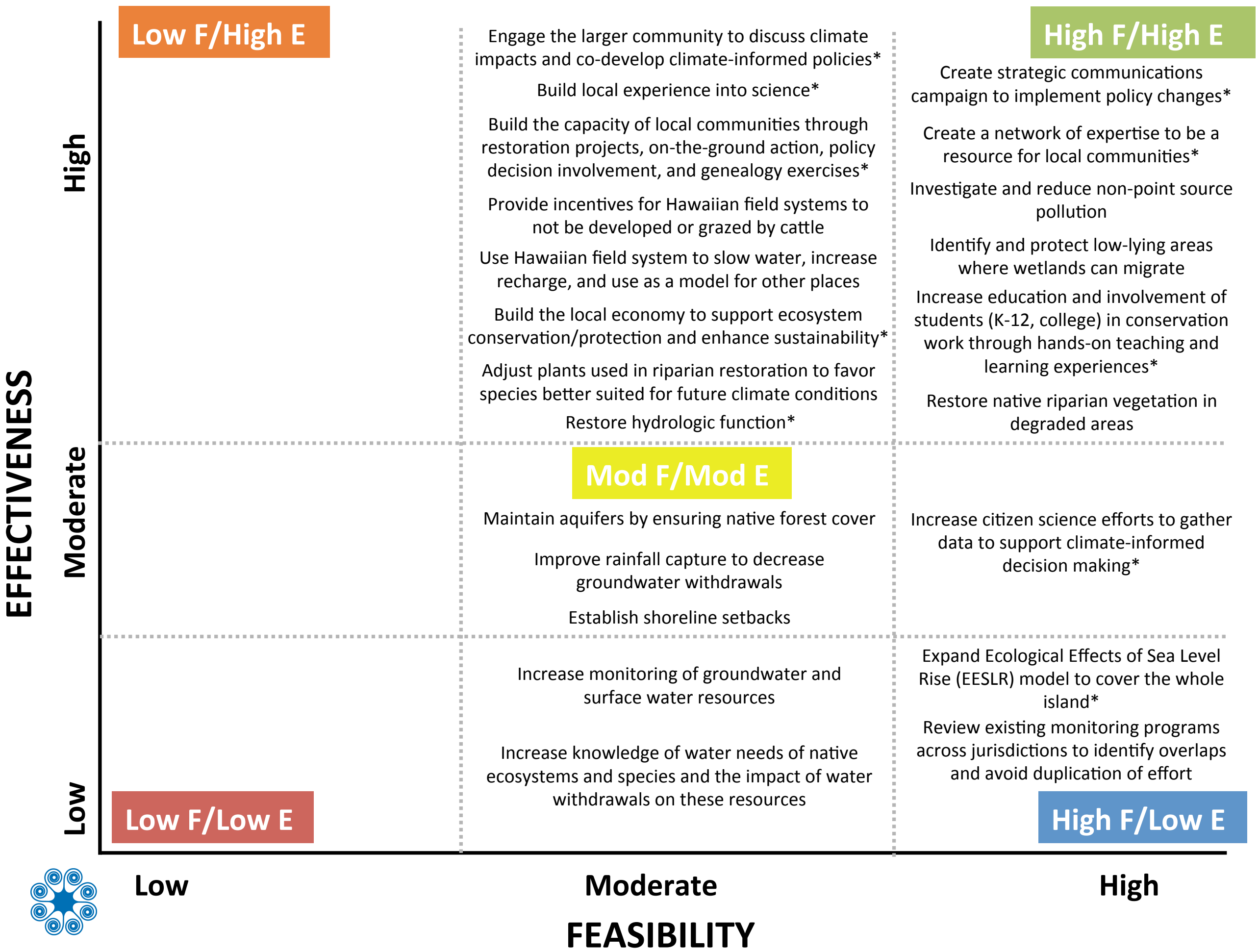

Figure 30. Hawaiʻi aquatic habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Dry Forest

Dry forests are typically found on the leeward side of Hawaiʻi from sea level up to elevations of about 2,000 m (6,560 ft), although Kaʻū has seasonal sub-montane dry forest area where seasonal rainfall is low enough to limit forest distribution despite higher annual rainfall totals. Dry forests are often associated with younger, shallow substrates comprised of cinder, ash, and lava flows, and plant succession corresponds to substrate age. Dominant vegetation in dry forests includes ʻōhiʻa, lama, naio, māmane, ʻaʻaliʻi, olopua, wiliwili, and pili grass.

Vulnerability Assessment Results

Dry forest habitats in Hawaiʻi were evaluated as having *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low* adaptive capacity. Dry forests are sensitive to climatic factors that increase water stress, such as changes in precipitation amount, reduced soil moisture, increased drought, warmer air temperatures, and changes in wind and circulation patterns, which are likely to impact recruitment, species composition, and forest distribution. Disturbance events (e.g., wildfire, disease, insects, volcanic activity) may damage forest areas, reducing forest cover and canopy integrity and increasing vulnerability to invasion. Non-climate stressors such as development and agriculture reduce habitat extent, degrade remaining habitat areas, and fragment the forest, limiting dispersal and recruitment. Invasive species (e.g., flammable grasses, ungulates, trees and shrubs, social insects, pathogens/parasites) also impair dry forest recruitment and recovery by competing with and displacing vegetation, altering ecosystem processes (e.g., water infiltration, pollination), and damaging vegetation.

Over 90% of historical dry forest area across the Hawaiian Islands has already been lost, and the remaining areas are highly fragmented and degraded by invasive species and other anthropogenic impacts. Habitat fragmentation and slow growth by native species make it difficult for dry forests to recover from disturbance without active management and contribute to the large number of endangered species found within this habitat type. This habitat type receives little societal support and is not typically recognized or valued by the public. However, restoration efforts have been successful at restoring native vegetation on several sites, and managers may be able to alleviate some of the impacts of climate change.

Adaptation Planning Results

Table 31 presents a summary of possible adaptation strategies and actions for Hawaiʻi dry forest habitat, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 31 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 31. Summary of possible adaptation strategies and actions for Hawaiʻi dry forest habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Reduce the impacts of non-climate stressors on remnant dry forest	• Fence high-quality habitat areas (e.g., areas with intact canopy and good structure) and remove invasive ungulates • Remove weeds, including invasive grasses, in all remnant dry forest habitat and areas that will likely remain dry under a changing climate • Increase fire prevention and fuel management (e.g., grazing, fuel breaks) in most intact dry forest habitats • Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals • Increase the number of fuel breaks below restoration and reforestation sites, and use non-native, non-invasive, drought-tolerant species when possible
	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	• Integrate climate change into Wildland-Urban Interface designations and future landscape development, particularly for areas that are dry or projected to become drier

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resilience *Near- to mid-term approach*	Maintain and restore existing dry forest habitat	• Outplant native species in microrefugia and at different elevations • Advocate for regulatory policy changes (e.g., zoning) that move away from decisions based on historic ranges and prioritize landscape approaches • Consider climate projections in the timing and seasonality of planting to promote natural recruitment • Explore genetic engineering for increased resilience (e.g., drought tolerance) • Revegetate dry forests by outplanting native species (i.e. along dry forest edges, Wildland-Urban Interface, higher elevations to increase survival)
Response *Long-term approach*	Identify and promote climate-adapted species composition	• Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions • Map transitional areas between dry and mesic habitat to identify and prioritize protection for areas of mesic habitat that may transition to dry habitat
	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
Knowledge *Near- to long-term approach*	Enhance long-term monitoring efforts to better understand changes in native and rare species	• Monitor regeneration/outplanting success, including the status of in situ populations • Develop monitoring strategies that are less cost- and time-intensive for rare species (e.g., rare birds)
	Develop more efficient technologies/tools for habitat restoration and invasive species control	• Increase research on any benefits that may be obtained from invasive species (e.g., invasive tree tobacco providing food for endangered Blackburn's sphinx moth)
Collaboration *Near- to long-term approach*	Increase community and cultural engagement through education and outreach focused on the importance of dry forest habitat	• Host volunteer planting days (e.g., weed removal, nursery) in sites where volunteers can see progress over time • Preserve forest access for stewardship and the gathering of important cultural species and materials (e.g., lei materials) • Host outreach events (e.g., Wiliwili festival, Biocultural Blitz, Run for the Dry Forest, hunting tournaments)

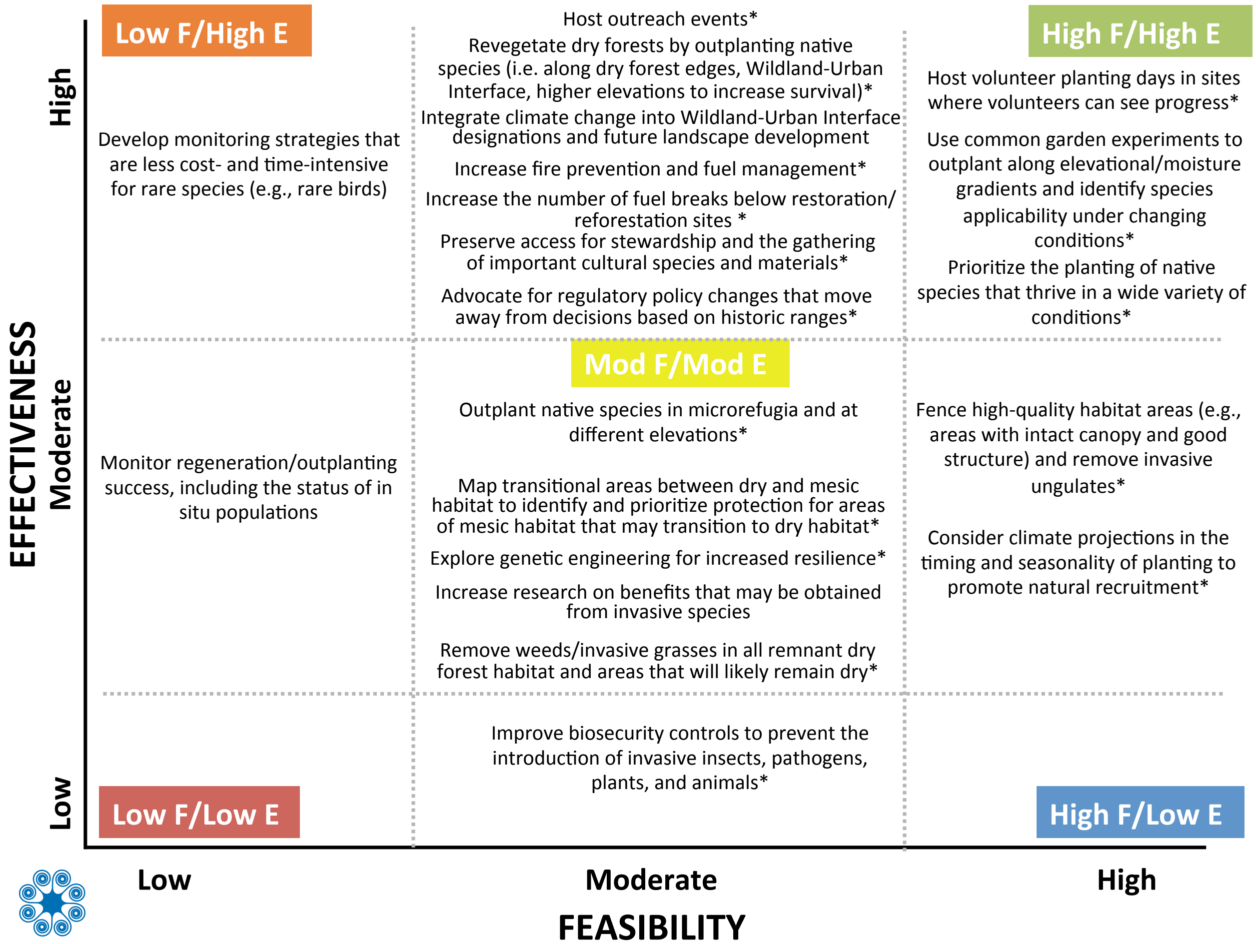

Figure 31. Hawaiʻi dry forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Mesic and Wet Forest

Mesic forests on Hawaiʻi occur at mid-elevation sites between 1,000 and 2,000 m (3,280 and 6,560 ft), and span both the windward and leeward sides of the island, including the Kona region and the slopes of Mauna Kea and Mauna Loa. Mesic habitats are typically dominated by koa, ʻōhiʻa, and lama trees. Wet forests are found in two bands on Hawaiʻi: lowland forests at sites up to 762 m (2,500 ft) in elevation, and montane forests at elevations of 762–1,830 m (2,500–6,000 ft). Wet forests are found primarily on the windward side of the island, support bog sub-habitats, and are typically dominated by ʻōhiʻa trees. Mesic and wet forest types have dense understories comprised of shrubs, ferns, and sedges.

Vulnerability Assessment Results

Mesic and wet habitats on Hawaiʻi were evaluated within three groups: mesic forests, montane wet forests, and lowland wet forests. Overall, mesic and wet forest habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity, although individual rankings varied slightly between the forest types.

Mesic and wet forest habitat types are primarily sensitive to factors that impact moisture gradients and water availability, including drought, changes in precipitation amount and timing, soil moisture, air temperature, and changes in wind and circulation patterns. Reduced water availability can alter species composition and forest distribution, potentially reducing habitat extent. Wildfire, tropical storms, disease, and volcanic activity can damage large areas of forest, resetting succession and increasing the risk of invasive species establishment. Invasive species (e.g., trees/shrubs, flammable grasses, ungulates, mammals, pathogens/parasites, social insects) are a major non-climate stressor for mesic and wet forest types, and these can alter ecosystem processes and directly compete with native species, contributing to species mortality and reduced recruitment and undermining the ecological integrity and persistence of native forests. Development, agriculture, and roads/highways reduce habitat extent and fragment and degrade remaining forest area.

Although mesic and wet forests are relatively extensive on Hawaiʻi, lower-elevation forests are more fragmented and degraded due to human activity. Native species diversity and endemism is high; however, habitat fragmentation and invasive species invasion have limited native mesic and wet forest regeneration following wildfire and other disturbances. Management and restoration efforts are not likely to alleviate the impacts of climate change, but mesic and wet forests have relatively high public value and societal support.

Adaptation Planning Results

Table 32 presents a summary of possible adaptation strategies and actions for Hawaiʻi mesic and wet forest habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 32 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 32. Summary of possible adaptation strategies and actions for Hawaiʻi mesic and wet forest habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage for invasive-resistant communities	• Expand fencing and ungulate removal in areas more resilient to invasion (e.g., aʻa lava flows, higher elevations) and Special Ecological Areas
	Increase biosecurity measures	• Support implementation of existing biosecurity plans
	Improve fire prevention and response	• Prevent off-road vehicle and pedestrian activity in high recharge areas, sensitive watersheds, and core native habitats through education and access limits • Increase funding for support of fire response agencies and Community Wildland Protection Plans
	Preserve, restore, and increase resilience of native ecosystems	• Protect and preserve remnant habitat, and include a diversity of sites
Resilience *Near- to mid-term*	Maintain intact, native-dominated ecosystems	• Augment native habitat through outplanting and seeding of temperature- and drought-tolerant species in post-disturbance sites and buffer zones

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
approach	Create a self-sustaining forest that requires limited or no on-the-ground human management	• Change policy to allow the use of unmanned aerial systems to aid management efforts (e.g., invasive control, mapping/monitoring)
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species) • Create test plots to determine where habitat may shift along ecotone boundaries and identify potential unintended consequences • Erect fences across biome and habitat borders to allow for potential habitat and species range shifts
Knowledge *Near- to long-term approach*	Increase development and implementation of new technology for invasive species control	• Increase small-scale testing to determine ideal site conditions (e.g., treatment area size) • Look into community-based implementation options for new technology
	Increase education and outreach to increase public engagement and stewardship in conservation	• Increase awareness of biocultural and ecosystem services
Collaboration *Near- to long-term approach*	Increase education and outreach to increase public engagement and stewardship in conservation	• Promote native species in tourism and marketing • Support ecotourism • Increase cross-sectoral partnerships and promote understanding of diverse perspectives
	Increase biosecurity measures	• Determine individual agency roles in promoting biosecurity plans (e.g., decontamination stations, vehicle cleaning)

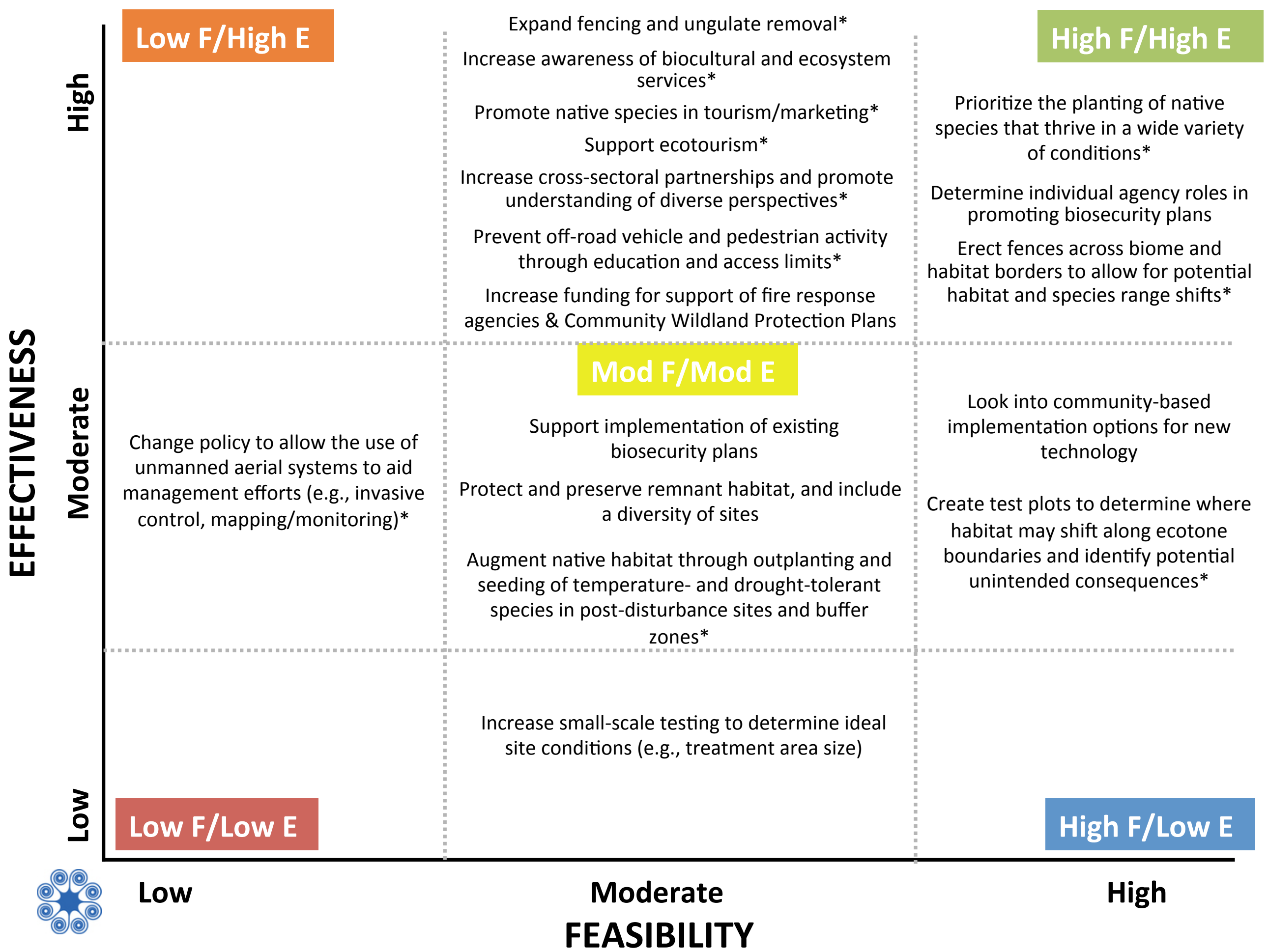

Figure 32. Hawaiʻi mesic and wet forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Alpine/Subalpine

Alpine and subalpine habitats are found in high-elevation areas on the island of Hawaiʻi, primarily on Mauna Loa and Mauna Kea. These habitats mostly lie above the mean height of the TWI, and therefore are arid with very little precipitation or fog. Unlike many areas of the world, high-elevation vegetation is most likely limited by moisture rather than by low temperature. Alpine communities are found above the tree line up to the summits of Mauna Loa, Mauna Kea, and Hualālai over 3,000 m (10,000 ft). Alpine areas are often comprised of shrubland, grassland, and stone desert habitats at increasingly high elevations, with many endemic and highly specialized plant and animal species that are adapted to extreme isolation. Subalpine communities lie between 2,000 and 3,000 m (6,560 to 10,000 ft) in elevation, and may consist of shrublands, grasslands, and forests with sparse, short trees; forests are primarily dry, although a subalpine mesic forest area can be found on Mauna Loa. Vegetation includes māmane, naio, aweoweo, aʻaliʻi, and ʻōhiʻa trees; ʻōhelo and pūkiawe shrubs; ʻāhinahina (Mauna Loa silversword); bracken fern; and alpine hairgrass.

Vulnerability Assessment Results

Alpine and subalpine habitats in Hawaiʻi were evaluated as having *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Alpine and subalpine habitats are sensitive to factors that contribute to water and thermal stress and allow upslope expansion by invasive plants and animals, such as changes in the amount and timing of precipitation, altered patterns of wind and circulation, increased air temperature, and increased solar radiation. Disturbance events, such as wildfire, disease, and volcanic activity, may cause native plant injury and/or mortality and allow invasive plants to become established. Non-climate stressors reduce habitat extent and fragment or degrade remaining habitat areas by introducing pollutants, increasing wildfire risk and erosion, and introducing invasive plants. Invasive plants, animals, and pathogens threaten native species by causing damage or mortality, inhibiting recruitment, and increasing competition for resources; invasive species also alter disturbance regimes, surface hydrology, and other ecosystem processes.

Alpine and subalpine habitats are severely degraded in some areas, particularly in subalpine areas impacted by ungulate grazing. The isolated nature of these habitat types has led to limited native species diversity, but levels of endemism are high and species are typically adapted to harsh conditions. Because there is little to no potential for upslope habitat migration, the loss of high-elevation refugia may make it difficult for many native species to survive. Although societal and public support for these habitat types is high, relatively little can be done to alleviate the impacts of climate change on alpine and subalpine habitats. Management activities focus primarily on minimizing the impacts of invasive species, followed by passive (e.g., allowing natural regeneration) or active (e.g. rare species reintroduction) recovery of native species, and successful habitat restoration efforts are occurring.

Adaptation Planning Results

Table 33 presents a summary of possible adaptation strategies and actions for Hawaiʻi alpine and subalpine habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 33 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 33. Summary of possible adaptation strategies and actions for Hawaiʻi alpine/subalpine habitat.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Minimize the impacts of non-native species (e.g., cats, rodents, mongoose, arthropods [Argentine ant])	• Remove ungulates and erect fencing to protect subalpine habitats • Increase public awareness of invasive species risk and spread • Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals
	Improve fire prevention and response	• Increase fuel reduction efforts in common ignition sites and areas of high conservation value
Resilience	Manage invasive species	• Prioritize invasive plant removal, focusing on areas

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Near- to mid-term approach		with high diversity or rare species
	Increase public understanding of alpine/subalpine habitats to decrease stress on these systems	• Increase stewardship of nearby, human-inhabited local conservation lands • Create remote sites and viewpoints that have sightlines of alpine/subalpine habitats and post public signage about the natural and cultural importance of habitats
	Maintain and augment native species populations	• Actively restore high-priority sites inside the fence, considering surrogate species that may be tolerant of future climate conditions • Identify a good seed bank and allow natural regeneration (i.e. passive restoration)
Response *Long-term approach*	Use assisted colonization to restore rare species (e.g., birds)	• Release rare species into suitable habitat and monitor survival, dispersal, reproductive success, abundance, and genetic diversity
Knowledge *Near- to long-term approach*	Gather information on fire vulnerability/resilience in native communities	• Research which native species are fire-tolerant and are appropriate for pre- and post-burn planting, taking climate change into consideration • Research seed production and storage to protect genetic integrity
	Conduct research to support adaptive policies and technology that increase landscape-level protection and restoration	• Research and develop new/improved methods of weed control • Research and develop new/improved methods of small predator control
Collaboration *Near- to long-term approach*	Coordinate with multiple landowners	• Collaborate with ranchers to contain ranching activities and minimize disturbance in subalpine habitats

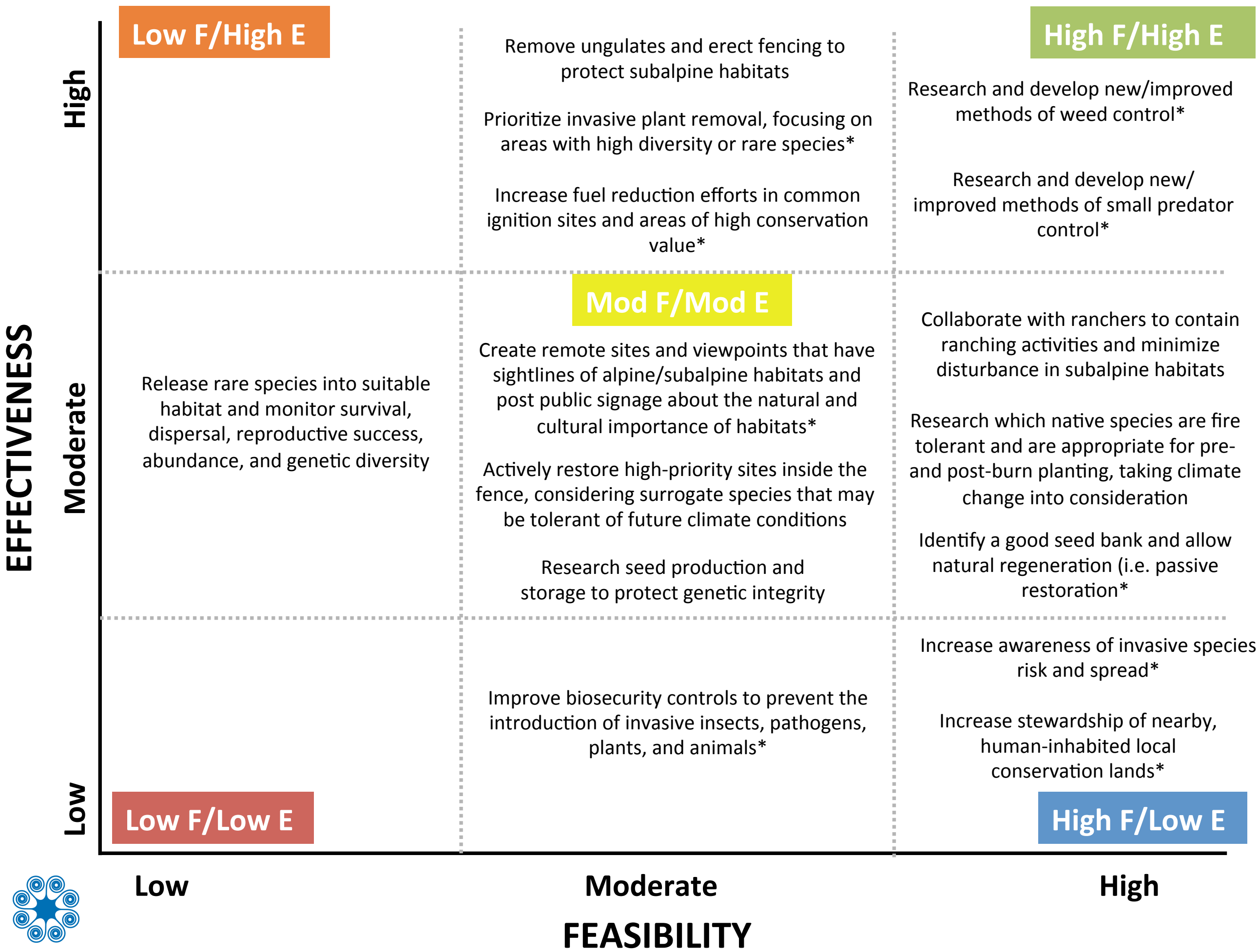

Figure 33. Hawai'i alpine and subalpine habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Cultural Knowledge and Heritage Values

Native Hawaiian culture is dynamic and inextricably tied to the surrounding land and seascapes. Native Hawaiians maintain a reciprocal relationship with ecosystems, ensuring that benefits are both received from and returned to a resource. Traditional practices are closely tied to the seasonal patterns of wind, rain, and other weather conditions, and this knowledge has been passed down in oral and written traditions. Cultural heritage incorporates past legacies that relate to ecosystems and a sense of place, and includes many aspects of identity and spirituality. Great cultural importance is placed on native species, especially the native plants and animals that have shaped the culture, including those that provide food and medicine. Many cultural practices are dependent on natural resources, such as the gathering of native plant and animal species for food, medicine, carving, tools, weaving, jewelry, hula or traditional dance, and ceremonial practices.

Vulnerability Assessment Results

Cultural knowledge and heritage values on Hawaiʻi were evaluated as having *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. This ecosystem service is vulnerable to climate changes that impact the health and integrity of ecosystems and/or native species, as well as to changes that damage or destroy valued cultural assets and heritage sites; these include sea level rise, air temperature, precipitation, and wind and circulation patterns. Disturbance events, such as wildfire, flooding, insects, disease, and volcanic eruptions, can affect large areas and cause extensive damage or loss of living things and landscapes of cultural importance, and they can also limit access to traditional gathering areas or the ability to carry out traditional practices. Many non-climate stressors are linked to increasing human populations and associated impacts of changes in land use and the overuse of natural resources (e.g., development, pollution, water diversions, recreation, etc.), which have fragmented and degraded natural habitats. The introduction and establishment of invasive species, including plants, wildlife, insects, fish, and pathogens/parasites, have had an especially large impact on cultural knowledge and heritage by altering ecosystem functions and driving the loss of native species and habitats. Finally, population growth exacerbates the impacts of both climate and non-climate stressors on cultural resources by increasing demands for natural resources (e.g., water) and accelerating habitat degradation.

Native Hawaiian knowledge and heritage is still affected by colonization, and these values receive relatively little public and societal recognition and support, though they are viewed as important by constituency groups and practitioners. The importance of cultural knowledge is starting to be incorporated into natural resource management and decision-making processes to a greater degree, and people may increasingly seek out traditional values and cultural knowledge as the impacts of climate change become more apparent.

Adaptation Planning Results

Table 34 presents a summary of possible adaptation strategies and actions for Hawaiʻi cultural knowledge and heritage values, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 34 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 34. Summary of possible adaptation strategies and actions for Hawaiʻi cultural knowledge and heritage values.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Preserve cultural practices and sites (e.g., landscapes, traditions)	• Protect/create dedicated spaces for cultural practices • Protect water rights and public access to the shoreline and forest • Preserve cultural foods
Resilience *Near- to mid-term*	Increase biocultural landscape-based planning and management	• Create cultural use and practice overlays for land-use planning and/or climate adaptation areas • Create overlay of resources and practices as they exist

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
approach		now and projected into the future (e.g., overlay cultural sites with sea level rise projections) • Identify and issue permits for all cultural land-use practices, increasing diversity of land-use designations where needed (e.g., agriculture, flexible land-use transects, floating zones) • Identify different elevational areas and various landscapes across the islands based on mokus (districts) and compare these with county community boundaries to create community-defined, practice-based zones
	Preserve cultural practices and sites (e.g., landscapes, traditions)	• Integrate climate change into ʻāina-based programming
	Prioritize and pair habitat restoration with cultural resource management	• Restore culturally significant habitats from mauka to makai (e.g., loʻi, forests, beaches) • Implement ahupuaʻa practices to encourage geographically based restoration and a sustainability mindset
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Protect upland areas for mauka migration in anticipation of sea level rise • Limit development in inland/upland areas where coastal habitats may migrate • Limit development in most vulnerable sites
Knowledge *Near- to long-term approach*	Ensure community-wide intergenerational transmission of knowledge	• Facilitate mentorship and knowledge exchange among and between practitioners
	Increase biocultural landscape-based planning and management	• Kilo ʻāina practice to document conditions of resources related to cultural practices and livelihood and identify their future locations
Collaboration *Near- to long-term approach*	Increase number of Native Hawaiian stewards for cultural resources	• Increase stewardship opportunities • Formally acknowledge/incentivize successful stewardship • Create/revise cultural stewardship agreements

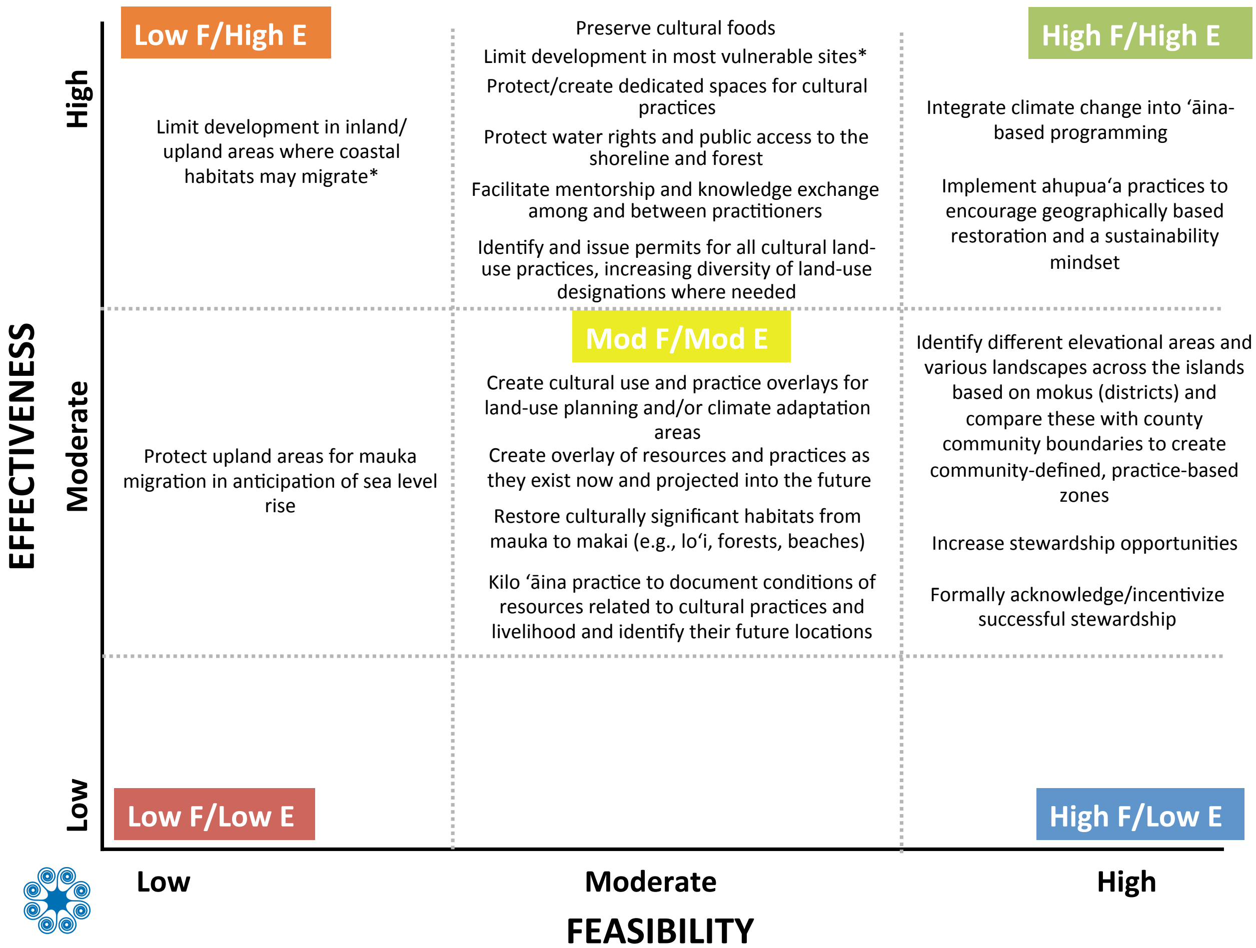

Figure 34. Hawaiʻi cultural knowledge and heritage values adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Flood and Erosion Control

Native terrestrial and aquatic ecosystems help regulate flooding and erosion by regulating surface and subsurface flow, storing and reducing rates of water discharge, and anchoring and retaining sediment. For example, Hawaiʻi's native forests intercept rain, slow runoff, and anchor forest sediment, and wetlands help slow floodwater velocity and attenuate sediment, thereby decreasing erosion. Coastal ecosystems also help mitigate flooding and erosion by anchoring coastal sediment and altering wave dynamics. The benefits from this regulating service include retention of fertile soil, prevention of nearshore siltation, better groundwater recharge, and source water for humans and watersheds. Despite getting more rain than other islands, Hawaiʻi experiences less flooding because it is a younger island with more porous substrate that allows for quick drainage. Additionally, as one of the lesser-developed islands, Hawaiʻi experiences enhanced flood control by having more native forests, rangeland, land with more gradual slopes, and many streams.

Vulnerability Assessment Results

Flood and erosion control ecosystem services on Hawaiʻi were evaluated to have *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Climatic factors such as extreme precipitation events, sea level rise, and riverine flooding can overwhelm the natural capacity of Hawaiʻi's habitats and landscapes to provide this ecosystem service. Other factors such as drought, wildfire, tropical storms, soil moisture changes, trade wind changes, disease, and insects affect the ability of natural systems to provide flood and erosion control by altering vegetative cover and composition, including increasing vulnerability to exotic species establishment. Non-climate stressors such as development, agriculture, roads, highways, trails, and invasive plants often alter sheet flow and surface runoff patterns, increasing flood volumes. These stressors, as well as invasive ungulates, invasive mammalian predators, invasive parasites and pathogens, energy production, and recreation can also increase erosion potential by reducing native vegetative cover and increasing bare ground. Some non-climate stressors (e.g., water diversions, groundwater withdrawals, hunting) may benefit flood control to a small degree. Population growth is likely to exacerbate many non-climate impacts.

Flooding and erosion management in the face of climate change is supported by high public value of this service, the protection of habitat areas that currently provide this service, and watershed restoration and protection work being conducted by watershed alliances and other groups. There is high public value placed on flooding and erosion control, but variable societal support for ecosystem service management. Management may be limited by funding, variable enforcement of existing regulations, and the difficulty of implementing management actions at larger scales. Additionally, flood and erosion control management may face increasing use conflicts with food and fiber, commercial agriculture, grazing, ranching, tourism, and coastal development.

Adaptation Planning Results

Table 35 presents a summary of possible adaptation strategies and actions for Hawaiʻi flood and erosion control, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 35 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 35. Summary of possible adaptation strategies and actions for Hawaiʻi flood and erosion control.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage for invasive-resistant communities	• Expand fencing and ungulate removal in areas more resilient to invasion (e.g., aʻa lava flows, higher elevations) and Special Ecological Areas • Remove weeds, including invasive grasses • Increase biosecurity
	Decrease erosion and sediment delivery to improve water quality and protect municipal water supplies	• Design and construct roads to minimize erosion and sediment production • Increase and/or relocate road cross drains to decrease hydrologic connectivity between roads

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		and streams
	Protect water quality	• Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)
Resilience *Near- to mid-term approach*	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion • Plant or seed fire-resilient species in burned areas, considering the presence of ungulates during species selection • Replace compromised fences and control invasive plants following a wildfire
	Promote technical and cultural practices to reduce stream flashiness	• Protect and restore culturally appropriate loʻi to decrease high flow events and stream flashiness
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Response *Long-term approach*	Identify and promote climate-adapted species composition	• Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions
	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
	Prepare for sea level rise impacts	• Plant salt- and flood-tolerant vegetation • Redesign development guidelines to account for sea level rise and other climate change impacts
Knowledge *Near- to long-term approach*	Gather information on fire vulnerability/resilience in native communities	• Research which native species are fire tolerant and are appropriate for pre- and post-burn planting, taking climate change into consideration
Collaboration *Near- to long-term approach*	Create new/improve partnerships to increase capacity	• Build off of existing programs by creating/enhancing networks with other agencies and organizations

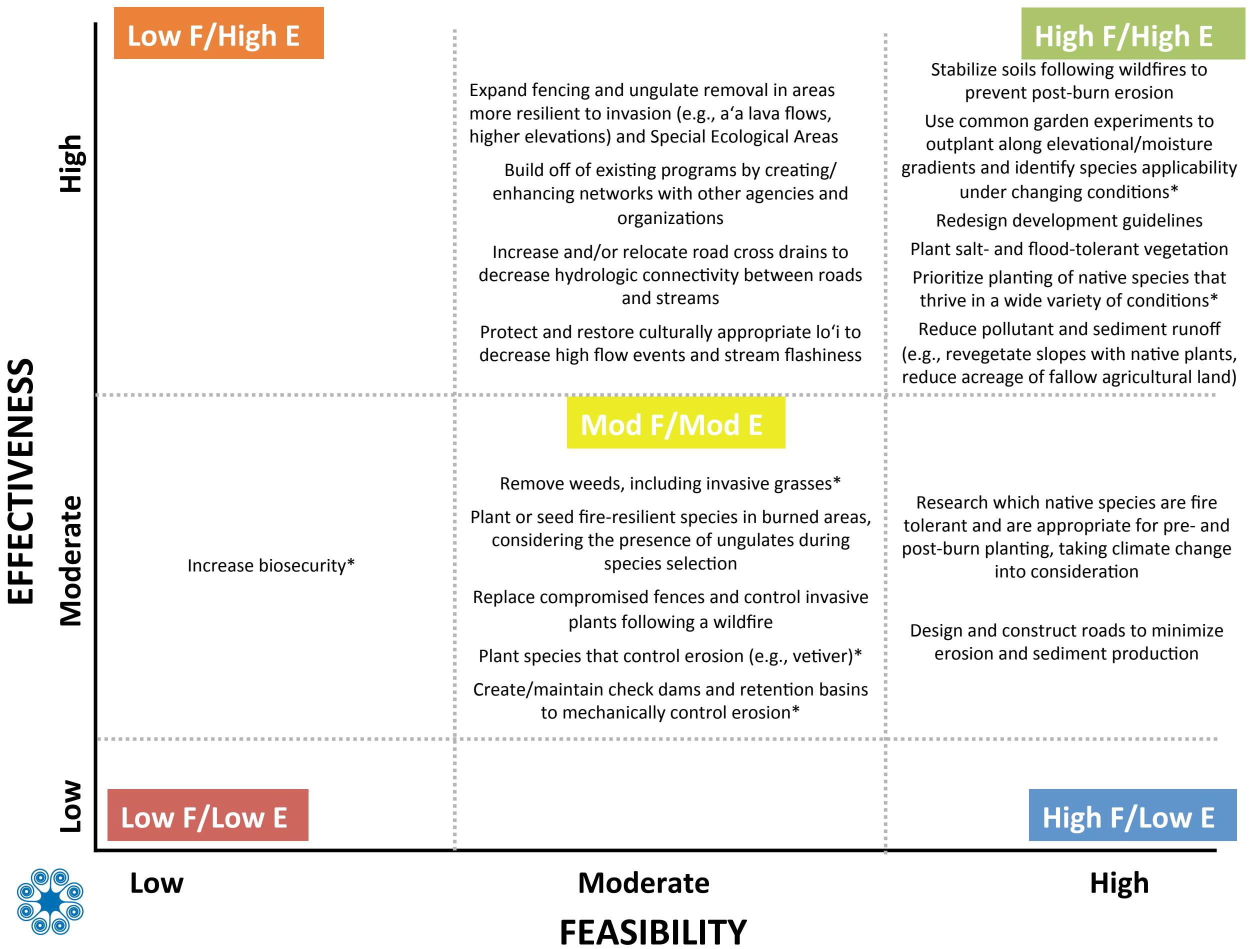

Figure 35. Hawai‘i flood and erosion control adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Fresh Water

Fresh water is classified as a provisioning ecosystem service because it supplies both consumptive (e.g., drinking water, agricultural and industrial use) and non-consumptive human uses (e.g., power generation). Fresh water also supports other natural systems and processes that provide additional ecosystem services. For example, fresh water supports aquatic habitats, which in turn provide ecosystem services such as food production, flood control, aesthetic values (e.g., waterfalls), and tourism and recreation. Native forests, wetlands, and other habitats help maintain water supply by intercepting, slowing, and storing water. Along with upland and lowland wetlands, native forests also help improve water quality by anchoring and filtering sediment and filtering pollutants. Hawai‘i has significant surface water resources in the form of perennial and intermittent streams and freshwater wetlands that support native wildlife and agricultural irrigation, as well as groundwater resources that are increasingly being used for municipal and private water supply.

Vulnerability Assessment Results

The fresh water ecosystem service on Hawaiʻi was evaluated to have *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Climatic factors including precipitation changes, drought, air temperature increases, tropical storms, and volcanic emissions are likely to affect future fresh water availability, either by directly reducing precipitation or by altering the health and integrity of Hawaiʻi's native landscapes and watersheds. Water quality may be impacted by tropical storms, flooding, and volcanic emissions, which can increase contaminant and sediment delivery and promote leaching of heavy metals. Non-climate stressors — including residential and commercial development, agriculture, aquaculture, energy development, water diversions, and groundwater withdrawal — alter water use and delivery, potentially compounding future climate-driven reductions in water availability. Human land uses (e.g., urban areas, agriculture) can also impair water quality by introducing pollution and poisons and affect water capture by increasing runoff and introducing invasive species. Invasive species undermine watershed health and integrity, reducing water storage and degrading water quality.

There are several statewide and island-based efforts focused on promoting water conservation and watershed health and function, which may help enhance the adaptive capacity of this service in the face of climate change and increasing pressure from non-climate stressors. There is high public value placed on fresh water and fresh water is considered a public trust. However, there is variable societal support for ecosystem service management, which may affect future management opportunities. Additionally, water management may face increasing use conflicts with food and energy production.

Adaptation Planning Results

Table 36 presents a summary of possible adaptation strategies and actions for Hawaiʻi fresh water, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 36 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 36. Summary of possible adaptation strategies and actions for Hawaiʻi fresh water.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain/improve water quantity and quality	• Provide incentives for Hawaiian field systems to not be developed or grazed by cattle • Investigate and reduce non-point source pollution • Alter well drill depths and practice optimal well placement to minimize vulnerability to saltwater intrusion
	Improve water conservation efforts	• Increase agricultural water conservation (i.e. promote soil moisture management, capture rain water) • Increase public and private water system conservation (i.e. alter rate structure, use low-flow fixtures, detect and fix leaks)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		• Develop a water budget to account for all water sources, connectivity, uses/withdrawals, and disposal/discharges
	Manage invasive species	• Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Increase biosecurity
Resilience *Near- to mid-term approach*	Preserve water supplies by increasing water use efficiency	• Use Hawaiian field system to slow down water, increase recharge, and benefit anchialine pools, and use as a model for other places • Improve rainfall capture to decrease groundwater withdrawals • Investigate alternative agricultural crops that have economic benefit and capture water • Maintain aquifers by ensuring native forest cover • Consider payment for ecosystem services (i.e. landowners that recharge water receive payment) • Increase use of alternative water sources (i.e. stormwater, gray water, recycled reclaimed water, capture fog drip)
	Protect forests to increase recharge and water retention	• Support healthy native forests through land acquisition and plant restoration
	Increase natural/built water storage to increase supply and capture floodwater	• Create distributed small-scale water storage (e.g., retention ponds) • Build additional water storage by mirroring natural processes (e.g., constructed wetlands)
Response *Long-term approach*	Identify and promote climate-adapted species composition	• Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions
	Maintain a resilient water supply	• Integrate climate projections into Water Commission planning efforts
Knowledge *Near- to long-term approach*	Increase understanding of water resources and their value	• Increase monitoring of groundwater and surface water resources • Utilize citizen science and increase community involvement to expand monitoring efforts • Increase knowledge of water needs of native ecosystems and species and the impact of water withdrawals on these resources
Collaboration *Near- to long-term approach*	Strengthen conversations about water as public trust	• Ensure continued cultural connections to water resources • Create and/or enhance water groups (e.g., watershed partnerships) • Elevate the value of freshwater through water conservation campaigns

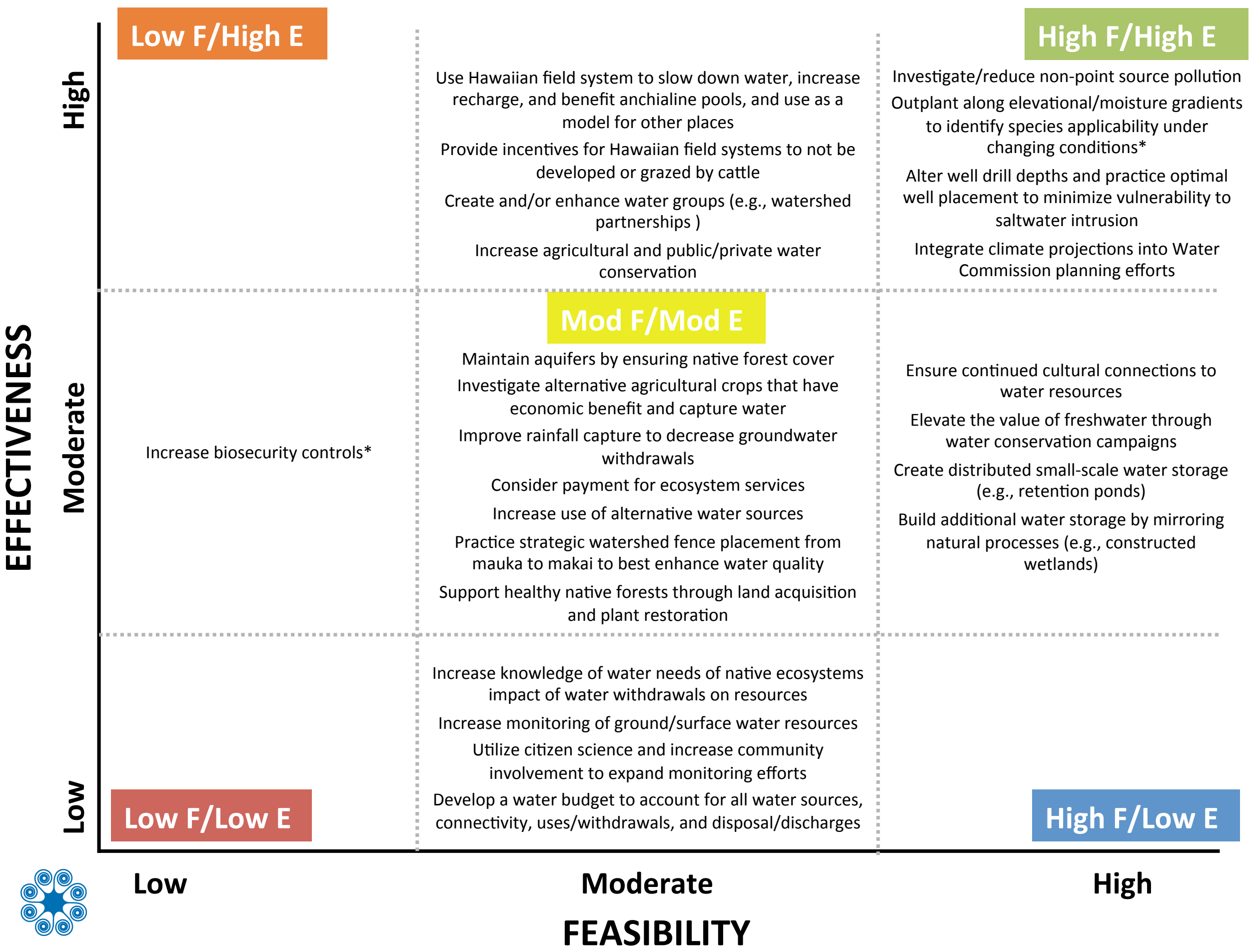

Figure 36. Hawai'i fresh water adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Food and Fiber

Food and fiber ecosystem services include non-industrial diversified agriculture that is ecologically and culturally appropriate, intended for local consumption, and carried out within a closed system. Aquaculture, hunting, fishing, and gathering are also used to obtain food and fiber resources, and all of these activities involve many traditional cultural practices such as pig hunting, taro cultivation, fishpond aquaculture, and forest, marine, and shoreline gathering. Fiber products include basketry, cordage, textiles important for cultural use, and lithics (e.g., rock material used for tools).

Vulnerability Assessment Results

Food and fiber ecosystem services on Hawai'i were evaluated as having *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low-moderate* adaptive capacity. Climate-driven changes and disturbance regimes such as altered precipitation regimes, increased air temperature, tropical storms and flooding, sea level rise, saltwater intrusion, changes in wind and circulation patterns, wildfire, insects, and disease are likely to impact both cultivated crops and other native species used for food and fiber on Hawaiʻi. These factors may reduce water supply and quality, stressing native ecosystems and limiting crop irrigation and plant growth. Food and fiber species may also be impacted by disturbances that damage habitats and infrastructure and cause direct species injury or mortality (e.g., tropical storms, wildfire, insects, disease). Non-climate stressors reduce habitat extent, introduce pollutants, and diminish surface- and groundwater sources, degrading habitat quality and availability for harvestable plant and animal species. Additionally, invasive plants and wildlife alter native ecosystems harboring species harvested for food, fiber, and other materials, in many cases out-competing native species for resources or leading to the damage or decline of cultivated and/or wild plants and animals.

Although food and fiber ecosystem services are highly valued by the public, societal support is relatively low. The Hawaiian Islands have low food security due to their isolated location and dependence on imported goods and energy, which drives up the price of local agricultural products and in turn increases the competitiveness of cheap imported food. Changes in climate may encourage a shift in focus towards sustainable land use and locally produced food, but little work is being done to specifically alleviate the impacts of climate change on food and fiber ecosystem services.

Adaptation Planning Results

Table 37 presents a summary of possible adaptation strategies and actions for Hawaiʻi food and fiber, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 37 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 37. Summary of possible adaptation strategies and actions for Hawaiʻi food and fiber.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain/improve water quantity and quality	• Provide incentives for Hawaiian field systems to not be developed or grazed by cattle
	Manage soil health and stability	• Provide erosion control by using fencing to exclude invasive species from upland areas
Resilience *Near- to mid-term approach*	Preserve water supplies by increasing water use efficiency	• Improve rainfall capture to decrease groundwater withdrawals • Increase use of alternative water sources (i.e. stormwater, gray water, recycled reclaimed water, capture fog drip) • Investigate alternative agricultural crops that have economic benefit and capture water
Response *Long-term approach*	Promote climate-adapted agricultural practices	• Investigate alternative agricultural crop varieties and mixes with economic value • Consider innovative locations to grow crops under future climate conditions

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Knowledge *Near- to long-term approach*	Increase understanding of water resources and their value	• Investigate automated groundwater monitoring techniques and organizations/agencies that could act as data managers • Utilize citizen science and increase community involvement to expand monitoring efforts
Collaboration *Near- to long-term approach*	Strengthen conversations about water as public trust	• Create and/or enhance water groups (e.g., watershed partnerships)
	Support whole systems approaches to agricultural production	• Increase support for community-supported agriculture (CSAs)

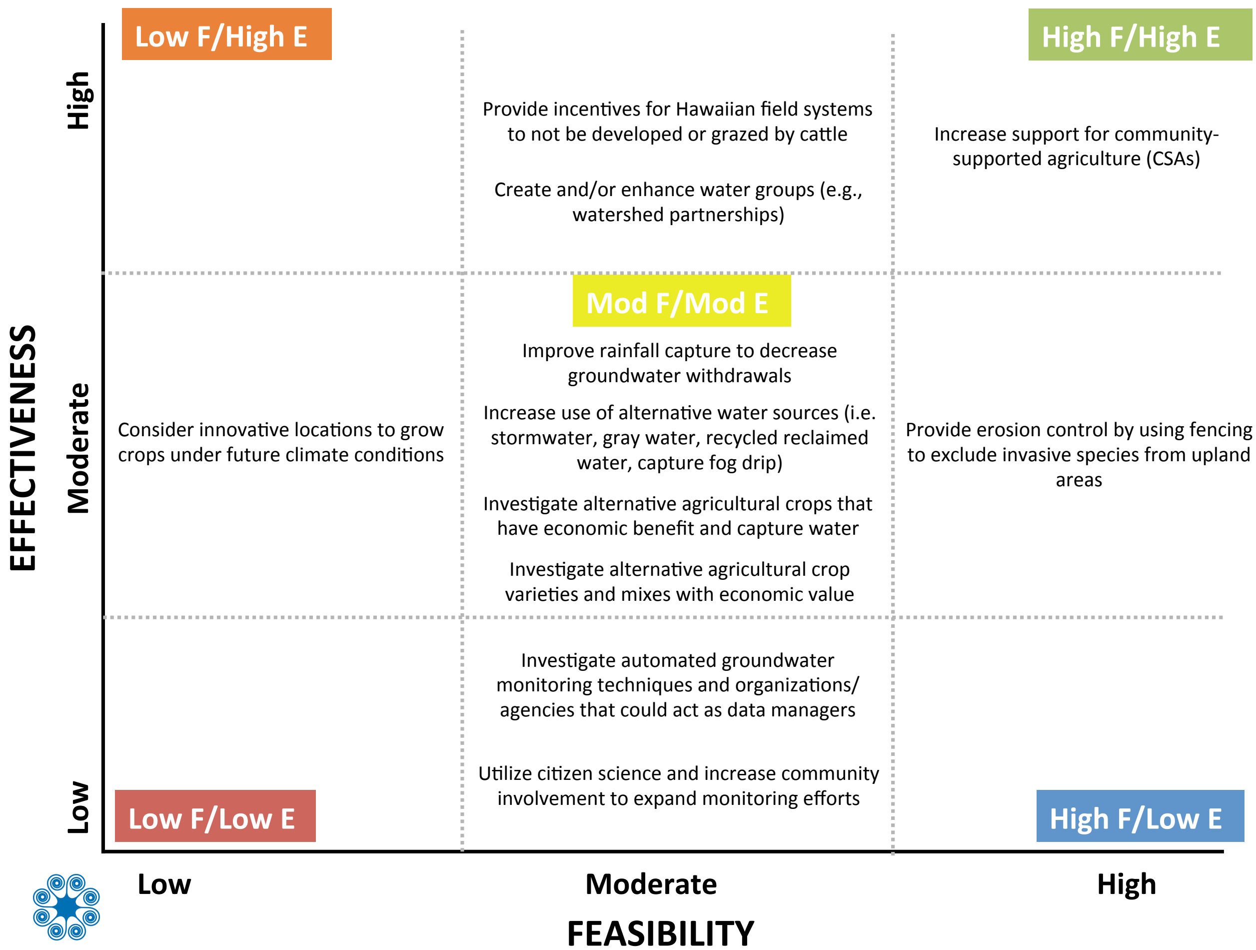

Figure 37. Hawai'i food and fiber adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Kauaʻi: Vulnerability Assessment and Adaptation Options

Summary

The following chapter provides a summary of the vulnerability assessment and adaptation planning results for Kauaʻi. Table 38 presents the overall vulnerability and confidence scores for habitats and ecosystem services on the island. Figure 38 presents the overall vulnerabilities of habitats and ecosystem services based on the assessment of climate and non-climate sensitivity and exposure and adaptive capacity.

Table 38. Overall vulnerability and confidence scores for Kauaʻi habitats and ecosystem services.

Focal Resource	Vulnerability Score	Confidence Score
Habitats		
Coastal: Shorelines	**High**	**High**
Coastal: Estuaries and Coastal Wetlands	**Moderate**	**Moderate**
Coastal: Cultural Coastal Habitats	**Moderate**	**High**
Aquatic: Streams	**Moderate**	**Moderate**
Aquatic: Lowland Wetlands	**Moderate-High**	**Moderate**
Aquatic: Upland Wetlands	**Moderate**	**Moderate**
Mesic and Wet Forest	**Moderate**	**Moderate**
Ecosystem Services		
Cultural Knowledge and Heritage Values	**Moderate**	**Moderate**
Flood and Erosion Control	**Moderate-High**	**Moderate**
Fresh Water	**Moderate-High**	**Moderate**
Food and Fiber	**Moderate**	**High**

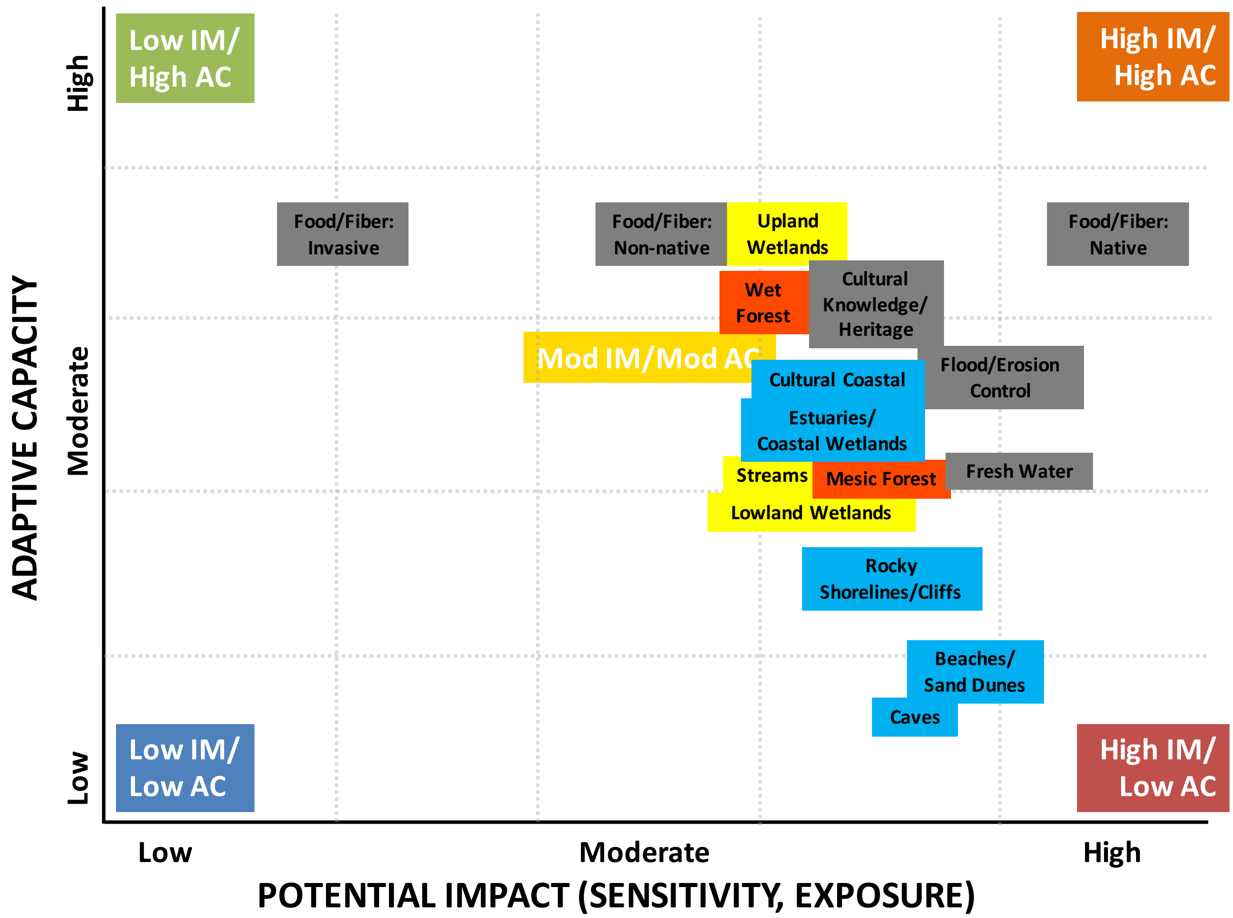

Figure 38. Overall vulnerabilities of Kauaʻi habitats and ecosystem services based on climate and non-climate sensitivity and exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure (i.e. potential impact) and decreasing adaptive capacity. Habitats listed near the upper left region were assessed as less vulnerable than those listed in the lower right region. Color code: Terrestrial habitats (red), Coastal habitats (blue), Aquatic habitats (yellow), Ecosystem services (grey)

Coastal Habitats

Workshop participants classified coastal habitats as shorelines, estuaries and coastal wetlands, and cultural coastal habitats (i.e. salt ponds, fishponds, kalo, and iwi). Kauaʻi has 110 miles of **shoreline**, featuring a variety of sub-habitats, including rocky shoreline, steep sea cliffs, lava tubes/caves, sandy beach, sand dunes (e.g., Polihale Dunes), and lithified sand dune coast (Mahaulepu). **Estuarine and coastal wetland habitats** occur at the fresh and saltwater interface, and are characterized by brackish water conditions. Estuarine habitats on Kauaʻi include Hanalei River Estuary, Kilauea River Estuary, Waimea River Estuary, Wainiha Valley Estuary, and Lawai Kai Estuary, among others. **Cultural coastal habitat** types include loʻi paʻakai (salt ponds), loko iʻa (fishponds), loʻi kalo (flooded taro farmland), and iwi kūpuna (ancestral burials). Salt ponds are traditionally used to cultivate paʻakai (sea salt), and one of the only remaining areas where this practice continues is in Hanapēpē on the southwestern coast of Kauaʻi. Loko iʻa (fishponds) are saltwater, brackish, or freshwater enclosures (natural or artificial) historically used to to cultivate fish, plants, and other freshwater and saltwater food sources in coastal areas. Kalo is a staple food, and the Hanalei Valley contains the largest area of kalo cultivation in the state. Native Hawaiian iwi kūpuna (ancestral burials) are traditionally buried along the coast.

Vulnerability Assessment Results

Shorelines

Shoreline habitats on Kauaʻi were evaluated in five sub-groups: sandy beaches, sand dunes, rocky shorelines, cliffs, and caves. Overall, shoreline habitats were evaluated to have a *high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *low* adaptive capacity. Climatic factors including tropical storms, sea level rise, and trade winds significantly affect sediment delivery patterns and shoreline vulnerability to erosion and inundation, potentially reducing overall habitat availability. Extreme precipitation events, streamflow, and riverine flooding also impact sediment delivery, erosion, and inundation risk to a lesser degree. Shoreline habitats are also sensitive to precipitation changes and drought, which affect vegetation communities and habitat conditions (e.g., cave humidity). Non-climate stressors such as pollution, invasive pathogens and parasites, recreation, and invasive vegetation can further alter shoreline vegetative and faunal composition by disturbing, outcompeting, or causing mortality of native species. Additionally, shoreline habitats are under pressure from those who want to increase development and military activities on shorelines.

The adaptive capacity of shoreline habitats is negatively affected by current habitat degradation and alteration as a result of human activities. Shoreline species are typically adapted to variable conditions, but human impacts undermine the natural ability of these habitats to cope with changing conditions. Additionally, shoreline habitats host many endangered, threatened, and climatically vulnerable species, reducing overall resilience. Some shoreline habitats are protected and managed, and shoreline habitats are highly valued by the public and provide many ecosystem services, which may increase overall management opportunities. However, managers lack funding and face challenges with private land ownership. Additionally, shoreline habitats face continued use interests with development and military activities.

Estuaries and Coastal Wetlands

Estuarine and coastal wetland habitats on Kauaʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors and disturbance regimes such as sea level rise, saltwater intrusion, drought, precipitation, soil moisture, streamflow, and flooding regimes affect coastal wetland and estuary extent and distribution, hydrology, salinity, and water quality. Shifts in habitat availability and condition can impact suitability and utilization by native wildlife and increase habitat vulnerability to exotic species establishment and dominance. Non-climate stressors including agriculture, aquaculture, water diversions, and roads can further limit available and/or suitable habitat by impacting estuarine and coastal wetland distribution, hydrology, and contaminant loads. Invasive species (e.g., trees, shrubs, grasses, aquatic weeds, fish, rats, cats, and pigs) can displace or eliminate native species by elevating competition and predation and/or increasing disturbance, sedimentation, and exotic diseases.

The adaptive capacity of Kauaʻi's estuaries and coastal wetlands is bolstered by a high habitat extent, high public value and constituency group support, and the location of some habitat areas within national wildlife refuges or other areas with protected status. Additionally, estuaries and coastal wetlands provide critical ecosystem services and support rare, endangered, and endemic wildlife, which may support their management and conservation. However, the adaptive capacity of Kauaʻi's estuaries and coastal wetlands is undermined by degraded habitat condition, competition for water with human uses (e.g., agricultural and municipal use), and a low-moderate ability for managers to alleviate or cope with impacts due to funding issues and a high number and extent of non-climate stressors. Additionally, many component species are very sensitive to potential changes in habitat distribution, salinity, or water quality, making it difficult to adapt to change. Managed wetlands may be most resilient to climate impacts.

Cultural Coastal Habitats (Salt Ponds, Fishponds, Kalo, Iwi)

Cultural coastal habitats on Kauaʻi were evaluated within four distinct groups: salt ponds, fishponds, kalo, and iwi. Overall cultural coastal habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Cultural coastal habitats are vulnerable to changes in climate factors and disturbances that affect water availability and quality and increase pollutants and sediment delivery (e.g., saltwater intrusion, increased water temperature, changes in precipitation and streamflow, more drought, tropical storms, wind, and flooding). Sea level rise and associated coastal flooding and erosion are likely to alter habitat extent, and disturbances may also destroy structures (e.g., tropical storms, wind, flooding) or contribute to injury or mortality in crops and fish stocks (e.g., insects, disease). Non-climate stressors, including development, invasive trees/shrubs, recreation, and pollution/poisons, contribute to cultural coastal habitat loss and degradation by damaging structures, increasing sedimentation, introducing nutrients and contaminants, and allowing the establishment of invasive species.

Almost all salt cultivation within the state and over half the area of kalo cultivation occur on Kauaʻi, although the extent of all cultural coastal habitats is much reduced. These habitat types receive relatively low public and societal support, but many constituency groups also influence support and some habitat areas have been protected. The right to continue traditional practices has also been recognized by the state constitution, but enforcement of these rights is low and increased public education and support is necessary for successful habitat management and conservation.

Adaptation Planning Results

Table 39 presents a summary of possible adaptation strategies and actions for Kauaʻi coastal habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 39 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 39. Summary of possible adaptation strategies and actions for Kauaʻi coastal habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Control invasive predators (cats, rats, snakes, mongooses) • Remove hau and mangroves • Increase biosecurity
	Maintain/improve water quality	• Manage runoff (stormwater, wastewater, nutrients) in

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	and quantity	areas affected by human activity
	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	• Identify climate-informed processes for conservation practices in vulnerable cultural sites
	Reduce non-climate stressors	• Reduce litter and marine debris • Remove existing debris from coastal habitats
Resilience *Near- to mid-term approach*	Prepare for sea level rise impacts	• Redesign development guidelines to account for sea level rise and other climate change impacts
	Restore coastal habitats	• Restore dune and coastal strand habitats • Nourish beaches in areas where habitat retreat is not an option • Use exclusion fencing and restoration in upland habitats to enhance coastal erosion control
	Practice climate-informed habitat restoration	• Maintain and/or increase coastal habitat restoration efforts that incorporate climate information
	Implement climate-informed coastal zoning protections	• Incorporate climate change into Special Management Area siting and permitting • Revise setback requirements to account for projected sea level rise
Response *Long-term approach*	Prepare for sea level rise impacts	• Plant salt- and flood-tolerant vegetation
	Anticipate and facilitate habitat migration	• Implement living shorelines and green infrastructure • Facilitate managed retreat of infrastructure and human communities • Plan for and facilitate inland/upland habitat migration • Limit development in inland/upland areas where coastal habitats may migrate • Investigate the utility of maintaining mangroves if they can effectively buffer sea level rise and flooding impacts • Acquire property with high future ecosystem value (e.g., less developed, less exposed/vulnerable sites)
Knowledge *Near- to long-term approach*	Prepare for sea level rise impacts	• Map sea level rise impacts and future shoreline position
Collaboration *Near- to long-term approach*	Reduce human pressure on native ecosystems and species	• Improve land-use planning and increase outreach on conservation-informed land uses • Increase and create different education and outreach campaigns based on target audiences (resident vs. tourist, older vs. younger)
	Create dialogue between cultural practitioners and natural resource managers	• Increase cultural participation in tracking environmental and climatic change (e.g., host community workshops teaching how to kilo [observe]

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		in different sites, reinstate volunteer work days to help people reconnect to the land)

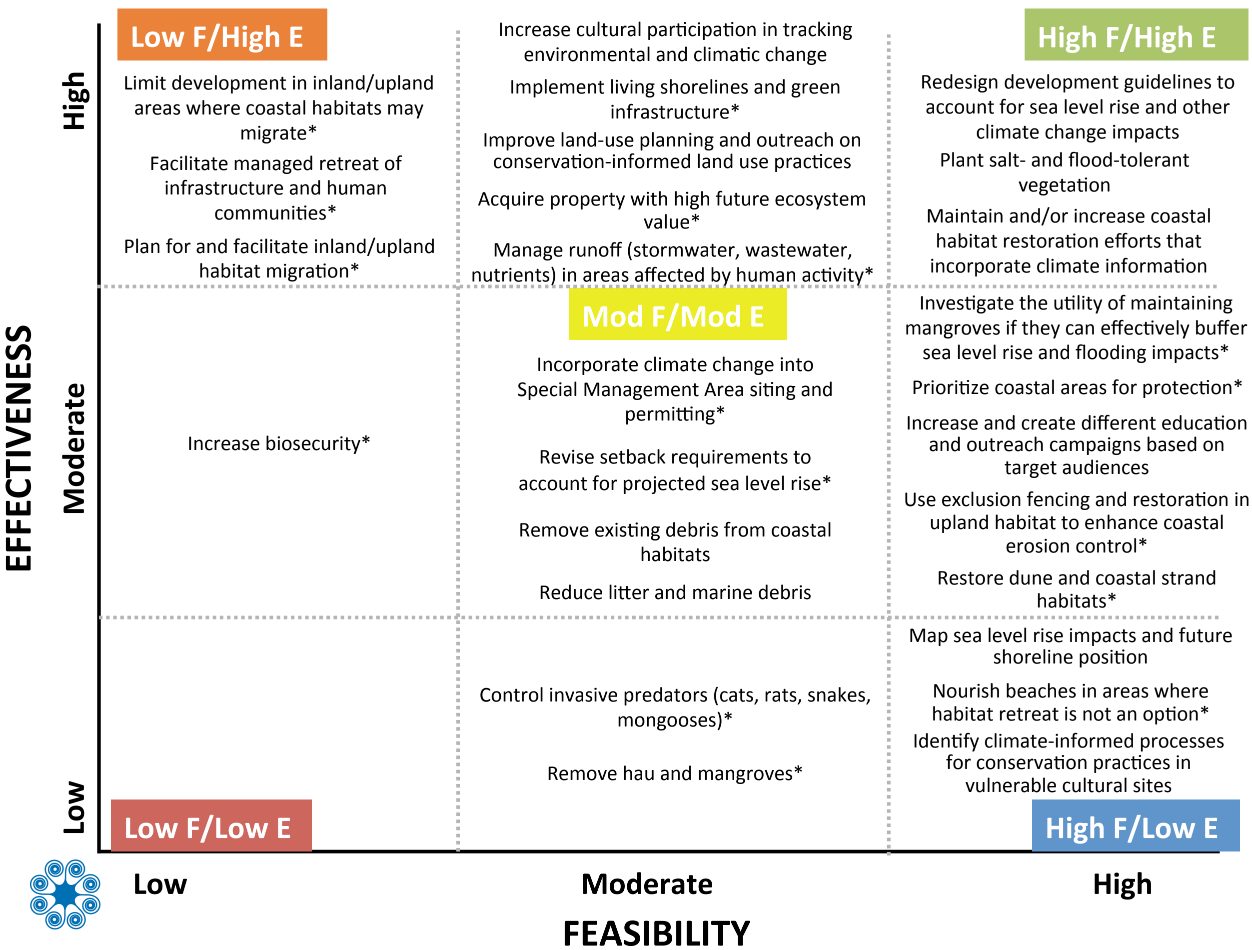

Figure 39. Kaua'i coastal habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Aquatic Habitats

Workshop participants classified aquatic habitats as streams, lowland wetlands, and upland wetlands. Kaua'i's **stream habitats** occur at varied elevations, have flowing water, and include a variety of sub-habitats, including perennial streams, intermittent streams, and man-made waterways (e.g., ditches, canals). Kaua'i has 61 perennial streams, 45 of which are continuous to the ocean; the Wailua and Hanalei Rivers have the largest discharges. **Lowland wetlands** feature permanent or intermittent ponded fresh water derived from precipitation, river and stream runoff, and groundwater inflow. Irrigated agricultural fields (e.g., taro, lotus, watercress) also provide lowland wetland habitat, as do loko i'a kalo (freshwater taro fishponds) and loko wai (natural freshwater fishponds), and constructed wetlands. **Upland wetlands** occur at elevations above 305 m (1,000 ft), and typically occur in openings of the surrounding rainforest, featuring a mixture of mud, standing water pockets, and highly endemic and specialized species, including mosses, lichen, hummock-forming endemic sedges and grasses, and dwarfed woody plants. Alakaʻi Swamp, which occurs on a plateau on Mt. Waiʻaleʻale, and Kanaele Bog in the mountains of south Kauaʻi represent significant upland wetland habitat areas on Kauaʻi.

Vulnerability Assessment Results

Streams

Stream habitats on Kauaʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors such as precipitation changes, drought, changing streamflow regimes, and tropical storms affect overall freshwater availability. Declines in water availability will limit stream habitat availability and connectivity, potentially affecting aquatic species' migrations, recruitment, and survival. Saltwater intrusion can further reduce stream habitat at lower elevations. Tropical storms, flooding, and wildfire also affect stream water quality by increasing sedimentation, turbidity, and contaminant delivery. A variety of non-climate factors further stress stream habitats by impacting water availability and quality. Water diversions, agriculture, energy production, groundwater withdrawals, and invasive trees and shrubs contribute to lower streamflows, while development and roads elevate surface runoff and flood volumes by increasing impermeable surface cover. Contaminant and sediment delivery to streams is increased by ungulate activity as well as agricultural and urban land use. Native aquatic species are negatively affected by increasing contaminant loads, and are also sensitive to competition with and predation by invasive fish.

The adaptive capacity of Kauaʻi's streams is undermined by low biodiversity (relative to mainland systems), high levels of endemism, and the alteration and degradation of some stream reaches as a result of human land use and activities. However, Kauaʻi has a high abundance of stream habitats, restoration efforts indicate that stream algal and invertebrate biomass can recover rapidly following natural flow restoration, and emerging watershed management plans may help mitigate some non-climate impacts on stream communities. Future stream management will likely be affected by policies, regulations, and funding.

Lowland Wetlands

Lowland wetland habitats on Kauaʻi were evaluated to have *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors such as precipitation, drought, streamflow, flooding, tropical storms, and sea level rise affect lowland wetland hydrology, which influences habitat availability, vegetation communities, and wildlife utilization. Sea level rise, saltwater intrusion, and storm surges also increase wetland salinity, which may cause loss of this habitat type and its associated freshwater-adapted species. Air temperature, water temperature, and soil moisture affect plant germination, vegetative composition, and habitat suitability for wildlife. Non-climate stressors such as agriculture, development, water diversions, and groundwater development affect overall lowland wetland habitat extent and quality. By influencing wetland hydrology, these stressors have the potential to compound climate-driven habitat losses and degradation, particularly in drier climate scenarios. Additional non-climate stressors such as pollution and poisons and invasive vegetation, fish, mammalian predators, and ungulates also affect lowland wetland habitat quality and suitability for wildlife.

Kauaʻi has lost less lowland wetland habitat than other Hawaiian islands, but remnant habitat includes extensive irrigated agricultural fields and artificial wetland habitat, and the ecological suitability of these areas is largely unknown. Roads, agriculture, alien vegetation, commercial development, and water diversions all affect the ability of lowland wetlands to migrate in response to climate change. Without migration, many native species may be lost to increasing inundation and changes in salinity as sea levels rise. Lowland wetland vegetation is adapted to some seasonal fluctuations in environmental variables, but is less resilient to invasion and human-induced hydrological shifts. Overall lowland wetland resilience may be bolstered by the fact that several habitat areas have protected status, are managed to maintain endemic waterbirds, and/or are experiencing restoration. Additionally, lowland wetland management and conservation may be supported because of the variety of ecosystem services wetlands provide. However, future management may be challenged by shifts in water availability, which could increase competition with other water uses and affect some current management actions (e.g., water supplementation).

Upland Wetlands

Upland wetland habitats on Kauaʻi were evaluated to have *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. Climatic factors including precipitation, soil moisture, and drought alter upland wetland water availability and water table levels, which, along with air temperature, can impact vegetative productivity, community composition, and upland wetland size, persistence, and vulnerability to forest encroachment. Upland wetlands are also sensitive to increasing disease and insect risk, which can affect the health and survival of component plants and wildlife. Invasive herbivores (e.g., rats, ungulates, slugs, snails) reduce native plant cover and reproduction, and ungulates and recreation facilitate invasive plant spread and establishment, resulting in loss of native vegetation. Additionally, water diversions can reduce water availability by lowering water tables.

Currently intact and functioning habitat areas comprised of vegetation that is adapted to extreme conditions and resilient to low levels of disturbance enhance the adaptive capacity of Kauaʻi's upland wetland habitats. Additionally, upland wetlands have high management potential because they are highly valued by the public, have several constituency groups that support habitat management, and several habitat areas are located within state-protected land areas. However, Kauaʻi does not have extensive upland wetland habitat area, and the geographic isolation of these systems along with the high number of endangered, threatened, rare, and endemic species increases overall system vulnerability to climate impacts. Additionally, conservation of upland wetlands may face increasing use conflicts with recreation interests.

Adaptation Planning Results

Table 40 presents a summary of possible adaptation strategies and actions for Kauaʻi aquatic habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 40 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 40. Summary of possible adaptation strategies and actions for Kauaʻi aquatic habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Maintain/improve water quantity and quality	• Manage runoff (stormwater, wastewater, nutrients) in areas affected by human activity
	Manage invasive species	• Use fencing in critical watersheds to exclude ungulates from upland forested areas
Resilience *Near- to mid-term approach*	Maintain water availability	• Establish required stream baseflows to maintain native stream species, cultural practices, and traditional rights • Encourage use of native plants that increase filtration and use water more efficiently
	Protect forests to increase recharge and water retention	• Support healthy native forests through land acquisition and plant restoration
	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	• Modify culverts to accommodate extreme flooding • Modify stream crossings to enhance fish passage and habitat connectivity • Modify diversions to allow flow passage, particularly on high-use streams under development pressure
Response *Long-term approach*	Use assisted colonization to restore rare species	• Identify and prioritize suitable habitat based on factors that suggest long-term ecological sustainability
Knowledge *Near- to long-term approach*	Increase understanding of water quantity, quality, and allocations under changing climate conditions	• Identify, map, and quantify groundwater and surface water conditions • Improve understanding of drought impacts on water resources • Research options for water allocations under changing climate conditions
Collaboration *Near- to long-term approach*	Build adaptation and resilience in local communities through education, engagement, and outreach	• Expand access to habitat in additional areas to increase societal connection and value

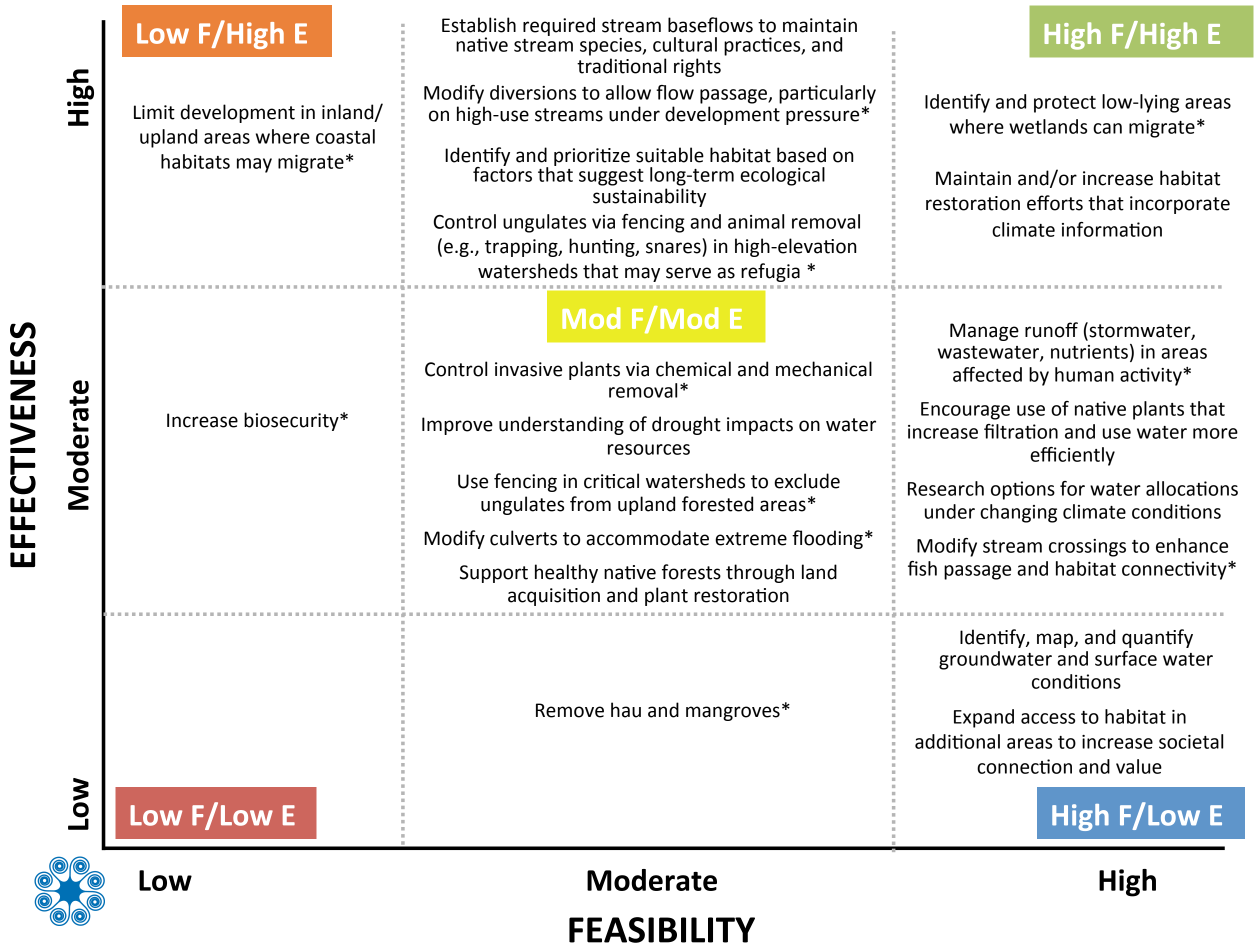

Figure 40. Kauaʻi aquatic habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Mesic and Wet Forest

Mesic and wet forests occur at mid- and high-elevation sites on Kauaʻi, spanning both the leeward and windward sides of the island between 600–1,500 m (2,000–5,000 ft). Mesic forests are found on the leeward slopes of Kauaʻi, immediately below the montane wet forests on the summit of the island. Wet forests cover the high plateau on the summit of Kauaʻi, as well as on the windward slopes. Forest structure ranges from closed high canopy cloud forests to open bogs and low-stature forests; the most significant bogs are found in the Alakaʻi Wilderness Preserve. Dominant tree species in mesic and wet forest types include ʻōhiʻa, koa, lama, ʻōlapa, lapalapa, olopua, and aʻe, with dense understories comprised of shrubs, ferns, and sedges.

Vulnerability Assessment Results

Mesic and wet forest habitats on Kauaʻi were evaluated within two separate groups: mesic forest and wet forest. Overall, mesic and wet forest habitats were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate* adaptive capacity. Mesic and wet forest habitat types are primarily sensitive to factors that alter moisture gradients and water availability, including drought, changes in precipitation amount and timing, soil moisture, and air temperature. Reduced water availability can alter species composition and forest distribution, potentially reducing habitat extent. Wildfire and storms can damage large areas of forest, resetting succession and increasing the risk of invasive species establishment. Invasive species (e.g., trees/shrubs, flammable grasses, ungulates, mammalian predators, pathogens/parasites, social insects) are a major non-climate stressor for mesic and wet forest types, altering ecosystem processes and competing directly with native species, contributing to species mortality and reduced recruitment. Direct human presence (e.g., recreational visits) and infrastructure associated with human activity (e.g., water diversions) also facilitate the introduction of invasive plants, increase erosion, and generally exacerbate existing stressors, undermining the ecological integrity and persistence of native forests.

Wet forests in the remote central areas of Kaua‘i remain relatively intact, but lower-elevation forests are more fragmented and degraded due to human activity. Native species diversity and endemism is high, and many species are able to recover rapidly from wildfire and other disturbances; however, habitat fragmentation has limited forest regeneration. Management and restoration efforts are not likely to alleviate the impacts of climate change, in part due to low public value and societal support for mesic and wet forests.

Adaptation Planning Results

Table 41 presents a summary of possible adaptation strategies and actions for Kaua‘i mesic and wet forest habitats, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 41 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 41. Summary of possible adaptation strategies and actions for Kaua‘i mesic and wet forest habitats.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Control ungulates via fencing and animal removal (e.g., trapping, hunting, snares) in high-elevation watersheds that may serve as refugia • Use biocontrol measures to reduce invasive plants that are expected to thrive under climate change
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Resilience *Near- to mid-term approach*	Maintain and augment native species populations	• Practice ex situ conservation of native species (e.g., seed banking, captive breeding) that represent genetic and habitat diversity
	Increase ecosystem resilience, connectivity, and integrity	• Restore hydrologic function (i.e. reduce/remove diversions, convert ditches to pipes)

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Response *Long-term approach*	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species) • Create test plots to determine where habitat may shift along ecotone boundaries and identify potential unintended consequences
Knowledge *Near- to long-term approach*	Conduct research on species, habitat requirements, and threats	• Increase research on diseases and pathogens • Increase research on invasive species to stay ahead of climatic impacts
	Increase capacity for mesic/wet forest restoration	• Conduct economic analyses on native forest value in light of climate change • Increase knowledge of how to propagate common and rare species
Collaboration *Near- to long-term approach*	Increase community outreach to elevate public awareness and value of mesic and wet forest habitats	• Increase K-12 education programs • Conduct community-based restoration projects in mesic/wet forest areas
	Create new/improve existing partnerships to increase capacity	• Collaborate with universities to conduct research on invasive species management • Improve data sharing within and between agencies

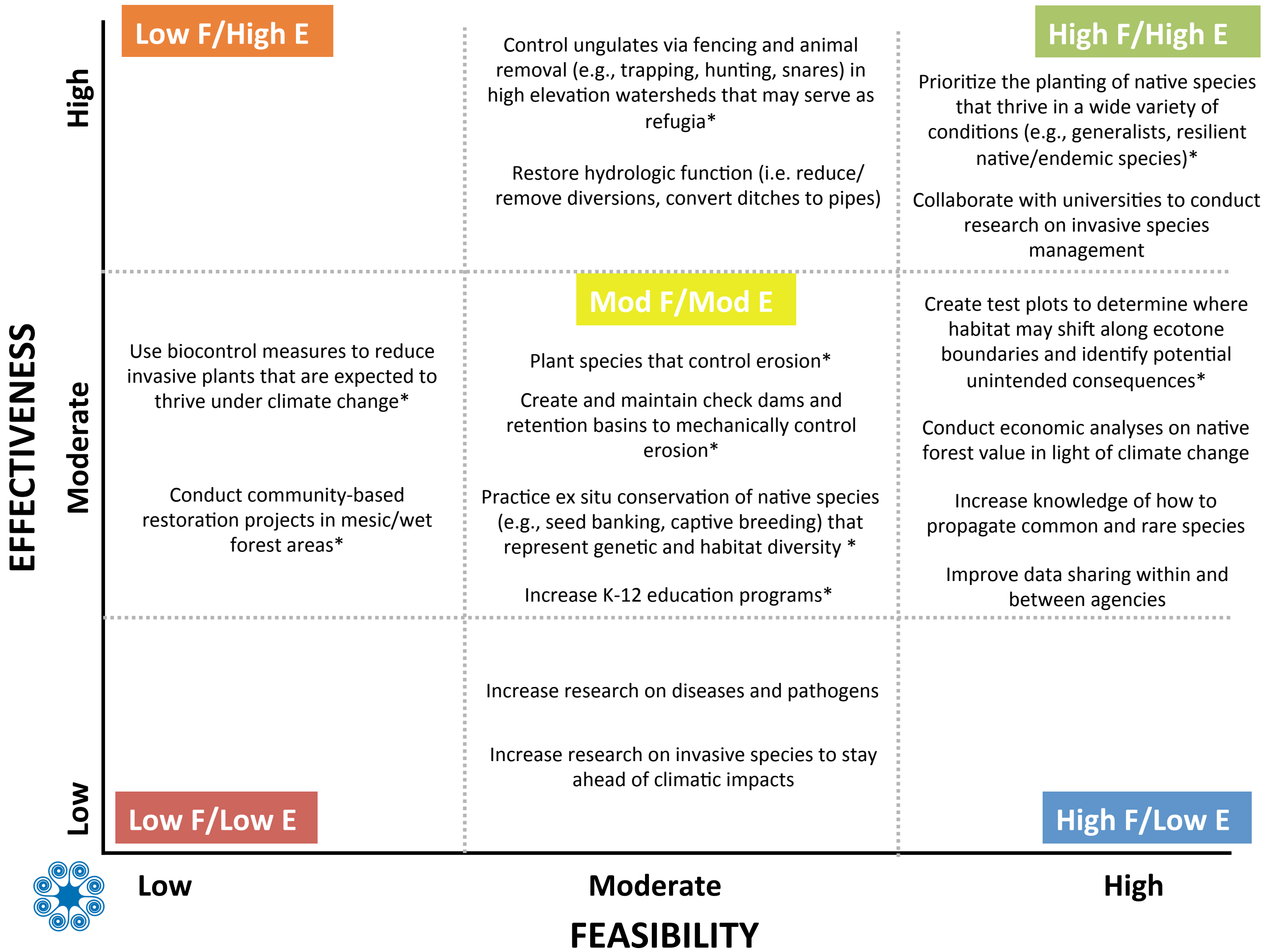

Figure 41. Kauaʻi mesic and wet forest habitat adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Cultural Knowledge and Heritage Values

Native Hawaiian cultural and heritage values are inextricably tied to the surrounding environment and ecosystem health, and this strong sense of place is maintained through stories of family and collective Hawaiian heritage, place names that hold cultural significance, and management of the ecosystems and resources. Cultural heritage includes many aspects of identity and spirituality. Native Hawaiians place great value on aloha ʻāina (love of the land), and maintain a reciprocal relationship with ecosystems, ensuring that benefits are both received from and returned to a resource.

Vulnerability Assessment Results

Cultural knowledge and heritage values on Kauaʻi were evaluated as having *moderate* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *moderate-high* exposure to projected future climate changes, and *moderate-high* adaptive capacity. This ecosystem service is vulnerable to climate changes that impact the health and integrity of ecosystems and/or native species, as well as to impacts that damage or destroy valued cultural assets and heritage sites. These changes include sea level rise, saltwater intrusion, air temperature, changes in wind and circulation patterns, and disturbance events such as wildfire, flooding, insects, and disease. Disturbance events can affect large areas and cause extensive damage or loss of living things and landscapes of cultural importance, and they can also limit access to traditional gathering areas or the ability to carry out traditional practices. Many non-climate stressors are linked to increasing human populations and associated impacts of changes in land use and the overuse of natural resources (e.g., residential and commercial development, pollution and poisons, water diversions, recreation), which have fragmented and degraded natural habitats, exacerbating the negative effects of climate change. The introduction and establishment of invasive species, including plants, wildlife, insects, fish, and pathogens/parasites, have had an especially large impact on cultural knowledge and heritage by altering ecosystem functions and driving the loss of native species and habitats.

Hawaiian cultural knowledge and heritage is valued by the public and relatively well supported by society, and natural resource managers are increasingly incorporating these values into management efforts. Although resources are likely to decline, climate change may increase the commitment to protect cultural values. However, although Hawaiian people are still affected by colonialism, some communities have been able to maintain local access to resources such as fisheries and have continued traditional practices.

Adaptation Planning Results

Table 42 presents a summary of possible adaptation strategies and actions for Kauaʻi cultural knowledge and heritage values, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 42 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 42. Summary of possible adaptation strategies and actions for Kauaʻi cultural knowledge and heritage values.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	• Identify climate-informed processes for conservation practices in vulnerable cultural sites
	Manage invasive species	• Remove invasive species in priority native ecosystems from mauka to makai
Resilience *Near- to mid-term approach*	Increase food security to build resilient cultural communities	• Use community gardens as pilot sites to test resilient crops • Use community gardens to emphasize cultural traditions (e.g., planting/harvesting by lunar calendar, becoming kilo) • Preserve cultural foods • Preserve salt making and taro production
	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes,	• Ensure cultural practitioners have ownership over what kind and detail of information is

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	traditions, and values)	shared about important cultural resources (e.g., site locations); identify what needs to be kept quiet and protected, versus what can be broadly shared • Identify where cultural sites are and how best preserve them into the future • Investigate whether iwi should be re-interred in more resilient areas or left in place
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Plan for and facilitate inland/upland habitat migration • Facilitate managed retreat of infrastructure and human communities
Knowledge *Near- to long-term approach*	Conduct research on native species, habitat requirements, and threats	• Increase research on diseases and pathogens • Research pesticide impacts on waterbird species
	Manage invasive species	• Increase research on invasive species to stay ahead of climatic impacts
	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	• Research historic conditions and trends in cultural practices (e.g., environmental baseline conditions) to inform current management
Collaboration *Near- to long-term approach*	Create dialogue between cultural practitioners and natural resource managers	• Establish and empower community-identified liaisons to help with conservation goals • Increase cultural participation in tracking environmental and climatic change (e.g., host community workshops teaching how to kilo [observe] in different sites, reinstate volunteer work days to help people reconnect to the land)
	Support linkages between cultural practitioners	• Increase cooperation and knowledge sharing between cultural communities • Use local stories about climate change impacts to encourage collaboration and on-the-ground action

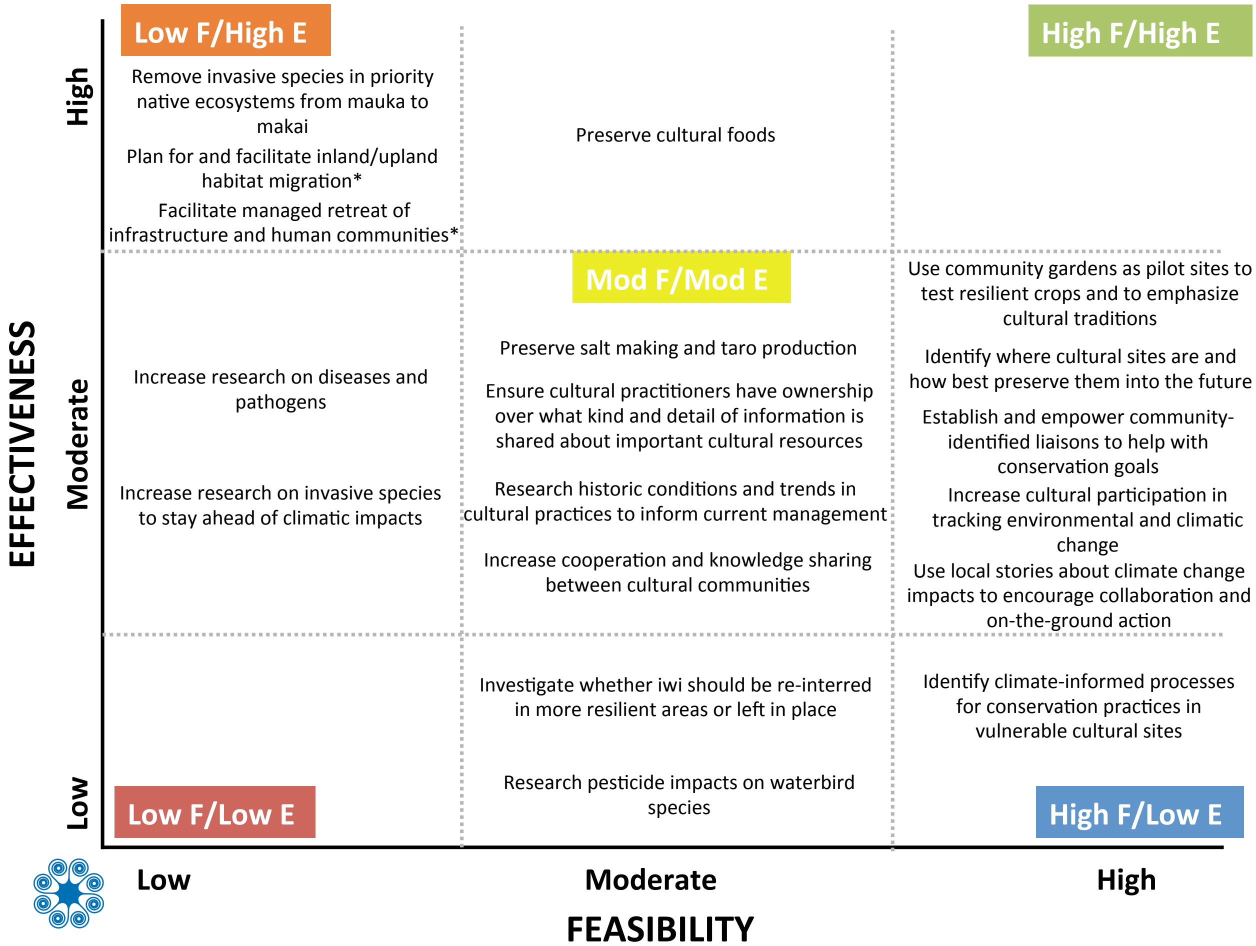

Figure 42. Kaua'i cultural knowledge and heritage values adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Flood and Erosion Control

Native terrestrial and aquatic ecosystems help regulate flooding and erosion by regulating surface and subsurface flow, storing and reducing rates of water discharge, and anchoring and retaining sediment. Vegetation and functioning habitats from mountain to sea maintain the ability of natural systems to absorb "shocks" and control coastal and riverine floods and erosion to manageable levels. For example, Kaua'i's native forests intercept rain, slow runoff, and anchor forest sediment, and wetlands help slow floodwater velocity and attenuate sediment, thereby decreasing erosion. Coastal ecosystems also help mitigate flooding and erosion by anchoring coastal sediment and altering wave dynamics.

Vulnerability Assessment Results

Flood and erosion control ecosystem services on Kaua'i were evaluated to have *moderate-high* vulnerability to climate change due to *high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors such as extreme precipitation events, sea level rise, and riverine flooding can overwhelm the natural capacity of Kaua'i's habitats and landscapes to provide this ecosystem service. Other factors such as drought, wildfire, tropical storms, and soil moisture changes affect the ability of natural systems to provide flood and erosion control by altering vegetative cover and composition, including increasing vulnerability to exotic species establishment. Non-climate stressors such as development, agriculture, roads, highways, trails, stream channelization, and invasive plants often alter sheet flow and surface runoff patterns, increasing flood volumes. These stressors, as well as invasive ungulates, recreation, and coastal armoring, can also increase erosion potential by reducing native vegetative cover and increasing bare ground. Some non-climate stressors (e.g., water diversions, groundwater withdrawals) may benefit flood control to a small degree.

Flooding and erosion management in the face of climate change is supported by watershed restoration, best management practices, collaborative watershed partnerships, and the continued protection of native terrestrial and coastal habitats. However, overall management opportunities are likely to be affected by funding, regulatory frameworks, collaborative capacity amongst public and private landowners, and societal value of this ecosystem service.

Adaptation Planning Results

Table 43 presents a summary of possible adaptation strategies and actions for Kauaʻi flood and erosion control, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 43 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 43. Summary of possible adaptation strategies and actions for Kauaʻi flood and erosion control.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Increase biosecurity
	Reduce non-climate stressors that affect water quality	• Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)
	Decrease erosion and sediment delivery to improve water quality and protect municipal water supplies	• Design and construct roads to minimize erosion and sediment production • Increase and/or relocate road cross drains to decrease hydrologic connectivity between roads and streams
Resilience *Near- to mid-term approach*	Promote technical and cultural practices to reduce stream flashiness	• Protect and restore culturally appropriate loʻi to decrease high-flow events and stream flashiness
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Maintain and restore water quality and quantity by controlling erosion and sedimentation	• Plant species that control erosion (e.g., vetiver) • Create and maintain check dams and retention basins to mechanically control erosion
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Implement living shorelines and green infrastructure
	Facilitate transition of species into new areas as climate regimes shift	• Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)
	Prepare for sea level rise impacts	• Redesign development guidelines to account for sea level rise and other climate change impacts • Plant salt- and flood-tolerant vegetation
	Provide sustainable recreation opportunities in response to changing supply and demand	• Adjust the timing of actions (e.g., open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing climate conditions
Knowledge *Near- to long-term approach*	Manage invasive species	• Increase research on invasive species to stay ahead of climatic impacts
Collaboration *Near- to long-term approach*	Reduce human pressure on native ecosystems and species	• Improve land-use planning and increase outreach on conservation-informed land uses

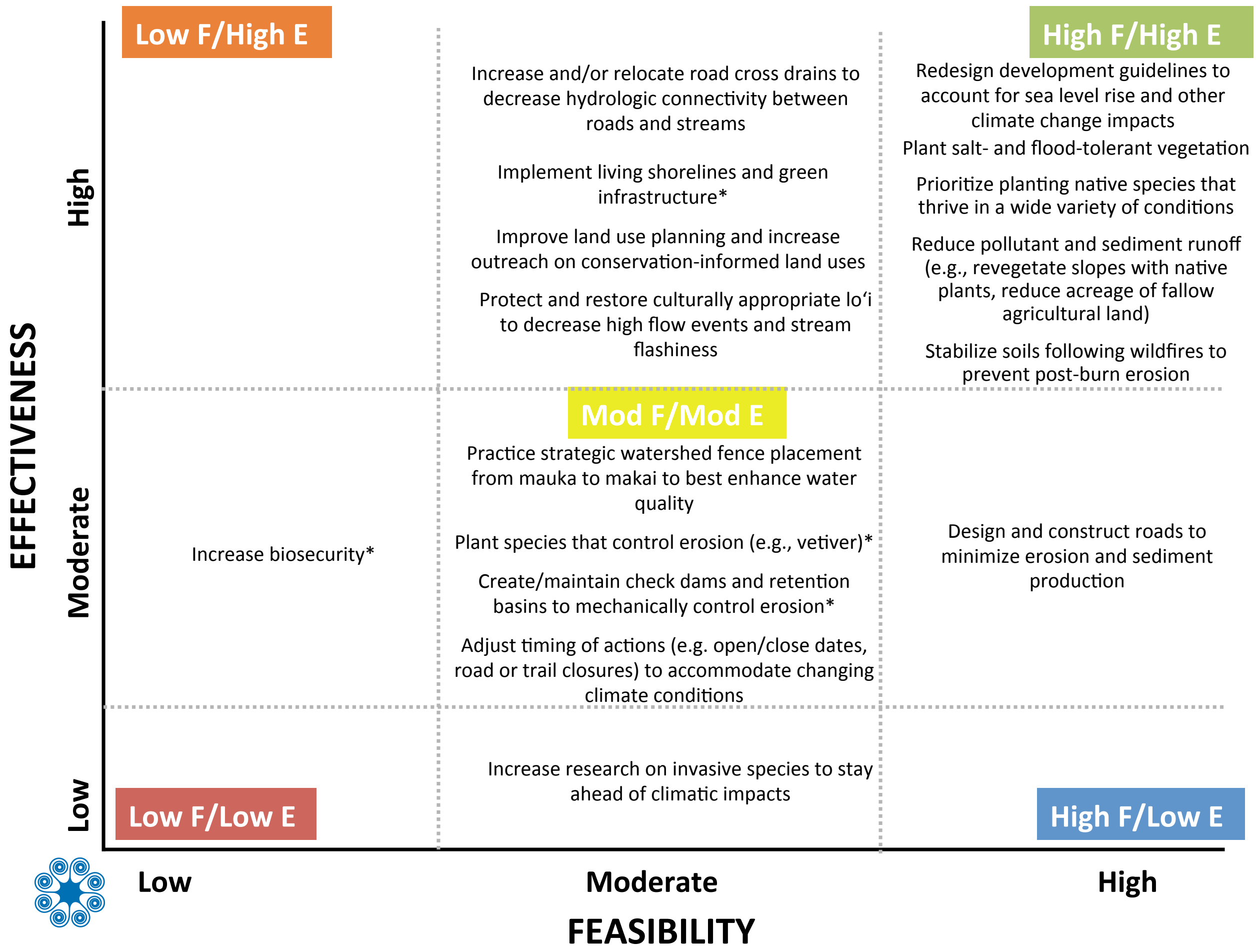

Figure 43. Kauaʻi flood and erosion control adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Fresh Water

Fresh water is classified as a provisioning ecosystem service because it supplies both consumptive (e.g., drinking water, agricultural and industrial use) and non-consumptive human uses (e.g., power generation). Fresh water also supports other natural systems and processes that provide additional ecosystem services. For example, it supports aquatic habitats, which in turn provide ecosystem services such as food production, flood control, aesthetic values, and tourism and recreation. Native forests, wetlands, and other habitats help maintain water supply by intercepting, slowing, and storing water. For example, Kauaʻi's forested mountains help intercept precipitation and slow runoff, and along with upland and lowland wetlands, help improve water quality by anchoring and filtering sediment and filtering pollutants. Kauaʻi has extensive groundwater resources that supply human uses, as well as significant surface water resources in the form of perennial and intermittent streams and freshwater wetlands that support native wildlife and agricultural irrigation.

Vulnerability Assessment Results

Fresh water on Kauaʻi was evaluated to have *moderate-high* vulnerability to climate change due to *moderate-high* sensitivity to climate and non-climate stressors, *high* exposure to projected future climate changes, and *moderate* adaptive capacity. Climatic factors including precipitation changes, drought, air temperature increases, sea level rise and trade wind changes are likely to affect future fresh water availability. Wildfire, flooding, and disease may also impact water availability and storage by affecting watershed integrity and vegetative composition. Water quality will similarly be affected by changes in watershed conditions as a result of wildfire and drought, and will also be affected by saltwater intrusion as a result of sea level rise. Non-climate stressors, including residential and commercial development, agriculture and aquaculture, energy development, water diversions, and groundwater development, alter water use and delivery, potentially compounding future climate-driven reductions in water availability. Human land uses (e.g., roads, urban areas) and activities (e.g., recreation) can also impair water quality by introducing pollution and poisons and affect water capture by increasing runoff and introducing invasive species. Invasive species undermine watershed health and integrity, reducing water storage and degrading water quality.

There are several statewide and island-based efforts focused on promoting water conservation and watershed health and function, which may help enhance the adaptive capacity of this service in the face of climate change and increasing pressure from non-climate stressors. However, society currently views fresh water as an unlimited resource.

Adaptation Planning Results

Table 44 presents a summary of possible adaptation strategies and actions for Kauaʻi fresh water, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 44 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 44. Summary of possible adaptation strategies and actions for Kauaʻi fresh water.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Manage invasive species	• Practice strategic watershed fence placement from mauka to makai to best enhance water quality • Increase biosecurity controls
	Maintain water availability	• Consider payment for ecosystem services (i.e. landowners that recharge water receive payment) • Encourage landowners to bank water and create new reservoirs
	Maintain/improve water quantity and quality	• Alter well drill depths and practice optimal well placement to minimize vulnerability to saltwater intrusion • Investigate and reduce non-point source pollution • Increase agricultural and public/private water

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
		conservation (e.g., use low-flow fixtures, detect and fix leaks, line pipes)
	Reduce non-climate stressors	• Increase public education to minimize disturbance and/or degradation of vulnerable habitats or species
Resilience *Near- to mid-term approach*	Maintain water availability	• Establish required stream baseflows to maintain native stream species • Encourage use of native plants that increase filtration and use water more efficiently • Maintain aquifers by ensuring native forest cover
	Build fire-resilient native communities	• Stabilize soils following wildfires to prevent post-burn erosion
Response *Long-term approach*	Identify and promote climate-adapted species composition	• Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions
	Maintain a resilient water supply	• Integrate climate projections into Water Commission planning efforts
Knowledge *Near- to long-term approach*	Increase understanding of water quantity, quality, and allocations under changing climate conditions	• Identify, map, and quantify groundwater and surface water conditions • Improve understanding of drought impacts on water resources • Research options for water allocations under changing climate conditions
Collaboration *Near- to long-term approach*	Increase public understanding of water cycle and how humans interact with island-wide water resources	• Create a visual, place-based method for communicating how individual locations receive water and how climate scenarios may affect future water supply and quality
	Strengthen conversations about water as a public trust	• Elevate the value of fresh water through water conservation campaigns

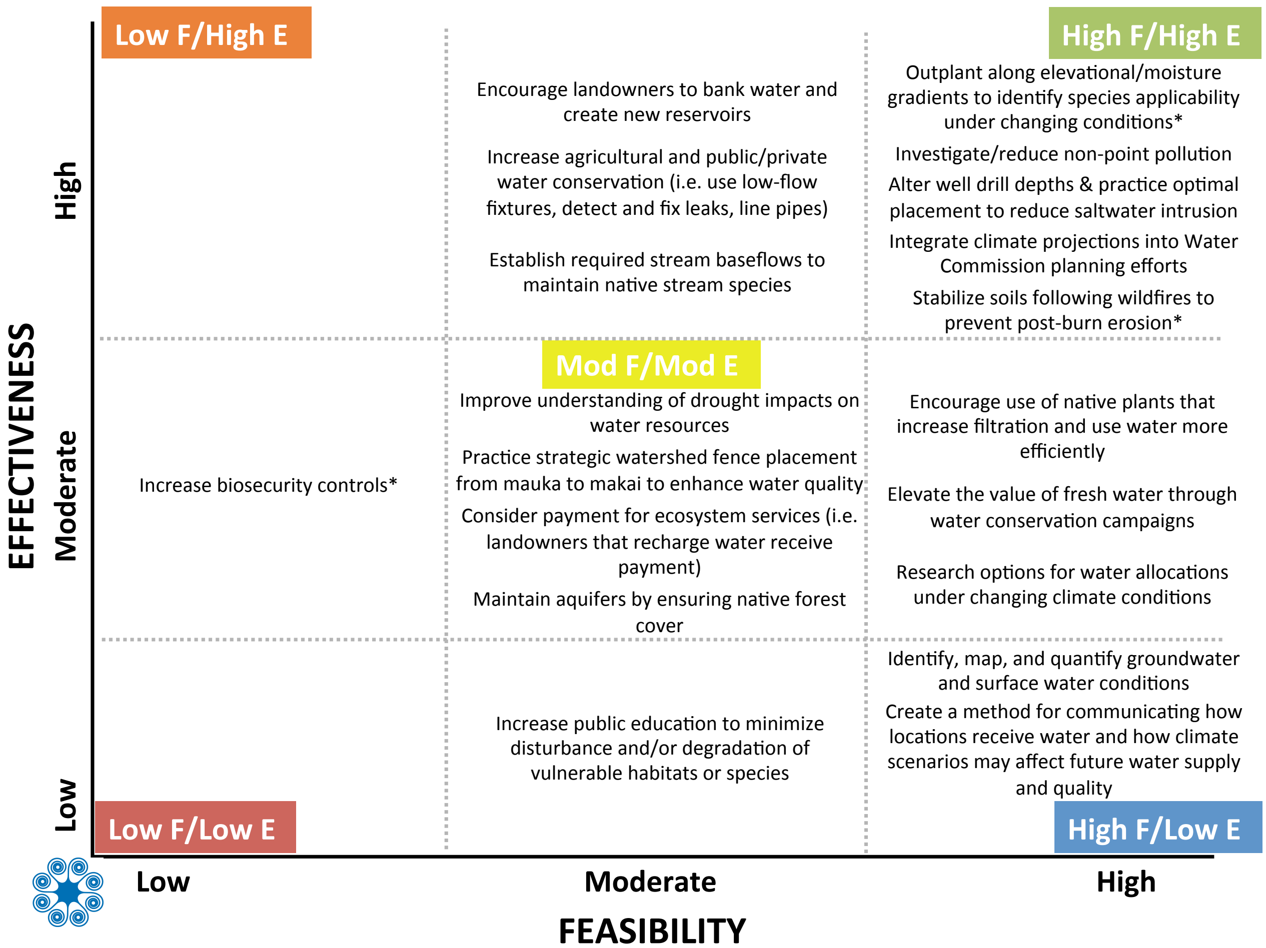

Figure 44. Kaua'i fresh water adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Food and Fiber

Food and fiber ecosystem services on Kaua'i include cultivated agriculture, hunted/gathered natural resources, biomass (i.e. green energy), and medicinal/cultural materials (e.g., noni, mamaki, kukui [candlenut tree], and cinnamon). Kaua'i supports conventional, organic, permaculture, and traditional Hawaiian agriculture, and agriculture is one of the primary economic drivers on the island. Cultivated crops currently grown on Kaua'i include tree fruits, berries, pineapple, vegetables, macadamia nut, coffee, cacao, and mahogany; livestock rearing includes chicken (for household meat and eggs), pigs, cattle, and goats (for commercial and household use).

Taro cultivation on Kaua'i is extensive compared to other Hawaiian islands, and fields in the Hanalei River Valley (including the Hanalei National Wildlife Refuge) represent 60% of the state's taro production. Natural resources utilized for food, fiber, and medicinal/cultural materials include goat, boar, deer, feral cattle, guava, banana, coconut, ornamental flowers, private/state timber, high-value wood (koa, sandalwood, teak, mahogany, mango), and cordage.

Vulnerability Assessment Results

Food and fiber on Kauaʻi were evaluated within three distinct groups: native species utilized for food and fiber (e.g., forest plants), non-native species that are not considered invasive (e.g., cultivated species such as taro), and non-native species that are considered invasive and are utilized for food/fiber. Overall food and fiber ecosystem services were evaluated as having *moderate* vulnerability to climate change due to *moderate* sensitivity to climate and non-climate stressors, *moderate* exposure to projected future climate changes, and *moderate-high* adaptive capacity.

Climate-driven changes such as increased soil temperature, changes in the amount and timing of precipitation, and UV impacts are likely to impact both cultivated crops and native species used for food and fiber on Kauaʻi. These factors may reduce water availability and quality, stress native ecosystems, and limit plant growth and vigor, especially where they interact with other stressors. Species and habitats may also be impacted by extreme events and disturbances (e.g., storms, wildfire, insects, disease, volcanic emissions) that can damage habitats and infrastructure and cause direct species injury or mortality. Non-climate stressors reduce habitat extent, introduce pollutants, and diminish surface and groundwater sources, degrading habitat quality and availability for harvestable plant and animal species. Additionally, invasive plants and wildlife alter native ecosystems harboring species harvested for food, fiber, and other materials, in many cases out-competing native species for resources or leading to the damage or decline of cultivated and/or wild plants and animals. Although food and fiber are highly valued by the public, societal support for management is relatively low, and little funding is available. Food security in the Hawaiian Islands is limited, but some efforts to restore fishponds and increase traditional taro cultivation have been successful.

Adaptation Planning Results

Table 45 presents a summary of possible adaptation strategies and actions for Kauaʻi food and fiber, and consists of stakeholder input during an adaptation workshop as well as additional options from the literature or other similar efforts. Stakeholders identified ways in which current management actions could be modified to reduce habitat vulnerabilities as well as future management actions that are not currently implemented but could be considered for future implementation. Figure 45 plots adaptation actions according to implementation feasibility (action is capable of being implemented) and effectiveness (action reduces vulnerability).

Table 45. Summary of possible adaptation strategies and actions for Kauaʻi food and fiber.

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
Resistance *Near-term approach*	Preserve water supplies by increasing water use efficiency	• Encourage landowners to bank water and create new reservoirs • Encourage use of native plants that increase filtration and use water more efficiently • Investigate alternative agricultural crops that have economic benefit and capture water • Maintain aquifers by ensuring native forest cover

Adaptation Approach	Adaptation Strategy	Specific Adaptation Actions
	Increase food security to build resilient cultural communities	• Preserve cultural foods • Preserve salt making and taro production
Resilience *Near- to mid-term approach*	Increase food security to build resilient cultural communities	• Use community gardens to emphasize cultural traditions (e.g., planting/harvesting by lunar calendar, becoming kilo) • Use community gardens as pilot sites to test resilient crops
Response *Long-term approach*	Anticipate and facilitate habitat migration	• Identify critical infrastructure that needs to be protected or relocated • Protect upland areas for mauka migration in anticipation of sea level rise
Knowledge *Near- to long-term approach*	Increase understanding of water quantity, quality, and allocations under changing climate conditions	• Identify, map, and quantify groundwater and surface water conditions • Improve understanding of drought impacts on water resources • Research options for water allocations under changing climate conditions
	Increase education and outreach to increase public engagement and stewardship in conservation	• Increase ahupuaʻa education • Increase public understanding of differences between native, non-native, and invasive species
Collaboration *Near- to long-term approach*	Manage invasive species	• Create an extension service to work with private landowners
	Increase public understanding of water cycle and how humans interact with island-wide water resources	• Create a visual, place-based method for communicating how individual locations receive water and how climate scenarios may affect future water supply and quality

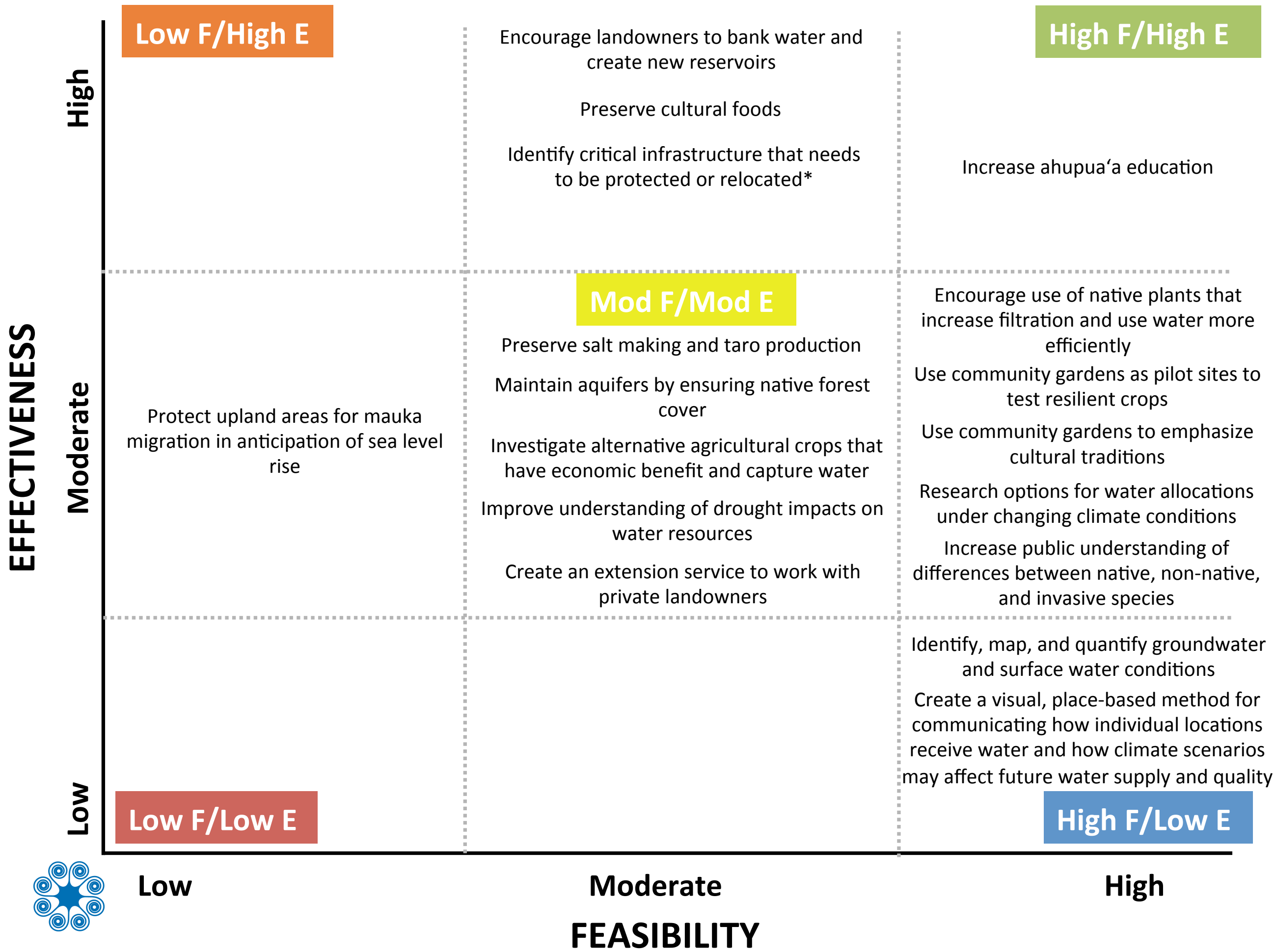

Figure 45. Kauaʻi food and fiber adaptation actions plotted according to implementation feasibility and effectiveness. Those actions having high feasibility (action capable of being implemented) and effectiveness (action reduces vulnerability) appear in the upper right corner and those actions having low feasibility and effectiveness appear in the bottom left corner. An asterisk (*) denotes adaptation actions evaluated for feasibility and effectiveness by workshop participants, although in some cases the ranking was shifted based on expert opinion. All other adaptation action evaluations are based on expert opinion.

Works Cited

Anderson TR, Fletcher CH, Barbee MM, Frazer LN, Romine BM. 2015. Doubling of coastal erosion under rising sea level by mid-century in Hawaiʻi. Natural Hazards **78**:75–103.

Atkinson CT, Utzurrum RB, Lapointe DA, Camp RJ, Crampton LH, Foster JT, Giambelluca TW. 2014. Changing climate and the altitudinal range of avian malaria in the Hawaiian Islands – an ongoing conservation crisis on the island of Kauaʻi. Global Change Biology **20**:2426–2436.

Australian Bureau of Meteorology, CSIRO. 2011. Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. Volume 2: Country Reports. Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO). Available from http://www.pacificclimatechangescience.org/publications/reports/report-climate-change-in-the-pacific-scientific-assessment-and-new-research (accessed December 28, 2016).

Banko PC, Camp RJ, Farmer C, Brinck KW, Leonard DL, Stephens RM. 2013. Response of palila and other subalpine Hawaiian forest bird species to prolonged drought and habitat degradation by feral ungulates. Biological Conservation **157**:70–77.

Bassiouni M, Oki DS. 2013. Trends and shifts in streamflow in Hawaiʻi, 1913–2008. Hydrological Processes **27**:1484–1500.

Benning TL, LaPointe D, Atkinson CT, Vitousek PM. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic information system. Proceedings of the National Academy of Sciences **99**:14246–14249.

Bopp L, Resplandy L, Orr JC, Doney SC, Dunne JP, Gehlen M, Halloran P, Heinze C, Ilyina T, Séférian R, Tjiputra J, Vichi M. 2013. Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. Biogeosciences **10**:6225–6245.

Brasher AMD. 2003. Impacts of human disturbances on biotic communities in Hawaiian streams. BioScience **53**:1052–1060.

Cai W, Borlace S, Lengaigne M, van Rensch P, Collins M, Vecchi G, Timmermann A, Santoso A, McPhaden MJ, Wu L, England MH, Wang G, Guilyardi E, Jin F. 2014. Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change **4**:111–116.

Cane, MA 2005. The evolution of El Niño, past and future. Earth and Planetary Science Letters **230**:227–240.

Cao G, Giambelluca TW, Stevens DE, Schroeder TA. 2007. Inversion variability in the Hawaiian trade wind regime. Journal of Climate **20**:1145–1160.

Casey KS, Cornillon P. 2001. Global and regional sea surface temperature trends. Journal of Climate **14**:3801–3818.

Chen YR, Chu P-S. 2014. Trends in precipitation extremes and return levels in the Hawaiian Islands under a changing climate. International Journal of Climatology **34**:3913–3925.

Chu P-S, Chen H. 2005. Interannual and interdecadal rainfall variations in the Hawaiian Islands. Journal of Climate **18**:4796–4813.

Chu P-S, Chen YR, Schroeder TA. 2010. Changes in precipitation extremes in the Hawaiian Islands in a warming climate. Journal of Climate **23**:4881–4900.

Chu P-S, Yan W, Fujioka F. 2002. Fire-climate relationships and long-lead seasonal wildfire prediction for Hawaiʻi. International Journal of Wildland Fire **11**:25–31.

Chu P-S. 2002. Large-scale circulation features associated with decadal variations of tropical cyclone activity over the Central North Pacific. Journal of Climate **15**:2678–2689.

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ. 2013. Sea level change. PM Cambridge University Press.

Cooper HM, Chen Q, Fletcher CH, Barbee MM. 2013. Assessing vulnerability due to sea-level rise in Maui, Hawaiʻi using LiDAR remote sensing and GIS. Climatic Change **116**:547–563.

Cordell S, Sandquist DR. 2008. The impact of an invasive African bunchgrass (*Pennisetum setaceum*) on water availability and productivity of canopy trees within a tropical dry forest in Hawaiʻi. Functional Ecology **22**:1008–1017.

D'Aleo J, Easterbrook D. 2010. Multidecadal tendencies in ENSO and global temperatures related to multidecadal oscillations. Energy & Environment **21**:437–460.

de Silva SC. 2012. High altitude climate of the island of Hawaiʻi. Master of Science. University of Hawaiʻi at Mānoa.

Diaz HF, Giambelluca TW, Eischeid JK. 2011. Changes in the vertical profiles of mean temperature and humidity in the Hawaiian Islands. Global and Planetary Change **77**:21–25.

Diaz HF, Wahl ER, Zorita E, Giambelluca TW, Eischeid JK. 2016. A Five-Century Reconstruction of Hawaiian Islands Winter Rainfall. Journal of Climate **29**(15): 5661-5674

Dolling K, Chu P-S, Fujioka F. 2005. A climatological study of the Keetch/Byram drought index and fire activity in the Hawaiian Islands. Agricultural and Forest Meteorology **133**:17–27.

Dolling K, Chu P-S, Fujioka F. 2009. Natural variability of the Keetch–Byram Drought Index in the Hawaiian Islands. International Journal of Wildland Fire **18**:459–475.

Dore JE, Lukas R, Sadler DW, Church MJ, Karl DM. 2009. Physical and biogeochemical modulation of ocean acidification in the central North Pacific. Proceedings of the National Academy of Sciences **106**:12235–12240.

EcoAdapt. 2014a. A Climate Change Vulnerability Assessment for Aquatic Resources in the Tongass National Forest. EcoAdapt, Bainbridge Island, WA. 124 pp.

EcoAdapt. 2014b. A Climate Change Vulnerability Assessment for Resources of Nez Perce-Clearwater National Forests. Version 3.0. EcoAdapt, Bainbridge Island, WA. 398 pp.

EcoAdapt. 2016. Decision Support Tools for Natural Resource Managers: Vulnerability-Adaptation Tables. http://ecoadapt.org/programs/adaptation-consultations/decsuptools

EcoAdapt. 2017. Southern California Climate Adaptation Project: Habitat Adaptation Summaries and Syntheses. http://ecoadapt.org/programs/adaptation-consultations/socal-asproducts

Elison Timm O, Diaz HF, Giambelluca TW, Takahashi M. 2011. Projection of changes in the frequency of heavy rain events over Hawaiʻi based on leading Pacific climate modes. Journal of Geophysical Research: Atmospheres **116**:D04109.

Elison Timm O, Giambelluca TW, Diaz HF. 2015. Statistical downscaling of rainfall changes in Hawaiʻi based on the CMIP5 global model projections. Journal of Geophysical Research: Atmospheres **120**:2014JD022059.

Elison Timm O, Takahashi M, Giambelluca TW, Diaz HF. 2013. On the relation between large-scale circulation pattern and heavy rain events over the Hawaiian Islands: Recent trends and future changes. Journal of Geophysical Research: Atmospheres **118**:4129–4141.

England MH, McGregor S, Spence P, Meehl GA, Timmermann A, Cai W, Gupta AS, McPhaden MJ, Purich A, Santoso A. 2014. Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus. Nature Climate Change **4**:222–227.

Eversole D, Andrews A. 2014. Climate change impacts in Hawaiʻi: A summary of climate change and its impacts to Hawaiʻi's ecosystems and communities. UNIHI-SEAGRANT-TT-12-04. University of Hawaiʻi at Mānoa Sea Grant College Program.

Ferguson G, Gleeson T. 2012. Vulnerability of coastal aquifers to groundwater use and climate change. Nature Climate Change **2**:342–345.
Firing YL, Merrifield MA. 2004. Extreme sea level events at Hawaiʻi: Influence of mesoscale eddies. Geophysical Research Letters **31**:L24306.
Fortini L, Price J, Jacobi J, Vorsino A, Burgett J, Brinck KW, Amidon F, Miller S, Gon III S, Koob G, Paxton E. 2013. A landscape-based assessment of climate change vulnerability for all native Hawaiian plants. Technical Report HCSU-044. Hawaiʻi Cooperative Studies Unit, University of Hawaiʻi at Hilo. Available from https://dspace.lib.hawaii.edu/bitstream/10790/2620/1/TR44_Fortini_plant_vulnerability_assessment.pdf.
Fortini LB, Vorsino AE, Amidon FA, Paxton EH, Jacobi JD. 2015. Large-scale range collapse of Hawaiian forest birds under climate change and the need for 21st century conservation options. PLoS ONE **10**:e0140389.
Frazier AG, Giambelluca TW, Diaz HF, Needham HL. 2016. Comparison of geostatistical approaches to spatially interpolate month-year rainfall for the Hawaiian Islands. International Journal of Climatology **36**:1459–1470.
Frazier AG, Giambelluca TW. 2017. Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. International Journal of Climatology **37**:2522–2531.
Garza JA, Chu P-S, Norton CW, Schroeder TA. 2012. Changes of the prevailing trade winds over the islands of Hawaiʻi and the North Pacific. Journal of Geophysical Research: Atmospheres **117**:D11109.
Gattuso J-P, Magnan A, Bille R, Cheung WWL, Howes EL, Joos F, Allemand D, Bopp L, Cooley SR, Eakin CM, Hoegh-Guldberg O, Kelly RP, Portner H-O, Rogers AD, Baxter JM, Laffoley D, Osborn D, Rankovic A, Rochette J, Sumaila UR, Treyer S, Turley C. 2015. Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. Science **349**:aac4722.
Gehrke PC, Sheaves MJ, Boseto D, Figa BS, Wani J. 2011. Chapter 10: Vulnerability of freshwater and estuarine fisheries in the tropical Pacific to climate change. Page in JD Bell, JE Johnson, and AJ Hobday, editors. Vulnerability of tropical pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, New Caledonia.
Giambelluca TW, Diaz HF, Luke MSA. 2008. Secular temperature changes in Hawaiʻi. Geophysical Research Letters **35**:L12702.
Gingerich SB, Engott JA. 2012. Groundwater availability in the Lahaina District, west Maui, Hawaiʻi. Page 90. Scientific Investigations Report 2012–5010. U.S. Geological Survey. Available from http://pubs.usgs.gov/sir/2012/5010
Glick P, Stein B, Edelson N. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Washington, D.C.: National Wildlife Federation.
Gregg RM, Feifel KM, Kershner JM, Hitt JL. 2012. The State of Climate Change Adaptation in the Great Lakes Region. EcoAdapt, Bainbridge Island, WA.
Gregg RM, Hansen LJ, Feifel KM, Hitt JL, Kershner JM, Score A, Hoffman JR. 2011. The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas. EcoAdapt, Bainbridge Island, WA.
Gregg RM, Reynier W, Score A, Hilberg L. 2017. The State of Climate Adaptation in Water Resources Management: Southeastern United States and U.S. Caribbean. EcoAdapt, Bainbridge Island, WA.
Gregg RM, Score A, Pietri D, Hansen L. 2016. The State of Climate Adaptation in U.S. Marine Fisheries Management. EcoAdapt, Bainbridge Island, WA.

Hamilton K. 2013. High resolution dynamical projections of climate change for Hawaiʻi and other Pacific islands. University of Hawaiʻi, Honolulu, HI. Available from https://www.sciencebase.gov/catalog/item/54b82e9ee4b03ff52703c95e.

Hotchkiss S. 2014. Predicting future distribution of cloud forest and high-elevation species in Hawaiʻi: integrating modern and paleoecological data to plan for climate change. University of Wisconsin-Madison.

Hutto SV, Higgason KD, Kershner JM, Reynier WA, Gregg DS. 2015. Climate Change Vulnerability Assessment for the North-central California Coast and Ocean. Marine Sanctuaries Conservation Series ONMS-15-02. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 473 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson (Eds.), pp. 617-652. Cambridge, U.K.: Cambridge University Press.

IPCC. 2013. Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kane HH, Fletcher CH, Frazer LN, Anderson TR, Barbee MM. 2015. Modeling sea-level rise vulnerability of coastal environments using ranked management concerns. Climatic Change **131**:349–361.

Keener VW, Hamilton K, Izuka SK, Kunkel KE, Stevens LE, Sun L. 2013. Regional climate trends and scenarios for the U.S. National Climate Assessment: Part 8. Climate of the Pacific Islands. NOAA Technical Report NESDIS 142-8. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Washington, D.C.

Keener VW, Marra JJ, Finucane ML, Spooner D, Smith MH. 2012. Climate change and Pacific Islands: Indicators and impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA). Island Press, Washington, D.C. Available from www.EastWestCenter.org/PIRCA.

Kershner JM, editor. 2014. A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada. Version 1.0. EcoAdapt, Bainbridge Island, WA. 418 pp.

Kershner JM, Pokallus J, Reynier W, Gregg RM. 2015. Climate Change Adaptation Strategies for Resources of the Nez Perce-Clearwater National Forests. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Kolivras KN. 2010. Changes in dengue risk potential in Hawaiʻi, USA, due to climate variability and change. Climate Research **42**:1–11.

Kopp RE, Horton RM, Little CM, Mitrovica JX, Oppenheimer M, Rasmussen DJ, Strauss BH, Tebaldi C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future **2**:2014EF000239.

Krushelnycky PD, Loope LL, Giambelluca TW, Starr F, Starr K, Drake DR, Taylor AD, Robichaux RH. 2012. Climate-associated population declines reverse recovery and threaten future of an iconic high-elevation plant. Global Change Biology **19**:911–922.

Lauer A, Zhang C, Elison Timm O, Wang Y, Hamilton K. 2013. Downscaling of climate change in the Hawaiʻi region using CMIP5 results: On the choice of the forcing fields. Journal of Climate **26**:10006–10030.

Lawler J. 2010. Pacific Northwest Climate Change Vulnerability Assessment. From http://climatechangesensitivity.org

Longman RJ, Diaz HF, Giambelluca TW. 2015. Sustained increases in lower-tropospheric subsidence over the central tropical North Pacific drive a decline in high-elevation rainfall in Hawaiʻi. Journal of Climate **28**:8743–8759.

Longman RJ. 2015. The effects of trade wind inversion variability on high elevation climates in Hawaiʻi. University of Hawaiʻi at Mānoa. Available from http://gradworks.umi.com/37/17/3717196.html (accessed April 4, 2016).

Longman RJ. 2015. The effects of trade wind inversion variability on high elevation climates in Hawaiʻi. Ph.D. dissertation, Department of Geography, University of Hawaiʻi at Mānoa, Honolulu, HI, 192 pp.

MacKenzie R, Giardina CP, Povak N, Hessburg P, Reynolds KM, Heider C, Salminen E, Kimball H. 2014. Development of a decision support tool for watershed management in the tropics. Institute of Pacific Islands Forestry, USDA Forest Service.

MacKenzie RA, Wiegner TN, Kinslow F, Cormier N, Strauch AM. 2013. Leaf-litter inputs from an invasive nitrogen-fixing tree influence organic-matter dynamics and nitrogen inputs in a Hawaiian river. Freshwater Science **32**:1036–1052.

Manomet Center for Conservation Sciences and National Wildlife Federation. 2012. The Vulnerabilities of Fish and Wildlife Habitats in the Northeast to Climate Change. A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative: Manomet: Manomet Center for Conservation Sciences.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC. http://www.millenniumassessment.org/documents/document.356.aspx.pdf

Moss R, Schneider S. 2000. Towards Consistent Assessment and Reporting of Uncertainties in the IPCC TAR. In R Pachauri, T Taniguchi (Eds.), Cross-Cutting Issues in the IPCC Third Assessment Report. Tokyo: Global Industrial and Social Progress Research Institute (for IPCC).

Murakami H, Wang B, Li T, Kitoh A. 2013. Projected increase in tropical cyclones near Hawaiʻi. Nature Climate Change **3**:749–754.

National Research Council (NRC). 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Committee on the Development of an Integrated Strategy for Ocean Acidification Monitoring, Research and Impacts Assessment, National Academies Press, Washington, D.C.

National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI). 2016a. Climate at a Glance: Global Time Series. Accessed December 2016, http://www.ncdc.noaa.gov/cag/

NOAA NCEI. 2016b. Extended reconstructed sea surface temperature (ERSST.v4). Accessed November 2016. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst

NOAA/National Ocean Service. 2017. NOAA Tides and Currents: Sea Level Trends. Available from http://tidesandcurrents.noaa.gov/sltrends/sltrends.html (accessed July 13, 2017).

Oki DS, Rosa SN, Yeung CW. 2010. Flood-frequency estimates for streams on Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi, State of Hawaiʻi. U.S. Geological Survey Scientific Investigations Report 2010–5035. U.S. Geological Survey. Available from http://pubs.usgs.gov/sir/2010/5035/ (accessed November 11, 2016).

Oki DS. 2004. Trends in streamflow characteristics at long-term gaging stations, Hawaiʻi. Page 120. 2004-5080, Scientific Investigations Report. U.S. Geological Survey.

Perkins KS, Nimmo JR, Medeiros AC, Szutu DJ, von Allmen E. 2014. Assessing effects of native forest restoration on soil moisture dynamics and potential aquifer recharge, Auwahi, Maui. Ecohydrology **7**:1437–1451.

Romine BM, Fletcher CH. 2012. A summary of historical shoreline changes on beaches of Kaua'i, O'ahu, and Maui, Hawai'i. Journal of Coastal Research **29**(3):605–614.

Rotzoll K, Fletcher CH. 2013. Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change **3**:477–481.

Rotzoll K, Oki DS, El-Kadi AI. 2010. Changes of freshwater-lens thickness in basaltic island aquifers overlain by thick coastal sediments. Hydrogeology Journal **18**:1425–1436.

Safeeq M, Fares A. 2012. Hydrologic response of a Hawaiian watershed to future climate change scenarios. Hydrological Processes **26**:2745–2764.

Schörghofer N, Kantar E, Nogelmeier MP. 2014. Snow on the summits of Hawai'i island: Historical sources from 1778 to 1870. The Hawaiian Journal of History **48**:89–113.

Score A, Gregg RM, Reynier W, Hilberg L, Paulin J, Hutto S, Marzin C, Tagarino KA. 2017. Rapid Vulnerability Assessment and Adaptation Strategies for the National Marine Sanctuary and Territory of American Samoa. EcoAdapt, Bainbridge Island, WA.

Storlazzi CD, Shope JB, Erikson LH, Hegermiller CA, Barnard PL. 2015. Future wave and wind projections for United States and United-States-affiliated Pacific Islands. Page 455. USGS Numbered Series Open-File Report 2015-1001, Open-File Report. U.S. Geological Survey, Reston, VA. Available from http://pubs.er.usgs.gov/publication/ofr20151001 (accessed May 24, 2016).

Strauch AM, MacKenzie RA, Giardina CP, Bruland GL. 2015. Climate driven changes to rainfall and streamflow patterns in a model tropical island hydrological system. Journal of Hydrology **523**:160–169.

Sweet WV, Kopp RE, Weaver CP, Obeysekera J, Horton RM, Thieler ER, Zervas C. 2017. Global and regional sea level rise scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Takahashi M, Elison Timm O, Giambelluca TW, Diaz HF, Frazier AG. 2011. High and low rainfall events in Hawai'i in relation to large-scale climate anomalies in the Pacific: Diagnostics and future projections. American Geophysical Union, Fall Meeting 2011, Abstract #GC51D-1024 51. Available from http://adsabs.harvard.edu/abs/2011AGUFMGC51D1024T (accessed June 2, 2016).

Trauernicht C, Pickett E, Giardina CP, Litton CM, Cordell S, Beavers A. 2015. The contemporary scale and context of wildfire in Hawai'i. Pacific Science **69**:427–444.

Vermeer M, Rahmstorf S. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences **106**:21527–21532.

Vorsino AE, Fortini LB, Amidon FA, Miller SE, Jacobi JD, Price JP, Gon S 'Ohukani'ohi'a III, Koob GA. 2014. Modeling Hawaiian ecosystem degradation due to invasive plants under current and future climates. PLoS ONE **9**:e95427.

Wada C, Bremer L, Burnett K, Trauernicht C, Giambelluca T, Mandle L, Parsons E, Weil C, Kurashima N, Ticktin T. 2017. Estimating the cost-effectiveness of Hawaiian dry forest restoration using spatial changes in water yield and landscape flammability under climate change. Pacific Science 71. In press.

Wentworth CK. 1949. Directional shift of trade winds at Honolulu. Available from https://scholarspace.manoa.hawaii.edu/handle/10125/8917 (accessed March 24, 2017).

Xie S-P, Deser C, Vecchi GA, Ma J, Teng H, Wittenberg AT. 2010. Global warming pattern formation: Sea surface temperature and rainfall. Journal of Climate **23**:966–986.

Zhang C, Hamilton K, Wang Y. 2017. Monitoring and projecting snow on Hawaiʻi Island. Earth's Future **5**:436–448.

Zhang C, Wang Y, Hamilton K, Lauer A. 2016. Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late twenty-first century. Journal of Climate **29**:8333–8354.

Appendix A. Observed and Projected Climate Changes for the Main Hawaiian Islands.

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
Air temperature	↑	**All Islands** • From 1975–2006, the rate of temperature increases accelerated to 0.2°C (0.36°F) per decade, compared to overall increases of 0.04°C (0.07°F) per decade for all records from 1919–2006 (Giambelluca et al. 2008). • Since 1975, higher-elevation sites (>800 m [>2,625 ft]) warmed faster (0.27°C [0.49°F] per decade) than low-elevation sites (0.09°C [0.16°F] per decade); the largest increases were in winter low temperatures (Giambelluca et al. 2008). **Maui** • The annual number of freezing days on Haleakalā declined from 1958–2009 (Hamilton 2013). **Hawaiʻi** • From 1958–2009, decline from ~4-5 freezing days/year to ~1 day/year (Diaz et al. 2011). • From 1958–2008, temperatures on the summit of Mauna Loa increased by 1.5°C (2.7°F) per decade; no significant trends were detected at the summit of Mauna Kea (de Silva 2012).	**All Islands** • By 2080–2099, increase of 2°C to 3.5°C (3.6°F to 6.3°F) in mean annual temperature, with more significant increases at higher elevations (Zhang et al. 2016). • Extreme heat days are expected to become more frequent and more intense (Keener et al. 2012). **Hawaiʻi** • Increase in the mean freezing level height of 600–700 m (1,969–2,296 ft; Zhang et al. 2017).	Overall confidence: **High** • High certainty that temperatures will increase • The amount of increase is somewhat uncertain because global climate models have a wide range of possibilities for this region, and the amount of increase expected changes depending on which emissions scenario is used.

Precipitation (amount and timing)	↑↓	**All Islands**
		• Since 1920, precipitation has decreased across the Hawaiian Islands, with the strongest drying trends occurring over the last 30 years (Frazier et al. 2016; Frazier & Giambelluca 2017).
		• La Niña events have historically been correlated with higher precipitation while El Niño events have been correlated with lower precipitation, and correlations have been magnified by changes in the PDO phase; however, in the last decade there has been a decoupling of these modes and
			Multiple possibilities for future precipitation trends exist, and differ in direction and magnitude of change. These include:
			Maui
			• Little to no change in precipitation by 2071–2099 (Keener et al. 2013)
			• Moderate to large declines in precipitation (Elison Timm et al. 2015):
			  ○ By 2041–2071: 16 to 18% (wet season), 24% to 32% (dry season)
			  ○ By 2071–2099: 17% to 25% (wet season),
				Overall confidence: **Low**
				
				• Precipitation is highly variable depending on location.
				• Studies have made very different projections, disagreeing on both the direction and magnitude of change (e.g., whether precipitation will increase or

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		precipitation patterns (Chu & Chen 2005). • A general drying trend in winter precipitation over the last 160 years (Diaz et al. 2016). **Maui** • From 1920 to 2012, dry season (May–Oct.) precipitation declined 1% to 5% per decade for most areas on Maui and Lānaʻi, particularly in leeward areas; Kahoʻolawe experienced more modest declines of up to 1.2% per decade; annual precipitation increased 0.28% (0.12 in [3.0 mm]) per decade on Molokaʻi (Frazier & Giambelluca 2017). • From 1920–2012, Maui experienced the most significant wet season (Nov.–April) precipitation declines of any island in the state, decreasing 27.6 mm (1.08 in) per decade, which ranged from 2% to 5% per decade in East Maui (Frazier & Giambelluca 2017). • The frequency of trade wind inversion (TWI) occurrence increased an average of 20% since 1990, resulting in a 31% reduction in wet-season rainfall and a 16% reduction in dry-season rainfall at nine high-elevation sites on Maui (over 1,900 m [6,234 ft]; Longman et al. 2015). **Kauaʻi** • From 1920 to 2012, dry season (May–Oct.) precipitation on Kaua'i declined an average of 1.05% per decade across the island with the largest declines at high elevations (Frazier & Giambelluca 2017). • From 1920–2012, wet-season (Nov.–April) precipitation on Kauaʻi declined an average of 0.94% per decade across the island with the largest declines at high elevations and on the windward side (as much as 4%; Frazier &	29% to 46% (dry season) • Increased rainfall on windward slopes of Maui (up to 30% in the dry season), and decreased rainfall on Lānaʻi and leeward slopes of Maui in both seasons by 2100 (Zhang et al. 2016). **Kauaʻi** • No change to moderate decrease in precipitation by 2071–2099 (Keener et al. 2013) • Moderate declines in precipitation (Elison Timm et al. 2015): ○ By 2041–2071: 23 to 26% (wet season), 2 to 4% (dry season) ○ By 2071–2099: 26 to 41% (wet season), 3 to 6% (dry season) • Increase in precipitation at high elevations (up to 20%) and slight decrease in precipitation at low elevations in the dry season; slight increase at high elevations and slight decrease at low elevations in the wet season (Zhang et al. 2016). **Oʻahu** • Slight decrease or no change in precipitation by 2071–2099 (Keener et al. 2013) • Moderate declines in precipitation (Elison Timm et al. 2015): ○ By 2041–2071: 14 to 16% (wet season), 14% to 18% (dry season) ○ By 2071–2099: 16% to 22% (wet season), 16% to 28% (dry season) • Slight increases in windward precipitation in the dry season (up to 20%) and slight to moderate decreases in wet-season windward precipitation and leeward precipitation in both	decrease, and by how much). • Factors such as the emissions scenario and climate models chosen, study methodology, geographic region included, and data resolution all contribute to differences in precipitation projections. • Not all models consider large-scale climate variability (e.g., El Niño) and possible changes in the trade winds. • Models with low resolution may not account for steep island topography.

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		Giambelluca 2017). **O'ahu** • From 1920 to 2012, dry-season (May–Oct.) precipitation on O'ahu declined an average of 0.8% per decade across the island. Declines were greatest at high elevations (as much as 4%); some areas on the leeward coast had very slight increases (up to 1%; Frazier & Giambelluca 2017). • From 1920 to 2012, wet-season (Nov.–April) precipitation on O'ahu declined an average of 1.68% per decade across the island, with the largest declines at moderate and high elevations, especially on the leeward side (Frazier & Giambelluca 2017). **Hawai'i** • From 1920 to 2012, dry-season (May–Oct.) precipitation declined an average of 3.19% per decade across the island; declines were greatest on the leeward side, and declines were at least 6% per decade for most of the Kona region (Frazier & Giambelluca 2017). • From 1920–2012, wet-season (Nov.–April) precipitation on Hawai'i declined an average of 1.64% per decade across the island, with the largest declines on the leeward side, especially in the Kona region (Frazier & Giambelluca 2017). • Since 1997 on Mauna Kea, dry years (annual rainfall lower than usual) were two times more common than wet years, and monthly rainfall was lower than normal in 65% of months at Pu'u Lā'au and 71% of months at Halepōhaku (Banko et al. 2013). • From 1958–2008, precipitation on the summit of Mauna Loa declined by 34.5 mm (1.36 in) per decade; no significant trends were detected at	seasons (Zhang et al. 2016). **Hawai'i** • Slight increase or no change in precipitation by 2071–2099 (Keener et al. 2013) • Declines in precipitation by 2071–2099 (Elison Timm et al. 2015): ○ By 2041–2071: 4 to 6% (wet season), 13 to 18% (dry season) ○ By 2071–2099: 4 to 6% (wet season), 16 to 28% (dry season) • Large increase in dry-season windward precipitation (up to 40%) and moderate increase in wet-season windward precipitation (up to 20%) by 2100; decreased leeward precipitation in both seasons (as much as 40%; Zhang et al. 2016). • Tenfold reduction in mean annual snowfall, resulting in a near-disappearance of snow on the summit of Mauna Kea (Zhang et al. 2017).	

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		the summit of Mauna Kea (de Silva 2012). • In the 1700–1800s, snow on Mauna Kea was far more common in both winter and summer than it is today (Schörghofer et al. 2014).		
Extreme precipitation events and tropical storms/hurricanes	↑↓	**All Islands** *Extreme precipitation events* (Chu et al. 2010) • Decreased frequency of moderate- and high-intensity extreme events and increased frequency of low-intensity events in 1980–2007 (compared to 1950–1979) • Trends are likely caused by natural variability associated with El Niño/La Niña events *Tropical storms* (Chu 2002) • 1966–1981: Relatively low activity (mean of 1.88 storms/year) • 1982–1994: Increase of 3.45 storms/year compared to 1966–1981 (mean of 4.31 storms/year) • 1995–2000: Decrease of 2.22 storms/year compared to 1982–1994 **Maui** *Extreme precipitation events* • Since 1950, overall trend towards decreased intensity and frequency of extreme events (Chu et al. 2010) • In recent years this trend appears to be reversing direction, with more frequent extreme events occurring except on Lāna‘i, where the frequency of extreme events has continued to decline (Chu et al. 2010) • From 1960–2009, annual maximum one-day precipitation volume decreased (Chen & Chu 2014) **Kaua‘i**	**All Islands** *Extreme precipitation events* Multiple possibilities differ in direction and magnitude of change: • Reduced frequency of extreme precipitation events by 2100, with greater reductions in dry areas (Elison Timm et al. 2011, 2013) • Little change in the frequency of extreme precipitation events (Takahashi et al. 2011) • Significant increase in extreme precipitation events by 2100 (Zhang et al. 2016) *El Niño events (by 2090; Cai et al. 2014)* • Slight decrease in the number of El Niño events (compared to 1891–1990) • Extreme El Niño events twice as likely to occur (from one event every 20 years to one event every 10 years) • No change in spatial pattern of El Niño events *Tropical storms* • Increased frequency and strength of tropical storm activity around the Hawaiian Islands due to a northwest shift in storm track and increased strength because of large-scale changes in environmental conditions (Murakami et al. 2013)	Overall confidence: **Low** • Climate models disagree about whether extreme events will become more or less frequent/severe • Changes may vary by location and the type of event (e.g., tropical cyclone, El Niño event, etc.) • Changes in the frequency/severity of extreme events are heavily impacted by topography, and will likely be impacted by changes in the trade winds • The frequency and severity of extreme precipitation events and tropical storms are highly variable, and are influenced strongly by natural climate variability (e.g., cycles of ENSO and PDO)

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		Extreme precipitation events (from 1950–2007; Chu et al. 2010): • Slight decrease in the intensity and magnitude of extreme events and significant decrease in the frequency of extreme events on the wet northern coast • No change in the intensity, magnitude, or frequency of extreme events on the dry western coast (no information on central Kaua'i) **O'ahu** *Extreme precipitation events* • Since 1950, intensity and frequency of extreme events has decreased in recent years (Chu et al. 2010). This trend may be reversing direction with more frequent extreme precipitation events occurring in recent years (Chu et al. 2010). • From 1960–2009, annual maximum one-day precipitation volume decreased (Chen & Chu 2014). **Hawai'i** *Extreme precipitation events* (from 1950-2007; Chu et al. 2010): • Increased intensity of extreme events in wet regions and on the summit of Mauna Loa, decreased intensity around Kona and the southeastern area of the island (increased intensity when averaged across all stations) • From 1960–2009 (Chen & Chu 2014): ○ Increased annual maximum one-day precipitation volume ○ Increased frequency in extreme precipitation events, especially during La Niña years ○ A 20-year storm in 1960 (300 mm precipitation) became a 3-5-year storm by 2009		

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
Wind and circulation	↑↓	**Pacific Ocean** *Trade wind strength/velocity/direction* • Since the 1990s, the Pacific trade winds (both the Walker and Hadley cells) have increased, corresponding with a negative PDO phase (England et al. 2014) • Increased winds are driving an acceleration of shallow overturning cells, which causes subduction of warmed surface waters and upwelling of cooler water (allows greater storage of heat in the ocean; England et al. 2014) • Trade wind direction has shifted from predominantly northeast to east from 1973–2009 (Garza et al. 2012), which represents a cyclical shift that is known to complete its cycle approximately every 45 years (Wentworth 1949) **All Islands** *Trade wind inversion (TWI) frequency* • The frequency of the TWI increased an average of 16% starting in 1990 (Longman et al. 2015) **Maui** *TWI frequency (Longman et al. 2015)* • From 1979–2003, TWI frequency was 82%, which caused a 40% reduction in wet-season rainfall (16% dry season) at high elevations (>1,900 m [6,233 ft]) • ENSO and PDO affect the proportion of days with a TWI (drier days), and so affect the conditions associated with each phase. During the warm phases of ENSO (El Niño) and PDO, mean TWI frequency is higher during the wet season and lower during the dry season, resulting in winter drought. During the cool phases of ENSO (La Niña) and PDO, mean TWI frequency is higher during the dry season and lower during the wet season,	**All Islands** *Surface wind speed* • Sept.–Nov. wind speed may decrease by 2026–2045 (compared to 1976–2005); strong Sept.–Nov. decreases may occur by 2081–2100, with smaller decrease in other seasons (Storlazzi et al. 2015) • Surface winds in the Hawaiian Islands may increase modestly by 2100, with a very modest increase in frequency of strong wind days (Zhang et al. 2016) *Surface wind direction* • Dec.–Feb. wind direction may rotate by a value of -0.50 to -10.0 degrees by 2026–2045 (compared to 1976–2005); no significant changes are projected by 2081–2100 (Storlazzi et al. 2015) *TWI* • 8% increase in TWI frequency of occurrence by 2100, corresponding to an almost 50% decrease in days without a well-defined TWI (decrease from 17% of days currently to 9% of days by 2100; Zhang et al. 2016) • Possible decrease in TWI base height, ranging from small (Zhang et al. 2016, 2017) to more significant (~160 m [525 ft]; Lauer et al. 2013) **Maui** *Trade wind inversion (Hamilton 2013)* By the late 21st century: • 8% increase in the proportion of days with a TWI (from 82% to 90%) • 10% increase in cloud top height on days with a TWI	Overall confidence: **Moderate** • Trade winds are driven by large-scale atmospheric processes, which are difficult to accurately predict • TWI frequency and height are variable, depending on location, time of day, season, and phases of ENSO and PDO • Surface winds are also influenced strongly by oceanic factors

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		resulting in drier summers. *TWI height (Hamilton 2013)* • From 1990–2009, range of variability for the TWI is 1.2–2.5 km (3,940–8,200 ft) for height, most frequently occurring height is 1,700–2,000m (5,580–6,560 ft). • A "bowl-like" depression in the TWI height and cloud top heights occurs on the leeward side of Maui, stretching several hundred kilometers **Hawaiʻi** • From 1958–2008, wind speed decreased slightly on the summit of Mauna Loa and increased on the summit of Mauna Kea (de Silva 2012)		
Streamflow and riverine flooding	↓	**All Islands** From 1943–2008 (compared to 1913–1943; Bassiouni & Oki 2013): • 22% decline in streamflow (19% wet season, 27% dry season) • 23% decline in baseflow (22% wet season, 27% dry season) • Increased high-flow variability (especially Jan.–March) • Shift towards more days with low-flow conditions and fewer days with high-flow conditions • Streamflow is typically highest from Jan.–March (wet season) and lowest during July–Sept. (dry season) • Jan.–March streamflow is typically low following El Niño events, and high following La Niña events; this pattern is enhanced during positive PDO phases *Riverine flooding* • No consistent trends were found in stream peak discharge statewide (Oki et al. 2010)	**All Islands** If mean annual rainfall decreases within a given watershed, it is likely that: • Low flows would become lower, and streamflow/baseflow would continue to decline (Strauch et al. 2015) • Flows would become more variable and more unstable ("flashy"), especially in wet years (Strauch et al. 2015) **Oʻahu** Leeward coast by 2100 (Makaha watershed study area; Safeeq & Fares 2012): • Annual: Decrease of 6.7% to 17.2% • Wet season: Decrease of 9.6% to 21.2% • Dry season: Increase of 1.7% to decrease of 5.3% **Hawaiʻi** Windward slopes (North Hilo-Hamakua study area; MacKenzie et al. 2014): • 29% reduction in water yield under warmer,	Overall confidence: **Low** • Streamflow is closely related to changes in both precipitation and temperature, but is also impacted by land cover and vegetation composition, substrate, groundwater withdrawals, and management practices • Increases in CO_2 could alter vegetation processes, all of which could also alter streamflow; these include evapotranspiration rates, leaf area, and stomatal conductance

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
			drier scenario, with the greatest declines in areas with higher current precipitation levels	
Drought	↑↓	**All Islands** • Increased drought length in 1980–2007 (compared to 1950–1979; Chu et al. 2010) • Drought conditions are usually less prevalent during La Niña years, and more prevalent during El Niño years (Chu et al. 2010; Dolling et al. 2009) **Hawaiʻi** Mauna Kea (Banko et al. 2013): • From 2000–2011, drought occurred in 74% of months (98 of 132 months) • From June 2006–Dec. 2010, drought occurred in 96% of months (52 of 54 months) • Low precipitation and drought were more severe in summer/early fall (June–Oct.)	**Maui** By 2080–2100 (Keener et al. 2012): • Increased risk in low- and mid-elevation leeward areas on Maui • Decreased risk on the mid-elevation windward slopes of Haleakalā and the summit of Mauna Kahālāwai • No change in risk in other areas on Maui • Increased risk by 2100 for Lānaʻi and Kahoʻolawe, except for the summit of Lānaʻi, which may not experience a change in drought risk (Keener et al. 2012) • Increased risk in west Molokaʻi, no change in risk in east Molokaʻi (Keener et al. 2012) **Kauaʻi** By 2080–2100 (Keener et al. 2012): • Increased risk in low-elevation leeward areas • Decreased risk at the highest elevations • No change in risk in other areas **Oʻahu** By 2080–2100 (Keener et al. 2012): • Increased risk in low-elevation leeward areas • Decreased risk at the highest elevations • No change in risk in other areas **Hawaiʻi** By 2080–2100 (Keener et al. 2012): • Increased risk in low- and mid-elevation leeward areas • Decreased risk on mid-elevation windward slopes • No change in risk in other areas	Overall confidence: **Low** • Few studies have projected drought risk • Drought projections are closely related to those for precipitation, which are variable and associated with high uncertainty • Existing projections in Keener et al. 2012 are based on data from Chu et al. 2010, Takahashi et al. 2011, and Elison Timm et al. 2011 (projections from Elison Timm et al. 2011 have since been corrected)

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
Soil moisture	↓	**All Islands** • No information is available about soil moisture trends over time • Soil moisture is typically lower on leeward sides and higher on windward sides (Longman 2015) • Soil moisture is typically lower in the dry season than during the wet season (Dolling et al. 2005) • Soil moisture typically decreases as elevation increases (Longman 2015)	**All Islands** • Soil moisture is likely to decline in the future, especially if precipitation decreases as air temperatures increase (Longman 2015)	Overall confidence: **Moderate-High** • Soil moisture is primarily dependent on precipitation amount, as well as soil properties, slope, temperature, humidity, and vegetation types present • Warmer temperatures and/or low humidity reduce soil moisture by increasing evaporation and plant transpiration • Soil moisture varies spatially depending on location relative to the trade winds (e.g., leeward vs. windward sides) and elevation • Soil moisture varies temporally across seasons, and large-scale climate variability (e.g., ENSO, PDO) impact soil moisture on annual and decadal scales by influencing rainfall • Although precipitation projections are highly uncertain, increased temperatures are very certain and are likely to result in reduced soil moisture under most precipitation possibilities

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
Stream temperature	↑	**All Islands** • No information is available about stream temperature trends • Stream temperatures are lower in forested areas compared to urban areas (Brasher 2003) • Stream temperatures are lower in the wet season than during the dry season (MacKenzie et al. 2013)	**All Islands** • Stream temperatures are likely to increase over the coming century (Gehrke et al. 2011)	Overall confidence: **Low** • No regional studies have been published on stream temperature projections, but researchers generally agree that stream temperatures will increase as air temperature increases • Several studies have compared forested vs. urban sites and dry vs. wet seasons • Studies of temperate streams may not be generalizable to tropical Hawaiian streams
Wildfire	↑	**All Islands** • Overall trend towards increases in area burned from 1904–2011, but with high interannual variability (Trauernicht et al. 2015) • From 1976–1997, large wildfires typically occurred during the spring and summer after an El Niño event (Chu et al. 2002) • Wildfire frequency on the Hawaiian Islands is positively correlated with human activity and population growth (Trauernicht et al. 2015) **Maui** • The majority of wildfires occur during summer (June–Aug.), when conditions are warm and dry, accounting for 57% of the annual area burned (Chu et al. 2002) • No data on wildfire is available for Lānaʻi, Kahoʻolawe, and Molokaʻi **Kauaʻi** • The majority of wildfires occur during summer (June–Aug.), when conditions are warm and dry,	**All Islands** • There are no wildfire projections available. • Wildfire will likely increase if drought events increase (Trauernicht et al. 2015) **Hawaiʻi** • The probability of fire occurrence in grassland, shrubland, and forest areas on the leeward side of the island is expected to roughly double; wildfire risk is highest at mid-elevation sites and in grasslands (Wada et al. 2017)	Overall confidence: **Low** • Wildfire is strongly correlated with dry conditions, and precipitation projections are highly uncertain

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		accounting for 39% of the annual area burned (Chu et al. 2002) **Oʻahu** • The majority of wildfires occur during summer (June–Aug.), when conditions are warm and dry, accounting for 60% of the annual area burned (Chu et al. 2002) **Hawaiʻi** • The majority of wildfires occur during summer (June–Aug.), when conditions are warm and dry, accounting for 31% of the annual area burned (Chu et al. 2002)		
Sea level	↑	**All Islands** *Extreme sea level events (Firing & Merrifield 2004)* • Extreme sea level events result from a combination of factors including long-term sea level rise, tides, and storms • Since 1920, extreme SLR events have increased from a frequency of every 20 years to every 5 years **Maui** *Sea level rise (NOAA/National Ocean Service 2017)* • Kahului station from 1947–2016: Average increase of 1.52 mm/year (0.06 in; equivalent to a change of 0.15 m [0.5 ft] in 100 years) *Shoreline change* • Maui beaches eroded by an average of 0.17 m/year (0.55 ft) across all beaches, with 85% of beaches eroding since the early 1900s (Romine & Fletcher 2012) • In that time, 11% of total beach length (7 km [4.35 mi]) was completely lost to erosion and is now seawalls (Romine & Fletcher 2012)	**Global** Multiple possibilities vary in magnitude, depending on which factors they take into account: • By 2100, global sea level will likely rise between 0.3 and 2.5 m (0.98–8.20 ft); relative sea level in Hawaiʻi may be higher compared to global levels, ranging from 0.4 to 3.3 m (1.3 to 10.8 ft; Sweet et al. 2017) • Likely global sea level (90% probability, compared to 2000; Kopp et al. 2014): ○ By 2030: 0.10–0.18 m (0.33–0.59 ft) ○ By 2050: 0.18–0.38 m (0.59–1.25 ft) ○ By 2100: 0.29–1.21 m (0.95–3.97 ft) **Maui** *Shoreline change* • Historical rates of beach erosion on Maui are likely to double with sea level rise by mid-century; 87% of beaches are likely to be eroding by 2050 (Anderson et al. 2015) • No projected future trends are available for	Overall confidence: **Moderate** • Although there is widespread agreement that the rate of sea level rise will continue to increase, projections vary widely depending on whether or not they include large-scale climate variability (ENSO, PDO) and the contribution of ice-sheet collapse • It is difficult to predict how ice sheets will respond to increasing temperatures; models are unable to estimate large non-linear changes in ice sheets • The emissions scenario and climate models chosen also contribute to large differences among the available projections

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		• No historical/current trends are available for Lānaʻi, Kahoʻolawe, and Molokaʻi **Kauaʻi** *Sea level rise (NOAA/National Ocean Service 2017)* • Nawiliwili station from 1955–2016: Average increase of 1.52 mm/year (0.06 in; equivalent to a change of 0.15 m [0.5 ft] in 100 years) *Shoreline change (Romine & Fletcher 2012)* • Kauaʻi beaches eroded by an average of 0.11 m/year (0.36 ft) across all beaches, with 71% of beaches eroding since the early 1900s • In that time, 8% of total beach length (6 km [3.73 mi]) was completely lost to erosion and is now seawalls **Oʻahu** *Sea level rise (NOAA/National Ocean Service 2017)* • Honolulu station from 1905–2016: Average increase of 1.44 mm/year (0.06 in; equivalent to a change of 0.14 m (0.47 ft) in 100 years) • Mokuoloe station from 1957–2016: Average increase of 1.26 mm/year (0.05 in; equivalent to a change of 0.12 m [0.41 ft] in 100 years) *Shoreline change (Romine & Fletcher 2012)* • Oʻahu beaches eroded by an average of 0.06 m/year (0.20 ft) across all beaches, with 60% of beaches eroding since the early 1900s • In that time, 8% of total beach length (9 km [5.59 mi]) was completely lost to erosion and is now seawalls **Hawaiʻi** *Sea level rise (NOAA/National Ocean Service 2017)* • Hilo station from 1927–2016: Average increase of	Lānaʻi, Kahoʻolawe, and Molokaʻi **Kauaʻi** *Shoreline change (Anderson et al. 2015)* • Historical rates of beach erosion on Kauaʻi are likely to double with sea level rise by mid-century; 100% of beaches are likely to be eroding by 2050 **Oʻahu** Shoreline change by 2050 and 2100 (compared to 2005; Anderson et al. 2015): • Ehukai and Sunset: -8.7 ± 6.2 by 2050, -25.2 ± 10.4 by 2100 (high seasonal variability) • Hauʻula: -9.0 ± 0.5 by 2050, -24.2 ± 1.0 by 2100 • Kailua: 7.1 ± 3.2 by 2050, 4.9 ± 6.8 by 2100 (only site with shoreline advancement) • Makaha: -6.9 ± 2.4 by 2050, -18.6 ± 3.9 by 2100	• Sea level rise measurements use various baselines, including Mean High Water, Mean Higher High Water, Mean Sea Level, and others • Tidal datums vary from island to island and there is no set standard for which to use and which time period to set as a reference

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		3.01 mm/year (0.13 in; equivalent to a change of 0.3 m [0.99 ft] in 100 years)		
Coastal flooding and saltwater intrusion	↑	**All Islands** *Coastal flooding* • Sea level rise has contributed to both marine inundation (i.e. flooding in areas with a direct hydrological connection to the ocean) and groundwater inundation (i.e. flooding in areas with an indirect hydrological connection due to elevated water tables; Rotzoll & Fletcher 2013) **Maui** *Saltwater intrusion (Gingerich & Engott 2012)* Waiehu Deep Monitor Well (north Maui) • From 1985–1999, saltwater intrusion increased, due primarily to groundwater withdrawals • The midpoint of the transition zone between freshwater and sea water rose 2.2 m (7.2 ft) per year (i.e. freshwater lens became shallower) Māhinahina Deep Monitor Well (west Maui) • No change in the midpoint of the transition zone over time	**All Islands** *Saltwater intrusion* • No projections available for saltwater intrusion, but it is likely to increase due to sea level rise, drought, and groundwater withdrawals (Rotzoll et al. 2010; Ferguson & Gleeson 2012) **Maui** *Coastal flooding* Kahului (Cooper et al. 2013): • At 0.75 m (2.5 ft) of SLR, 0.55 km^2 inundated (land and building value of $18.7 m); saltwater intrusion would significantly impact the freshwater Kanaha Pond Wildlife Sanctuary • At 1.90 m (6.2 ft) of SLR, 2.13 km^2 inundated (value of $296 m) Lahaina (Cooper et al. 2013): • At 0.75 m (2.5 ft) of SLR, 0.04 km^2 inundated (land and building value of $57.5 m) • At 1.90 m (6.2 ft) of SLR, 0.37 km^2 inundated (value of $394 m) Kanaha Pond State Wildlife Sanctuary (Kahului in north Maui; Kane et al. 2015): • At 0.3 m (0.98 ft) of SLR (est. by 2057), 24.9% of total area inundated • At 0.74 m (2.4 ft) of SLR (est. by 2100), 25.3% of total area inundated (0.3% by marine inundation, 25% of area flooded by groundwater inundation) Keālia Pond National Wildlife Refuge (south Maui; Kane et al. 2015): • At 0.3 m (0.98 ft) of SLR (est. by 2057), 21.9%	Overall confidence: **Moderate** • Because there are no downscaled sea level rise projections for this region, models of flooding/inundation use set amounts of sea level rise to determine the area flooded (rather than reporting the amount of change by 2050/2100 like many other studies do) • Cooper et al. (2013) based their coastal inundation models on SLR estimates by Vermeer and Rahmstorf (2009) • Kane et al. (2015) based their models on global SLR projections by Church et al. (2013), which do not take melting ice sheets into account • Saltwater intrusion is also impacted by recharge rates and groundwater pumping/withdrawals (withdrawals likely play a larger role in saltwater intrusion than does sea level rise; Ferguson & Gleeson 2012)

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
			of total area inundated • At 0.74 m (2.4 ft) of SLR (est. by 2100), 28.2% of total area inundated (0.6% of total area flooded by marine inundation, 27.6% of area flooded by groundwater inundation) No projected future trends for coastal flooding are available for Lānaʻi, Kahoʻolawe, and Molokaʻi **Oʻahu** *Coastal flooding (includes marine and groundwater inundation)* Within a 1-km shoreline buffer in Honolulu (heavily urbanized; Rotzoll & Fletcher 2013): • If 0.33 m (1.08 ft) SLR: 0.5% flooded area (51% due to groundwater inundation) • If 0.66 m (2.16 ft) SLR: 2.5% flooded area (69% due to groundwater inundation) • If 1 m (3.28 ft) SLR: 10% flooded area (58% due to groundwater inundation) • Flooded area is greater in Waikiki (13.5% flooded area) and Ala Moana (19% flooded area) James Campbell National Wildlife Refuge (north Oʻahu; Kane et al. 2015) • At 0.3 m (0.98 ft) (est. by 2057), 0.1% of total area inundated • At 0.74 m (2.42 ft) (est. by 2100), 2.5% of total area inundated (0.1% of area flooded by marine inundation, 1.4% by groundwater inundation)	
Sea surface temperature	↑	**Global** • Since 1870–1899, increase of 0.44°C (0.79°F) by 1990–1999 (Bopp et al. 2013) • Between 1901–2015, increase at average rate of 0.07°C (0.13°F) per decade (NOAA NCEI 2016b)	**Global** • By 2090–2099: Increase of 0.71°C to 2.73°C (1.28°F to 4.91°F) compared to 1990–1999 (Bopp et al. 2013)	Overall confidence: **High** • SST patterns over the tropical Pacific are influenced by ocean circulation (e.g.,

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		Pacific Ocean • 0.07°C to 0.23°C (0.13°F to 0.41°F) increase per decade from 1970–2010 (Australian Bureau of Meteorology & CSIRO 2011; IPCC 2013) **Northeast Pacific** • 0.12°C (0.22°F) increase per decade from 1960–1990 (Casey & Cornillon 2001)	**Pacific Ocean** • By 2100: Increase between 1.3°C and 2.7°C (2.3°F and 4.9°F) compared to 1970–2010 (Australian Bureau of Meteorology & CSIRO 2011)	currents and mixing) and surface flux adjustments (e.g., wind speed, evaporation) • SST is highly variable on seasonal, interannual, and decadal scales, corresponding to changes in air temperature and large-scale climate variability processes such as ENSO and the PDO
Ocean pH	↓	**Global** • Since 1750, the mean surface ocean pH decreased by 30%, a change of 0.1 units from 8.2 to 8.1 units (IPCC 2013) • Since 1870–1899, mean ocean surface pH decreased 0.07 units by 1990–1999 (Bopp et al. 2013) • This corresponds to a 26% increase in pH, towards more acidic oceans (Eversole & Andrews 2014) **Central North Pacific** • From 1998–2007, surface pH decreased by 0.0019 to 0.0002 per year (Dore et al. 2009)	**Global** • By 2090–2099: 0.07–0.33 unit decrease in surface pH (more acidic) compared to 1990–1999 (Bopp et al. 2013)	Overall confidence: **High** • There is high certainty that ocean pH will decline because changes in pH correspond very closely to the amount of atmospheric CO_2 absorbed by oceans (e.g., a ~30% increase in CO_2 absorbed by oceans has been associated with a ~30% drop in pH since pre-industrial times; IPCC 2013; Bopp et al. 2013; Gattuso et al. 2015) • Ocean pH is variable across seasons, as well as interannual and decadal scales, depending on temperature, mixing, and the amount of CO_2 used in photosynthetic processes
Species distribution *(forest birds and mosquitos)*	↑ □ ↓ □	**All Islands** *Mosquito distribution (Kolivras et al. 2010)* • Based on precipitation and temperature data from 1971–2000, mosquito habitat expands	**All Islands** *Forest birds (Fortini et al. 2015)* • By 2100, species richness is expected to decline, with 90% of modeled bird species	Overall confidence: **Moderate** *Mosquito distribution* • Mosquito expansion is

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
		during increased rainfall years (e.g. La Niña years), with predominant expansions occurring in windward locations and small to moderate increases in habitat area in leeward locations • Mosquito habitat declines under drought conditions (e.g., El Niño years), with core habitat remaining in windward locations **Kauaʻi** *Mosquito distribution (Atkinson et al. 2014)* • Avian malaria infection rates increased at all elevations (1,100–1,350 m [3,610–4,430 ft]) on the Alakaʻi Plateau from 2007–2013 (relative to 1994–1997) • During the same time period, increased mosquito larval numbers were detected along stream margins, likely due to reduced high streamflow and scouring events associated with reduced precipitation and drier overall conditions **Hawaiʻi** *Forest birds (Banko et al. 2013)* From 2003–2011: • Palila populations declined 73% in response to drought conditions and feral ungulate grazing • Palila distribution decreased to 23% of core habitat area	likely losing over 75% of their current range (due to increased temperatures and risk of avian malaria) • Small-island endemic species are most vulnerable to climate-driven habitat loss **Kauaʻi** *Forest area at risk for avian malaria (Benning et al. 2002)* • By 2100, the area of forest at moderate risk for malaria will decrease by 85% on Kauaʻi (Alakaʻi Swamp), which already has no low-risk area, due to mosquito range expansion *Forest birds (Fortini et al. 2015)* • Only island with bird species projected to lose all of current range (ʻakekeʻe, ʻakikiki, puaiohi) **Maui** *Forest birds (Fortini et al. 2015)* • Over 90% range loss for the ʻAkohekohe and Maui Parrotbill by 2100, and 75% range loss for the Maui ʻAlauahio *Forest area at risk for avian malaria (Benning et al. 2002)* • By 2100, the area of forest at low risk for malaria will decrease by 50% within the Hanawi Forest, due to range expansion of mosquitos **Hawaiʻi** *Forest area at risk for avian malaria (Benning et al. 2002)* • By 2100, the area of forest at low risk for malaria will be nearly eliminated within the Hakalau National Wildlife Refuge, due to	heavily dependent on increasing temperatures (high certainty) and adequate precipitation (low certainty) *Forest birds* • Modeled ranges vary depending on the emissions scenario chosen, and they may end up being smaller than presented in the Fortini et al. 2015 study • Forest bird distribution models did not incorporate potential habitat loss to urban or agricultural development • Additional factors that were not addressed in the models but may impact bird distributions include ecological interactions and non-climate stressors

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
			mosquito range expansion *Forest birds (Fortini et al. 2015)* • Hawai'i 'akepa will lose 93% of its current range • Hawai'i creeper and akiapōlā'au will lose >75% of their current range	
Species distribution *(native and invasive plants)*	⬆ □ ⬇ □	**Maui** *Native plant species (Krushelnycky et al. 2012)* • The upper limit of cloud forests on Haleakalā has shifted downslope during dry periods over the last 3,000 years, in response to El Niño drought events and local moisture availability • Haleakalā silversword population growth has decreased in response to drier conditions since 1990 (lower elevations) and 2000 (higher elevations) • Silversword mortality is highest and population declines started earliest at low-elevation areas within the plant's distribution	**All Islands** *Native plant species (Fortini et al. 2013)* By 2100: • 39% average reduction in climatically suitable habitat for native plants • 15% of modeled species will likely have no overlap between current and future suitable habitat (e.g., will have to migrate to persist) • 5% of modeled species are projected to lose >99% of their current climate envelope (i.e. these species will "wink-out") • Most vulnerable species include: single-island endemics, species with a conservation listing (e.g., endangered), coastal species, monocots, and dry forest-affiliates *Invasive plant species (Vorsino et al. 2014)* By 2100: • 11% increase in land area suitable for invasion (12% increase in critical habitat areas) • All but four modeled species (Miconia [*Miconia calvescens*], koa haole [*Leucaena leucocephala*], strawberry guava [*Psidium cattleianum*], firetree [*Morella faya*]) are projected to expand • Invasion risk increases at higher elevation locations **Maui** *Native plant species (Hotchkiss 2014)*	Overall confidence: **Moderate** *Native plant species* • Modeled changes in plant distribution are dependent on the emissions scenario used, as well as additional factors that affect species distribution and survival, but which were not considered here (e.g., reductions in habitat quality/availability, adaptive capacity traits, disease risk, new invasions) • El Niño events can significantly affect vegetation distribution by altering patterns of precipitation and drought, but projected changes in these factors are poorly understood *Invasive plant species* • Models may under-represent invasive species distribution because the majority of the data was sourced from areas of conservation concern rather than from across the entire landscape • Climatic tolerances of

Climate Variable/Impact	Trend	Observed Change	Projected Change	Confidence
			• Downslope contraction of cloud forest vegetation on Haleakalā if rainfall decreases • Upslope movements may be possible if rainfall increases, but habitat gains would be modest compared to the losses associated with drought	individual species and how they may react to changes are not well-understood • On islands where invasive plants have only recently become established, populations have not reached an equilibrium with the environment and models may predict future distributions less accurately

Appendix B. Compilation of Adaptation Strategies and Actions Designed by Workshop Participants

The following table presents the complete list of 417 climate adaptation strategies and actions generated by workshop participants for habitats and conservation activities.

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Develop more efficient technologies/tools for habitat restoration and invasive species control	Collaborate with research and management entities on new technology (i.e. drone surveys, genetically modified mosquitos)	Hawai'i	Invasive species management		
Collaboration	Create new/improve partnerships to increase capacity	Create new/improve existing partnerships to increase capacity	O'ahu	Mesic/wet forest & upland wetlands	High	High
Collaboration	Increase community and cultural engagement through education and outreach focused on the importance of dry forest habitat	Host volunteer planting days (e.g., weed removal, nursery) in sites where volunteers can see progress over time	Hawai'i	Dry forest	High	High
Collaboration	Create dialogue between cultural practitioners and natural resource managers	Increase cultural participation in tracking environmental and climatic change (e.g., host community workshops teaching how to kilo [observe] in different sites, reinstate volunteer work days to help people reconnect to the land)	Kaua'i	Cultural resources and practices	High	Mod
Collaboration	Increase collaboration between researchers and the community	Require researchers outside the Native Hawaiian community to take cultural components into account (e.g., within permitting processes)	O'ahu	Cultural resources and practices	Mod	Mod
Collaboration	Create healthy communities	Break plantation mentality and strengthen ancestral connections	Maui	Cultural resources and practices	High	Mod
Collaboration	Create new/improve partnerships to increase capacity	Build off of existing programs by creating/enhancing networks with other agencies, organizations	Hawai'i	Native ecosystems and rare species conservation rare species conservation	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Reconnect/enhance connections of people to place	Build the capacity of local communities through restoration projects, on-the-ground action, involvement in policy decisions, and genealogy exercises	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	Mod-high (mod)
Collaboration	Raise public awareness and community support for dry forest protection	Celebrate success to keep the community involved	Maui	Dry forest	Mod	Mod
Collaboration	Coordinate and amplify public education and outreach messages	Collaborate with other outreach/education efforts to create more consistent messaging	Oʻahu	Public engagement & outreach	Mod	High
Collaboration	Coordinate with multiple landowners	Collaborate with ranchers to contain ranching activities and minimize disturbance in subalpine habitats	Hawaiʻi	Alpine/subalpine	Mod	High
Collaboration	Build support for coastal habitat protection with climate-informed public education and advocacy	Conduct climate-informed public education and outreach about protected areas and habitats at risk	Maui	Coastal	High	Mod
Collaboration	Increase community outreach to elevate public awareness and value of mesic and wet forest habitats	Conduct community-based restoration projects in mesic/wet forest areas	Kauaʻi	Mesic/wet forest	Mod	Low
Collaboration	Increase direct community restoration	Conduct place-based community education, organizing, management, and action focused on habitat restoration, cultural practices, and climate change impacts	Maui	Cultural resources and practices	Mod	Mod
Collaboration	Increase collaborative efforts to conserve streams and watersheds	Conduct place-based education to encourage watershed conservation	Maui	Aquatic	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Increase public support and involvement in wetland conservation and management	Convene multi-stakeholder groups to create public education material and encourage continued involvement in wetland conservation and management	Oʻahu	Lowland freshwater wetlands	Mod	Mod
Collaboration	Increase capacity for dry forest restoration	Create a community workforce to implement restoration in historic dry forest and high-priority sites in a timely manner	Maui	Dry forest	High	High
Collaboration	Change laws/policies to protect and promote community response to climatic changes and impacts	Create a network of expertise (e.g., natural and cultural resource managers, students) to be a resource for local communities	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	High
Collaboration	Increase public understanding of water cycle and how humans interact with island-wide water resources	Create a visual, place-based method for communicating how individual locations receive water and how climate scenarios may affect future water supply and quality	Kauaʻi	Water resources	Low	High
Collaboration	Manage invasive species	Create an extension service to work with private landowners	Kauaʻi	Invasive species management	Mod	Mod
Collaboration	Strengthen conversations about water as public trust	Create and/or enhance water groups (e.g., watershed partnerships)	Hawaiʻi	Water resources	High	Mod
Collaboration	Change laws/policies to protect and promote community response to climatic changes and impacts	Create strategic communications campaign to implement policy changes	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	High
Collaboration	Create healthy communities	Create/build relationships within the community, non-profit, and government sectors	Maui	Cultural resources and practices	High	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Increase number of Native Hawaiian stewards for cultural resources	Create/revise cultural stewardship agreements	Hawaiʻi	Cultural resources	Mod	Mod
Collaboration	Increase biosecurity measures	Determine individual agency roles in promoting biosecurity plans (e.g., decontamination stations, vehicle cleaning, better maintain roadside eradication)	Hawaiʻi	Invasive species management	High	High
Collaboration	Refine communication strategies to increase buy-in and engagement	Develop materials and methods to communicate climate impacts in empowering ways (e.g., promote collaborative conversations vs. outsiders coming in)	Oʻahu	Cultural resources and practices	High	High
Collaboration	Build adaptation and resilience in local communities through education, engagement, and outreach	Develop multiple avenues to increase local education on climate-informed native species conservation (e.g., schools, public story events, exhibits, videos, social media)	Kauaʻi	Aquatic	High	Mod-High (mod)
Collaboration	Strengthen conversations about water as public trust	Elevate the value of fresh water through water conservation campaigns	Hawaiʻi	Water resources	Mod	High
Collaboration	Increase environmental and climate literacy across all ages	Engage communities that have experienced weather/climate disturbances in the past to help amplify climate change messages	Oʻahu	Public engagement & outreach	Mod	High
Collaboration	Raise public awareness and community support for dry forest protection	Engage community (i.e. cultural woodworkers, agricultural producers) in addressing knowledge gaps and restoration work	Maui	Dry forest	Mod	Mod
Collaboration	Build support for coastal habitat protection with climate-informed public education and advocacy	Engage community groups, develop constituencies, align interest groups, and mobilize people to demand conservation action	Maui	Coastal	High	Mod-high (mod)

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Change laws/policies to protect and promote community response to climatic changes and impacts	Engage the larger community to discuss climate impacts and co-develop climate-informed policies and plans	Hawai'i	Shorelines, aquatic, tidally-influenced habitats	High	Low-mod (mod)
Collaboration	Develop more efficient technologies/tools for habitat restoration and invasive species control	Enhance interagency coordination between groups working in same landscape area (e.g., collaboratively identify priority areas and high risk invasive species, collaborate on monitoring and surveys)	O'ahu	Invasive species management	Mod	High
Collaboration	Strengthen conversations about water as public trust	Ensure continued cultural connections to water resources	Hawai'i	Water resources	Mod	High
Collaboration	Create dialogue between cultural practitioners and natural resource managers	Establish and empower community-identified liaisons to help with conservation goals	Kaua'i	Cultural resources and practices	Mod	High
Collaboration	Build adaptation and resilience in local communities through education, engagement, and outreach	Expand access to habitat in additional areas to increase societal connection and value	Kaua'i	Aquatic	Low	High
Collaboration	Increase capacity and manpower to address invasive species	Expand terrestrial community-based management areas	Hawai'i	Invasive species management	Mod	Mod
Collaboration	Increase capacity and manpower to address invasive species	Expand the Big Island Invasive Species Committee	Hawai'i	Invasive species management		
Collaboration	Increase collaborative efforts to conserve streams and watersheds	Expand watershed conservation to lower elevations by enhancing watershed partnerships and seeking legislative changes at the state and local levels	Maui	Aquatic	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Increase public support and involvement in wetland conservation and management	Facilitate community events where public can visit wetlands as a first step to increasing action, awareness, and education	O‘ahu	Lowland freshwater wetlands	Low	High
Collaboration	Increase number of Native Hawaiian stewards for cultural resources	Formally acknowledge/incentivize successful stewardship	Hawai‘i	Cultural resources	Mod	High
Collaboration	Increase community and cultural engagement through education and outreach focused on the importance of dry forest habitat	Host outreach events (e.g., Wiliwili Festival, Biocultural Blitz, Run for the Dry Forest, hunting tournaments) and integrate climate change (e.g., lei competition with different climate-adapted species)	Hawai‘i	Dry forest	High	Mod
Collaboration	Coordinate and amplify public education and outreach messages	Identify additional non-governmental funders that might be interested in investing to protect what they value (e.g., corporations, canoe clubs that rely on koa wood, Elks clubs, golf/country clubs)	O‘ahu	Public engagement & outreach	High	Mod
Collaboration	Refine communication strategies to increase buy-in and engagement	Identify and cultivate community leaders to help share messages about cultural resilience and adaptation	O‘ahu	Cultural resources and practices	HIgh	High
Collaboration	Encourage local participation in preserving cultural resources	Identify community roadblocks for local conservation/preservation and cultural resources most at risk	O‘ahu	Cultural resources and practices	Mod	Mod
Collaboration	Encourage local participation in preserving cultural resources	Identify partners that could provide additional space for cultural activities and resources (e.g., schools, botanical gardens, unused lots)	O‘ahu	Cultural resources and practices	High	Mod
Collaboration	Coordinate and amplify public education and outreach messages	Identify potential outreach/education partners (e.g., active Hawaiian civic clubs, Office of Hawaiian Affairs, Kamehameha Schools)	O‘ahu	Public engagement & outreach	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Create new/improve partnerships to increase capacity	Improve data sharing within and between agencies	O'ahu	Mesic/wet forest & upland wetlands	Mod	High (Mod for streams)
Collaboration	Reduce human pressure on native ecosystems and species	Improve land use planning and increase outreach on conservation-informed land uses	Kaua'i	Native ecosystems and rare species conservation	High	Mod
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Incentivize use of native plants in landscaping projects (i.e. "plant pono" certifications)	O'ahu	Invasive species management	High	Mod
Collaboration	Increase collaboration between researchers and the community	Incorporate community engagement protocols into funding requirements and research permits and ensure it is continued throughout the lifetime of the project	O'ahu	Cultural resources and practices	Mod	Low
Collaboration	Refine communication strategies to increase buy-in and engagement	Incorporate cultural and/or uniquely Hawaiian components into climate change communication products (e.g., cultural voyaging, lei)	O'ahu	Cultural resources and practices	Mod	High
Collaboration	Create more nimble planning and zoning processes that promote natural landscapes and community values and is adaptable to climate change	Increase access to digestible information to support community engagement	Hawai'i	Land-use planning	Mod	High
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Increase accessibility of outreach messaging through ecotourism operations	Hawai'i	Native ecosystems and rare species conservation rare species conservation		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Reduce human pressure on native ecosystems and species	Increase and create different education and outreach campaigns based on target audiences (e.g., older vs. younger, tourists vs. residents)	Kauaʻi	Native ecosystems and rare species conservation	Mod	High
Collaboration	Develop more efficient technologies/tools for habitat restoration and invasive species control	Increase community engagement in decision-making process around new technology	Hawaiʻi	Invasive species management		
Collaboration	Support linkages between cultural practitioners	Increase cooperation and knowledge sharing between cultural communities	Kauaʻi	Cultural resources and practices	Mod	Mod
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Increase cross-sectoral partnerships and promote understanding of diverse perspectives	Hawaiʻi	Mesic/wet forest	High	Mod
Collaboration	Create healthy communities	Increase cultural community input on water use decisions	Maui	Cultural resources and practices	Mod	High
Collaboration	Build adaptation and resilience in local communities through education, engagement, and outreach	Increase education and involvement of students (K-12, college) in conservation work through hands-on teaching and learning experiences	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	High
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Increase education of the legislature, as well as public engagement with natural resource decisions made by the legislature	Oʻahu	Mesic/wet forest & upland wetlands	High	Low
Collaboration	Increase community outreach to elevate public awareness and value of mesic and wet forest habitats	Increase K-12 education programs on mesic/wet forest value	Kauaʻi	Mesic/wet forest	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Increase lobbying efforts and create a committed group (Hawai'i Conservation Alliance, Conservation Council of Hawai'i) to bring the messages to elected officials and voters	Hawaiʻi	Native ecosystems and rare species conservation		
Collaboration	Integrate climate adaptation into legal state frameworks	Increase network of managers and scientists to address climate change needs	Hawaiʻi	Land-use planning		
Collaboration	Integrate climate adaptation into legal state frameworks	Increase networks to build products that can inform policy and be used by managers to decrease vulnerability	Hawaiʻi	Land-use planning		
Collaboration	Increase local food security	Increase school education (e.g., promote agriculture as a profession), school gardens, and collaboration with agricultural educators (e.g., Ag Curious)	Oʻahu	Land-use planning		
Collaboration	Create new/improve partnerships to increase capacity	Increase state leadership, coordination, and engagement with organizations and stakeholders (e.g., watershed partnerships)	Oʻahu	Mesic/wet forest & upland wetlands	Mod	Mod
Collaboration	Increase number of Native Hawaiian stewards for cultural resources	Increase stewardship opportunities	Hawaiʻi	Cultural resources	Mod	High
Collaboration	Support whole systems approaches to agricultural production (e.g., healthy ecosystems and food production)	Increase support for community-supported agriculture (CSAs)	Hawaiʻi	Land-use planning	High	High
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Integrate invasive species education into existing programs (e.g., hunter education, kids camps)	Kauaʻi	Invasive species management		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Develop more efficient technologies/tools for habitat restoration and invasive species control	Look into community-based implementation options for new technology	Hawai'i	Invasive species management	High	Mod
Collaboration	Increase community and cultural engagement through education and outreach focused on the importance of dry forest habitat	Preserve forest access for stewardship and the gathering of important cultural species and materials (e.g., lei materials)	Hawai'i	Dry forest	High	Mod
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Promote native species in tourism and marketing	Hawai'i	Mesic/wet forest	High	Mod
Collaboration	Increase collaboration between researchers and the community	Provide background cultural material to support research in order to avoid putting the education burden on communities	O'ahu	Cultural resources and practices	Mod	High
Collaboration	Create new/improve partnerships to increase capacity	Review existing monitoring programs across jurisdictions to identify overlaps and avoid duplication of effort	Hawai'i	Native ecosystems and rare species conservation	Low	High
Collaboration	Improve science-management communication and partnerships	Share new climate models and tools to increase accessibility to information	O'ahu	Lowland freshwater wetlands	High	Mod
Collaboration	Increase education and outreach to increase public engagement and stewardship in conservation	Support ecotourism	Hawai'i	Mesic/wet forest	High	Mod
Collaboration	Support linkages between cultural practitioners	Use local stories about climate change impacts to encourage collaboration and on-the-ground action	Kaua'i	Cultural resources and practices	Mod	High
Collaboration	Utilize citizen science to help manage invasive species	Use phone applications and GPS location services to identify and track invasive species locations	Kaua'i	Invasive species management		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Collaboration	Integrate climate adaptation into legal state frameworks	Use the Pacific Islands Climate Change Cooperative (PICCC) and Pacific Islands Climate Science Center (PICSC) as fora to gather experts and settle on island-wide climate standards (e.g., sea level rise, fire risk) that can inform law	Hawaiʻi	Land-use planning		
Collaboration	Integrate cultural knowledge into resource management	Work with cultural practitioners during development of management plans	Oʻahu	Cultural resources and practices	Mod	High
Knowledge	Enhance long-term monitoring efforts to better understand changes in abundance, distribution, and ecological impacts of native and rare species	Develop monitoring strategies that are less cost- and time-intensive for rare species (e.g., rare birds)	Hawaiʻi	Native ecosystems and rare species conservation	High	Low
Knowledge	Conduct research to support adaptive policies and technology that increase landscape-level protection and restoration	Research and develop new/improved methods of weed control	Maui	Alpine/subalpine	High	High
Knowledge	Gather information on fire vulnerability/resilience in native communities	Research which native species are fire-tolerant and are appropriate for pre- and post-burn planting, taking climate change into consideration	Hawaiʻi	Native ecosystems and rare species conservation	Mod	High
Knowledge	Increase collaboration between researchers and the community	Foster research from Native Hawaiian communities and knowledge systems to increase access to traditional ecological knowledge	Oʻahu	Cultural resources and practices	Mod	High
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Increase research on any benefits that may be obtained from invasive species (e.g., invasive tree tobacco providing food for endangered Blackburn's sphinx moth)	Hawaiʻi	Dry forest	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Collect data on stream habitats	Add additional gauges to monitor streamflow, water temperature, and salinity	Maui	Aquatic	Low	Mod
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Build capacity to effectively manage invasive species (i.e. funding, data, monitoring, staff, technology [e.g., drones])	Oʻahu	Invasive species management		
Knowledge	Reconnect/enhance connections of people to place	Build local experience of landscapes and seascapes into science and decision making	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	Mod-high (mod)
Knowledge	Increase understanding of cultural resources in need of protection	Collect data from the community in order to better protect cultural resources	Maui	Cultural resources and practices	Mod	High
Knowledge	Raise public awareness and community support for dry forest protection	Conduct a comprehensive public media campaign to highlight the importance of dry forest habitats and what is at risk from climate change (e.g., culture, economy, ecosystem services)	Maui	Dry forest	Mod-high (mod)	Mod
Knowledge	Anticipate and facilitate habitat migration	Conduct a cost-benefit analysis for a range of management alternatives based on climate change vulnerability assessments and prioritization processes	Maui	Coastal	High	High
Knowledge	Coordinate and amplify public education and outreach messages	Conduct a needs assessment of agencies/organizations doing outreach, education, and on-the-ground stewardship/engagement service projects	Oʻahu	Public engagement & outreach	Mod	High
Knowledge	Increase research efforts to improve capacity and management tools in dry forest	Conduct controlled fuel break trial burns in previously burned and low-risk sites to identify fuel break characteristics and other measures that may minimize risk	Oʻahu	Dry forest	Low-mod (mod)	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Increase capacity for mesic/wet forest restoration	Conduct economic analyses on native forest value in light of climate change	O‘ahu	Mesic/wet forest & upland wetlands	Mod	High
Knowledge	Preserve genetic diversity	Conduct genetic research on common and rare plant species	O‘ahu	Native ecosystems and rare species conservation		
Knowledge	Preserve genetic diversity	Conduct research on the factors driving extinction of rare species and the landscape conditions are needed for reestablishment	O‘ahu	Native ecosystems and rare species conservation		
Knowledge	Anticipate potential shifts in invasive species distributions	Conduct weed mapping to identify location of worst weeds and areas where preventing weed introduction is most critical	O‘ahu	Invasive species management	Mod	Mod
Knowledge	Collect data on stream habitats	Create a flexible monitoring system to track water extraction, including who is withdrawing water and for what purpose	Maui	Aquatic	Low	Mod
Knowledge	Increase environmental and climate literacy across all ages	Create a suite of products to educate decision-makers about likely impacts of climate change	O‘ahu	Public engagement & outreach	Low	High
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Create an "eat the invasives" campaign	Kaua‘i	Invasive species management		
Knowledge	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	Create broader communications strategy to best reach people at risk (e.g., civil defense sirens, radio, social media, geolocation of posts, airport kiosks, flight introductory videos, texting tools in multiple languages, in-hotel video feed)	O‘ahu	Land-use planning		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Anticipate potential shifts in invasive species distributions	Create invasive species risk assessment tool by expanding beyond current weed risk assessment tool (e.g., include both flora and fauna risk assessment, incorporate climate change)	Oʻahu	Invasive species management	Mod	Mod
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Create policy for technologies not currently allowed	Hawaiʻi	Invasive species management		
Knowledge	Increase biosecurity measures	Develop a public database of biosecurity strategies and actions, including agency contact information (i.e. iNaturalist app, BioBlitz events)	Hawaiʻi	Invasive species management	Mod	Mod
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Develop alternative removal technologies that the public can do themselves	Oʻahu	Invasive species management	Mod	High
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Develop biocontrol methods for invasive species	Maui	Mesic/wet forest	High	High
Knowledge	Increase public understanding of water cycle and how humans interact with island-wide water resources	Develop educational resources	Kauaʻi	Water resources		
Knowledge	Increase knowledge to improve dry forest restoration	Develop new technologies to increase survival and long-term restoration success (e.g., fog drip capture, irrigation, invasive species, biomimicry, nanobots)	Maui	Dry forest	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Develop sites across the island where public can learn about and compare natural conditions, invaded conditions, pre-climate change conditions, etc.	Kauaʻi	Invasive species management		
Knowledge	Change laws/policies to protect and promote community response to climatic changes and impacts	Expand Ecological Effects of Sea Level Rise (EESLR) model to cover the whole island	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	Low	High
Knowledge	Increase research efforts to improve capacity and management tools in dry forest	Explore use of goat grazing to minimize fuel loads on a small scale	Oʻahu	Dry forest	Mod	High
Knowledge	Ensure community-wide intergenerational transmission of knowledge	Facilitate mentorship and knowledge exchange among and between practitioners	Hawaiʻi	Cultural resources	High	Mod
Knowledge	Collect data on existing non-climate stressors	Gather baseline information on the state of current diversions	Oʻahu	Aquatic (streams)	Low	High
Knowledge	Increase knowledge to improve dry forest restoration	Identify gaps in cultural and technical knowledge to prioritize research needs	Maui	Dry forest	High	Mod
Knowledge	Increase research efforts to improve capacity and management tools in dry forest	Identify limiting factors and develop forestry tools to improve management	Oʻahu	Dry forest	Mod	Low
Knowledge	Improve resilience of key dry forest species/communities	Identify native, ethnobotanically-important species that are drought- and wind-tolerant	Maui	Dry forest	Mod	Mod
Knowledge	Enhance long-term monitoring efforts to better understand changes in abundance, distribution, and ecological impacts of native and rare species	Identify which rare species are most vulnerable to climate change and prioritize for monitoring	Hawaiʻi	Native ecosystems and rare species conservation	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Increase understanding of water quantity, quality, and allocations under changing climate conditions	Identify, map, and quantify groundwater and surface water conditions	Kauaʻi	Water resources	Low	High
Knowledge	Improve silvicultural practices for priority species	Improve methodology for seed propagation	Maui	Alpine/subalpine	Low to high (mod)	Moderate
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Improve methods for native species propagation (all taxa) in high-quality core habitat	Maui	Mesic/wet forest	High	High
Knowledge	Improve silvicultural practices for priority species	Improve seed storage capacity	Maui	Alpine/subalpine	High	High
Knowledge	Improve silvicultural practices for priority species	Improve silvicultural planting methods	Maui	Alpine/subalpine	Moderate	Moderate
Knowledge	Increase understanding of water quantity, quality, and allocations under changing climate conditions	Improve understanding of drought impacts on water resources	Kauaʻi	Water resources	Mod	Mod
Knowledge	Create more nimble planning and zoning processes that promote natural landscapes and community values and is adaptable to climate change	Increase 'āina-based education and use of ahupua'a considerations	Hawai'i	Land-use planning	Low	High
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Increase ahupua'a education	Kauaʻi	Invasive species management	High	High
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Increase awareness of biocultural and ecosystem services	Hawaiʻi	Mesic/wet forest	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Build adaptation and resilience in local communities through education, engagement, and outreach	Increase citizen science efforts to gather data to support climate-informed decision making	Hawai'i	Shorelines, aquatic, tidally-influenced habitats	Low-mod	High
Knowledge	Increase capacity for mesic/wet forest restoration	Increase in-state capacity to conduct research on pests and pathogens	O'ahu	Mesic/wet forest & upland wetlands	Low	Mod
Knowledge	Preserve genetic diversity	Increase information on pollinators for different habitat types	O'ahu	Native ecosystems and rare species conservation		
Knowledge	Increase capacity for mesic/wet forest restoration	Increase knowledge of how to propagate common and rare species	O'ahu	Mesic/wet forest & upland wetlands	Mod	High
Knowledge	Increase understanding of water resources and their value	Increase knowledge of water needs of native ecosystems and species and the impact of water withdrawals on these resources	Hawai'i	Water resources	Low	Mod
Knowledge	Improve public education on the importance of dry forest habitats	Increase layperson knowledge of dry-forest related ecosystem services and linkages between dry forests and coral reefs	O'ahu	Dry forest	Low-mod (low)	High
Knowledge	Increase understanding of water resources and their value	Increase monitoring of groundwater and surface water resources	Hawai'i	Water resources	Low	Mod
Knowledge	Increase understanding of water resources and their value	Investigate automated techniques and organizations/agencies that could serve as data managers	Hawai'i	Water resources	Low	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Improve water conservation efforts	Increase outreach and education on water conservation in light of climate change (e.g., mauka to makai event at aquarium)	O'ahu	Aquatic (streams)	Mod-high (Mod)	High
Knowledge	Minimize the impacts of non-native species (e.g., cats, rodents, mongoose, arthropods [Argentine ant])	Increase public awareness of invasive species risk and spread	Hawai'i	Alpine/subalpine	Low	High
Knowledge	Reduce non-climate stressors that limit water supply	Increase public education (industries, agriculture, residents, tourists) on water conservation in light of climate change (i.e. integrate messaging into water bills)	O'ahu	Water resources	Mod	High
Knowledge	Reduce invasive plants across the landscape in areas not being managed as weed-free	Increase public education on native species and detriments of planting non-native species	Hawai'i	Invasive species management		
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Increase public understanding of differences between native, non-native, and invasive species	Kaua'i	Invasive species management	Mod	High
Knowledge	Conduct research on species, habitat requirements, and threats	Increase research on diseases and pathogens	Kaua'i	Native ecosystems and rare species conservation	Low	Mod
Knowledge	Manage invasive species	Increase research on invasive species to stay ahead of climatic impacts	Kaua'i	Native ecosystems and rare species conservation	Low	Mod
Knowledge	Manage invasive species	Increase research on novel biocontrol techniques (biotechnology, gene drive to eliminate species)	Kaua'i	Invasive species management	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Increase small-scale testing to determine ideal site conditions (e.g., treatment area size)	Hawai'i	Invasive species management	Low	Mod
Knowledge	Increase education and outreach to increase public engagement and stewardship in conservation	Increase social science efforts to identify triggers in social behavior change and create messaging based on findings to share (e.g., murals, billboards, etc.)	Hawai'i	Native ecosystems and rare species conservation		
Knowledge	Increase biosecurity measures	Increase social science research to monitor biosecurity effectiveness (e.g., incentivizing action, unlock emoji for posting picture at cleaning station)	Hawai'i	Invasive species management		
Knowledge	Develop more efficient technologies/tools for habitat restoration and invasive species control	Increase technical capacity and decrease regulations of invasive species removal (e.g., herbicide delivery)	Maui	Mesic/wet forest	Mod-high (mod)	High
Knowledge	Increase understanding of water resources and their value	Increase understanding of groundwater influence on anchialine pools	Hawai'i	Water resources	Low	Mod
Knowledge	Collect data on stream habitats	Install automatic sensors that monitor streams 24/7	Maui	Aquatic	High	High
Knowledge	Increase biocultural landscape-based planning and management	Kilo 'āina practice to document conditions of resources related to cultural practices and livelihood and identify their future locations	Hawai'i	Cultural resources	Mod	Mod
Knowledge	Prepare for sea level rise impacts	Map sea level rise impacts and future shoreline position	Kaua'i	Native ecosystems and rare species conservation	Low	High
Knowledge	Collect data on existing non-climate stressors	Monitor abundance of native and invasive forest species as temperature rises and precipitation changes	O'ahu	Mesic/wet forest	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Monitor pollutants to protect water quality	Monitor and regulate salinity and other indicators of water quality in wells and groundwater	Maui	Aquatic	Mod	Low
Knowledge	Monitor pollutants to protect water quality	Monitor point- and non-point source pollutants associated with agriculture and development (e.g., fertilizers, insecticides, agricultural byproducts)	Maui	Aquatic	Mod	Low
Knowledge	Enhance long-term monitoring efforts to better understand changes in abundance, distribution, and ecological impacts of native and rare species	Monitor regeneration/outplanting success, including the status of in situ populations	Hawai'i	Dry forest	Mod	Low
Knowledge	Enhance long-term monitoring efforts to better understand changes in abundance, distribution, and ecological impacts of native and rare species	Monitor the long-term effectiveness of rare species management and restoration	Hawai'i	Native ecosystems and rare species conservation		
Knowledge	Conduct research to support adaptive policies and technology that increase landscape-level protection and restoration	Research and develop new/improved methods of small predator control	Maui	Alpine/subalpine	High	High
Knowledge	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Research historic conditions and trends in cultural practices (e.g., environmental baseline conditions) to inform current management	Kaua'i	Cultural resources and practices	Mod	Mod
Knowledge	Increase understanding of water quantity, quality, and allocations under changing climate conditions	Research options for water allocations under changing climate conditions	Kaua'i	Water resources	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Conduct research on species, habitat requirements, and threats	Research pesticide impacts on waterbird species	Kauaʻi	Native ecosystems and rare species conservation	Low	Mod
Knowledge	Anticipate potential shifts in invasive species distributions	Research range of conditions invasive species can tolerate to determine where invasive species may expand	Oʻahu	Invasive species management	Mod	Mod
Knowledge	Gather information on fire vulnerability/resilience in native communities	Research seed production and storage to protect genetic integrity	Hawaiʻi	Native ecosystems and rare species conservation	Mod	Mod
Knowledge	Gather information on fire vulnerability/resilience in native communities	Research the relationship of invasive and non-native species to fire	Hawaiʻi	Native ecosystems and rare species conservation		
Knowledge	Improve water conservation efforts	Use ENSO Climate Outlooks to facilitate public understanding of potential climate impacts on water resources	Oʻahu	Aquatic (streams)	Mod	High
Knowledge	Protect current and future habitat	Use gap analysis planning to identify areas that need protection based on specific climate-informed criteria	Maui	Coastal	High	Mod
Knowledge	Increase understanding of water resources and their value	Utilize citizen science and increase community involvement to expand monitoring efforts	Hawaiʻi	Water resources	Low	Mod
Knowledge	Enhance long-term monitoring efforts to better understand changes in abundance, distribution, and ecological impacts of native and rare species	Utilize existing climate monitoring framework to define priorities and goals (e.g., Hawai'i Rare Plant Restoration Group)	Hawaiʻi	Native ecosystems and rare species conservation		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Knowledge	Identify community concerns about climate change and variability to help direct research	Work with communities and cultural practitioners to identify the cultural resources most at risk	Oʻahu	Cultural resources and practices	Mod	Mod
Resilience	Increase streamflow	Artificially enhance impaired streams by using recycled water in urban sites and near streams with reduced flow	Oʻahu	Aquatic (streams)	High	Low
Resilience	Reconnect/enhance connections of people to place	Build the local economy to support ecosystem conservation and protection and enhance sustainability (e.g., create jobs, preserve human needs, preserve natural and cultural heritage)	Hawaiʻi	Shorelines, aquatic, tidally-influenced habitats	High	Mod-high
Resilience	Increase local food security	Create rating system for public to emphasize and promote local foods grown through Native Hawaiian practices	Oʻahu	Land-use planning	Mod	High
Resilience	Reduce non-climate stressors that affect water quality	Encourage low-impact development and green infrastructure to reduce the extent of impervious pavement	Oʻahu	Water resources	Mod	High
Resilience	Increase biocultural landscape-based planning and management	Identify and issue permits for all cultural land-use practices, increasing diversity of land-use designations where needed (e.g., agriculture, flexible land-use transects, floating zones)	Hawaiʻi	Cultural resources	High	Mod
Resilience	Prioritize and pair habitat restoration with cultural resource management	Implement ahupuaʻa practices to encourage geographically based restoration and a sustainability mindset	Maui	Cultural resources and practices	High	High
Resilience	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	Modify stream crossings to enhance fish passage and habitat connectivity	Oʻahu	Aquatic (streams)	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Prepare for sea level rise impacts	Redesign development guidelines to account for sea level rise and other climate change impacts	Kauaʻi	Native ecosystems and rare species conservation	High	High
Resilience	Prioritize and pair habitat restoration with cultural resource management	Restore culturally significant habitats from mauka to makai (e.g., loʻi, forests, beaches)	Maui	Cultural resources and practices	Mod	Mod
Resilience	Maintain/improve water quantity and quality	Retrofit infrastructure to reduce water losses and improve water conservation	Oʻahu	Water resources	Mod	High
Resilience	Restore degraded dry forest habitat	Revegetate dry forests by outplanting native species (i.e. along dry forest edges, Wildland-Urban Interface, higher elevations to increase survival)	Oʻahu	Dry forest	Mod-high (high)	Mod
Resilience	Build fire-resilient native communities	Stabilize soils following wildfires to prevent post-burn erosion	Hawaiʻi	Native ecosystems and rare species conservation	High	High
Resilience	Maintain and augment native species populations	Actively restore high-priority sites inside the fence, considering surrogate species that may be tolerant of future climate conditions	Maui	Alpine/subalpine	Mod	Mod
Resilience	Maintain and restore existing dry forest habitat	Advocate for regulatory policy changes that move away from decisions based on historic ranges and prioritize landscape approaches	Hawaiʻi	Dry forest	High	Mod-high (mod)
Resilience	Create more nimble planning and zoning processes that promote natural landscapes and community values and is adaptable to climate change	Allow community priorities to drive strategic planning processes	Hawaiʻi	Land-use planning	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Prioritize and pair habitat restoration with cultural resource management	Articulate the value of culturally-significant habitats (especially for cultural resource improvement)	Maui	Cultural resources and practices	Mod	High
Resilience	Maintain intact, native-dominated ecosystems	Augment native habitat through outplanting and seeding of temperature- and drought-tolerant species in post-disturbance sites and buffer zones	Hawaiʻi	Mesic/wet forest	Low-mod (mod)	Mod
Resilience	Create a self-sustaining forest that requires limited or no on-the-ground human management	Change policy to allow the use of unmanned aerial systems to aid management efforts (e.g., invasive control, mapping/monitoring)	Hawaiʻi	Mesic/wet forest	Mod-high (mod)	Low-mod (low)
Resilience	Maintain and restore existing dry forest habitat	Collect and propagate native seeds for revegetation in disturbed areas	Maui	Dry forest	Mod	Mod
Resilience	Maintain and restore existing dry forest habitat	Consider climate projections in the timing and seasonality of planting to promote natural recruitment	Oʻahu	Dry forest	Mod	High
Resilience	Integrate cultural knowledge into resource management	Consider cultural values, resources, and sites in responding to extreme weather events, climate change, and storms	Oʻahu	Cultural resources and practices	Mod	Mod
Resilience	Promote climate-adapted agricultural practices	Consider innovative locations to grow crops under future climate conditions	Hawaiʻi	Suggested by VA workshop participants	Mod	Low
Resilience	Maintain and augment native species populations	Control and remove invasive plants and predators	Oʻahu	Lowland freshwater wetlands	High	Mod
Resilience	Manage invasive species	Control invasive plants via chemical and mechanical removal	Kauaʻi	Aquatic	Mod-High (mod)	Low-Mod (mod)
Resilience	Improve resilience of key dry forest species/communities	Create a digital and physical genetic database to protect remaining species, using both in situ (outplanting) and ex situ (seed storage) methods	Maui	Dry forest	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Maintain and restore water quality and quantity by controlling erosion and sedimentation	Create and maintain check dams and retention basins to mechanically control erosion	Maui	Mesic/wet forest	Mod	Mod
Resilience	Manage invasive species	Create and manage invasive-free buffer zones to protect high-value habitats (e.g., prioritize removal of fire-adapted invasives)	Kauaʻi	Invasive species management	High	Low
Resilience	Increase biocultural landscape-based planning and management	Create cultural use and practice overlays for land use planning and/or climate adaptation areas	Hawaiʻi	Cultural resources	Mod	Mod
Resilience	Increase environmental and climate literacy across all ages	Create key messages and engagement strategies for specific vulnerabilities and/or different areas/islands and tailor them for specific audiences (e.g., decision-makers, communities, and individuals)	Oʻahu	Public engagement & outreach		
Resilience	Increase biocultural landscape-based planning and management	Create overlay of resources and practices as they exist now and projected into the future (e.g., overlay cultural sites with sea level rise projections)	Hawaiʻi	Cultural resources	Mod	Mod
Resilience	Revise environmental policies to elevate cultural resource concerns	Create policies that maintain public access to coastal, forest, and wetland areas	Maui	Cultural resources and practices	Mod	Mod
Resilience	Engage developers, real estate, and insurance companies on climate-related risk and response for coastlines	Create policy to require climate-informed development (e.g., law to require real estate disclosures)	Oʻahu	Land-use planning	High	Mod
Resilience	Increase environmental and climate literacy across all ages	Create preparedness kits in advance with outreach materials (e.g., key messages and actions, press releases) to quickly gain public support after weather/climate events	Oʻahu	Public engagement & outreach		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Increase public understanding of alpine/subalpine habitats to decrease stress on these systems	Create remote sites and viewpoints that have sightlines of alpine/subalpine habitats and post public signage about the natural and cultural importance of habitats	Hawai'i	Alpine/subalpine	Mod	Mod-high (mod)
Resilience	Maintain/improve water quantity and quality	Develop a stormwater residential tax, and use revenue to fund water capture and reuse projects	O'ahu	Water resources	Mod	Mod
Resilience	Increase education and outreach to increase public engagement and stewardship in conservation	Develop metrics to evaluate the success of public stewardship conservation campaign	Hawai'i	Native ecosystems and rare species conservation		
Resilience	Increase streamflow to protect habitat and water supply	Encourage non-extractive water uses (e.g., taro farming)	Maui	Aquatic	Low	Mod
Resilience	Maintain water availability	Encourage use of native plants that increase filtration and use water more efficiently	Kaua'i	Water resources	Mod	High
Resilience	Revise environmental policies to elevate cultural resource concerns	Enforce existing conservation zoning laws (e.g., Haleakalā)	Maui	Cultural resources and practices	Mod	High
Resilience	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Ensure cultural practitioners have ownership over what kind and detail of information is shared about important cultural resources (e.g., site locations); identify what needs to be kept quiet and protected, versus what can be broadly shared	Kaua'i	Cultural resources and practices	Mod	Mod
Resilience	Incorporate cultural concerns and community relations into climate adaptation projects	Ensure projects are consistent with cultural resource protection	O'ahu	Cultural resources and practices	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	Establish and enforce instream flow standards in streams with multiple diversions and existing conflicts/competition	Oʻahu	Aquatic (streams)	High	Low (enforcement) to moderate (establishment)
Resilience	Increase streamflow to protect habitat and water supply	Establish and enforce mandated instream flow standards	Maui	Aquatic	High	Mod
Resilience	Maintain water availability	Establish required stream baseflows to maintain native stream species, cultural practices, and traditional rights	Kauaʻi	Water resources	High	Mod
Resilience	Improve resilience of key dry forest species/communities	Explore genetic engineering for increased resilience (e.g., drought tolerance)	Maui	Dry forest	Mod	Mod
Resilience	Mandate acquisition of new technologies to maintain and enhance water quality	Extract sodium to increase fresh water supplies	Maui	Aquatic	High	High
Resilience	Build fire-resilient native communities	Gather information on areas of increased vulnerability to fire to change the way areas are prioritized for fire management	Hawai'i	Native ecosystems and rare species conservation	Mod	Mod
Resilience	Maintain and augment native species populations	Identify a good existing seed bank and allow for natural regeneration	Maui	Alpine/subalpine	Mod	High
Resilience	Improve resilience of key dry forest species/communities	Identify and prioritize existing dry forest biomes and create a strategy to expand protection and restoration	Maui	Dry forest	High	Mod
Resilience	Increase biocultural landscape-based planning and management	Identify different elevational areas and various landscapes across the islands based on mokus (districts) and compare these with county community boundaries to create community-defined, practice-based zones	Hawai'i	Cultural resources	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Create more nimble planning and zoning processes that promote natural landscapes and community values and are adaptable to climate change	Identify island carrying capacity and examine novel ways to manage growth (e.g., Florida Keys)	Hawai'i	Land-use planning	Mod	High
Resilience	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Identify where cultural sites are and how to best preserve them into the future	Kaua'i	Cultural resources and practices	Mod	High
Resilience	Preserve, restore, and increase resilience of native ecosystems	Identify, prioritize, protect, and create future potential sites along mauka to makai corridors (i.e. existing native habitat, areas with overlapping future projected habitat)	O'ahu	Native ecosystems and rare species conservation		
Resilience	Build fire-resilient native communities	Implement larger-scale seed production/storage for pre- and post-burn planting efforts	Hawai'i	Native ecosystems and rare species conservation	Mod	Low
Resilience	Preserve water supplies by increasing water use efficiency	Improve rainfall capture to decrease groundwater withdrawals	Hawai'i	Water resources	Mod	Mod
Resilience	Maintain and restore existing dry forest habitat	Improve seed collection and storage by creating common native seed orchards and increasing the number of seed labs	O'ahu	Dry forest	Low-mod (mod)	Low-mod (mod)
Resilience	Increase local food security	Incentivize and subsidize local food sources	O'ahu	Land-use planning		
Resilience	Create more nimble planning and zoning processes that promote natural landscapes and community values and is adaptable to climate change	Include climate change as a component of community plans and zoning	Hawai'i	Land-use planning	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Implement climate-informed coastal zoning protections	Incorporate climate change into Special Management Area siting and permitting	Maui	Coastal	Mod-high (mod)	Low-mod (mod)
Resilience	Encourage local participation in preserving cultural resources	Increase availability of cultural education and apprenticeships	O'ahu	Cultural resources and practices	High	Mod
Resilience	Increase education and outreach to increase public engagement and stewardship in conservation	Increase environmental science education opportunities	Hawai'i	Native ecosystems and rare species conservation		
Resilience	Create more nimble planning and zoning processes that promote natural landscapes and community values and is adaptable to climate change	Increase flexibility of policies that guide management in response to climate change (e.g., shorten land use/general planning timeframe, adjust constituency of updates)	Hawai'i	Land-use planning	Mod	Mod
Resilience	Manage invasive species	Increase invasive species eradication efforts through manual removal and/or biocontrol of ungulates, predators, and plants with a high rate of spread	O'ahu	Mesic/wet forest & upland wetlands	Mod (removal) to unknown (biocontrol) (mod)	Mod
Resilience	Increase public understanding of alpine/subalpine habitats to decrease stress on these systems	Increase stewardship of nearby, human-inhabited local conservation lands	Hawai'i	Alpine/subalp ine	Low-mod (low)	High
Resilience	Preserve water supplies by increasing water use efficiency	Increase use of alternative water sources (i.e. stormwater, gray water, recycled reclaimed water, capture fog drip)	Hawai'i	Water resources	Mod	Mod
Resilience	Maintain/improve water quantity and quality	Increase water catchments and reservoirs	O'ahu	Water resources	Mod	High
Resilience	Maintain/improve water quantity and quality	Increase watershed management planning	Kaua'i	Coastal	Low-Mod (mod)	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Mandate acquisition of new technologies to maintain and enhance water quality	Install diversion gates	Maui	Aquatic	High	High
Resilience	Preserve cultural practices and sites (e.g., landscapes, traditions, and values)	Integrate climate change into aina-based programming	Hawai'i	Cultural resources	High	High
Resilience	Maintain/improve water quantity and quality	Integrate climate projections into forest and watershed restoration and protection efforts	O'ahu	Water resources	High	High
Resilience	Engage developers, real estate, and insurance companies on climate-related risk and response for coastlines	Integrate climate risk and adaptation into continuing education requirements and real estate magazines to promote resilient residential areas	O'ahu	Land-use planning	Mod	Mod
Resilience	Engage developers, real estate, and insurance companies on climate-related risk and response for coastlines	Integrate design and engineered solutions into development (e.g., resilient shorelines, xeriscaping, floodable development)	O'ahu	Land-use planning	High	High
Resilience	Promote climate-adapted agricultural practices	Investigate alternative agricultural crop varieties and mixes with economic value	Hawai'i	Suggested by VA workshop participants	Mod	Mod
Resilience	Preserve water supplies by increasing water use efficiency	Investigate alternative agricultural crops that have economic benefit and capture water	Hawai'i	Water resources	Mod	Mod
Resilience	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Investigate whether iwi should be re-interred in more resilient areas or left in place	Kaua'i	Cultural resources and practices	Low	Mod
Resilience	Increase local food security	Limit exports of locally-produced food	O'ahu	Land-use planning		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Maintain water availability for cultural groups to sustain traditional practices (e.g., loʻi and spring use)	Oʻahu	Cultural resources and practices	High	Mod
Resilience	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	Modify culverts to accommodate extreme flooding	Oʻahu	Aquatic (streams)	Mod	Mod
Resilience	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	Modify diversions to allow flow passage, particularly on high-use streams under development pressure	Oʻahu	Aquatic (streams)	High	Mod
Resilience	Implement climate-informed coastal zoning protections	Modify the formula for erosion control to incorporate data on climate change	Maui	Coastal	Mod-high (mod)	Low-mod (Mod)
Resilience	Improve fire prevention and response	Outplant drought- and fire-resistant native species	Maui	Native ecosystem conservation	Mod	Mod
Resilience	Maintain intact, native-dominated ecosystems	Outplant native species to create habitat and facilitate biome shifts	Maui	Mesic/wet forest	High	Low-mod (mod)
Resilience	Build fire-resilient native communities	Plant or seed fire-resilient species in burned areas, considering the presence of ungulates during species selection	Hawaiʻi	Native ecosystems and rare species conservation	High	Mod
Resilience	Build fire-resilient native communities	Plant or seed fire-resilient species in vulnerable areas while excluding flammable invasive species	Hawaiʻi	Native ecosystems and rare species conservation	High	Mod
Resilience	Maintain and restore water quality and quantity by controlling erosion and sedimentation	Plant species that control erosion (e.g., vetiver)	Maui	Mesic/wet forest	Mod	Low-mod (mod)

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Maintain and augment native species populations	Practice ex situ conservation of native species (e.g., seed banking, captive breeding) that represent genetic and habitat diversity	Kauaʻi	Mesic/wet forest	Mod	Mod
Resilience	Restore streamflows to restore connectivity, stream quality, and native species movement and re-establishment	Practice holistic management by eliminating watershed transfers and restoring traditional decision-making	Oʻahu	Aquatic (streams)	High	Low
Resilience	Manage invasive species	Prioritize invasive plant removal, focusing on areas with high diversity or rare species	Maui	Alpine/subalpine	High	Mod
Resilience	Manage invasive species	Prioritize invasive species removal in high-quality fenced habitat, particularly in lowland areas to prevent upward invasive movement	Oʻahu	Mesic/wet forest & upland wetlands	Mod	Mod
Resilience	Promote technical and cultural practices to reduce stream flashiness and associated invasive species transport	Protect and restore culturally appropriate loʻi to decrease high flow events and stream flashiness	Maui	Invasive species management	High	Mod
Resilience	Increase local food security	Rediscover and integrate historic/native food sources into local diets and culture (e.g., breadnut, breadfruit)	Oʻahu	Land-use planning		
Resilience	Increase local food security	Support markets for local foods (CSA boxes, grocery, farmers market)	Oʻahu	Land-use planning		
Resilience	Increase local food security	Integrate native food sources into school food programs	Oʻahu	Land-use planning		
Resilience	Build fire-resilient native communities	Replace compromised fences and control invasive plants following a wildfire	Hawaiʻi	Native ecosystems and rare species conservation	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Increase local food security	Research and promote adaptive crop strains to promote resilient crops (e.g., drought-, salt-, and temperature-tolerant species/varieties)	Oʻahu	Land-use planning	Mod	Mod
Resilience	Incorporate cultural concerns and community relations into climate adaptation projects	Research community priorities to avoid adversely affecting cultural resources	Oʻahu	Cultural resources and practices	High	High
Resilience	Restore coastal habitats	Restore dune and coastal strand habitats	Maui	Coastal	Mod	High
Resilience	Maintain and restore native mesic and wet forest habitat	Restore forests with resilient common species, as well as rare species	Oʻahu	Mesic/wet forest & upland wetlands	Mod (not paired with fencing & invasive removal) to high (if paired) (high)	Low-mod (mod)
Resilience	Increase ecosystem resilience, connectivity, and integrity	Restore hydrologic function (i.e. reduce/remove diversions, convert ditches to pipes)	Maui	Water resources	High	Mod
Resilience	Restore and conserve native shoreline and estuary habitat	Restore native species	Oʻahu	Shorelines & estuaries	Mod	Mod
Resilience	Revise environmental policies to elevate cultural resource concerns	Revise planning documents (e.g., Maui Island Plan) based on climate change data	Maui	Cultural resources and practices	Mod	High
Resilience	Implement climate-informed coastal zoning protections	Revise setback requirements to account for projected sea level rise	Maui	Coastal	Mod-high (mod)	Low-mod (mod)
Resilience	Revise environmental policies to elevate cultural resource concerns	Revise the coastal erosion formula and setback requirements in Special Management Areas to account for projected sea level rise	Maui	Cultural resources and practices	Mod	Mod
Resilience	Encourage local participation in preserving cultural resources	Streamline permitting system for practitioners and partners (e.g., one permit for a fishpond system instead of several)	Oʻahu	Cultural resources and practices	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resilience	Protect forests to increase recharge and water retention	Support healthy native forests through land acquisition and plant restoration	Maui	Aquatic	Mod	Mod
Resilience	Increase food security to build resilient cultural communities	Use community gardens as pilot sites to test resilient crops	Kauaʻi	Cultural resources and practices	Mod	High
Resilience	Increase food security to build resilient cultural communities	Use community gardens to emphasize cultural traditions (e.g., planting/harvesting by lunar calendar, becoming kilo)	Kauaʻi	Cultural resources and practices	Mod	High
Resilience	Preserve water supplies by increasing water use efficiency	Use Hawaiian field system to slow water, increase recharge, and use as a model for other places	Hawaiʻi	Water resources	High	Mod
Resilience	Maintain and augment native species populations	Use native out plantings to relocate and/or increase native plant and animal populations	Oʻahu	Lowland freshwater wetlands	Mod	High
Resilience/Response	Restore coastal habitats	Outplant native species in current and potential future coastal wetland habitats	Maui	Coastal	Mod	High
Resistance	Manage invasive species	Control invasive predators (cats, rats, snakes, mongooses)	Kauaʻi	Coastal	Low	Mod
Resistance	Maintain and protect existing dry forest habitat	Develop tree fall protocols for storm damage to fences (i.e. strategic removal of trees pre-storm) and increase funding for repairs	Oʻahu	Dry forest	Mod	High
Resistance	Manage for invasive-resistant communities	Expand fencing and ungulate removal in areas more resilient to invasion (e.g., a'a lava flows, higher elevations) and Special Ecological Areas	Hawaiʻi	Mesic/wet forest	High	Mod
Resistance	Perpetuate cultural knowledge, practices, and sites (e.g., landscapes, traditions, and values)	Identify climate-informed processes for conservation practices in vulnerable cultural sites	Kauaʻi	Cultural resources and practices	Low	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Increase biosecurity measures	Look to other places with good biosecurity (e.g., New Zealand) to copy successful strategies	Hawai'i	Invasive species management		
Resistance	Maintain/improve water quantity and quality	Manage runoff (stormwater, wastewater, nutrients) in areas affected by human activity	Kaua'i	Coastal	Mod	High
Resistance	Integrate invasive species management into societal operations	Add invasive plant survey to home inspection process	Kaua'i	Invasive species management		
Resistance	Maintain and enhance groundwater quality and quantity	Adopt well source protection ordinances	Maui	Aquatic	High	High
Resistance	Maintain/improve water quantity and quality	Alter well drill depths and practice optimal well placement to minimize vulnerability to saltwater intrusion	O'ahu	Water resources	High	High
Resistance	Increase biosecurity measures	Change policies to update exclusion laws and prevent species import	O'ahu	Invasive species management		
Resistance	Increase local food security	Conduct disaster planning with private shipping companies (Matson, Young Brothers, Pasha)	O'ahu	Land-use planning		
Resistance	Preserve water supplies by increasing water use efficiency	Consider payment for ecosystem services (i.e. landowners that recharge water receive payment)	Hawai'i	Water resources	Mod	Mod
Resistance	Reduce non-climate stressors that limit water supply	Continue fencing to maintain water yields of one million gallons per day	O'ahu	Water resources	High	Mod
Resistance	Manage invasive species	Control invasive predators via trapping in priority areas (i.e. critical habitats, areas less vulnerable to flooding) during dry periods	Kaua'i	Aquatic	Mod-High (mod)	Mod
Resistance	Manage invasive species	Control ungulates via fencing and animal removal (e.g., trapping, hunting, snares) in high elevation watersheds that may serve as refugia	Kaua'i	Mesic/wet forest	High	Mod-High (mod)

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Reduce non-climate stressors that affect water quality	Convert cesspools to septic systems	O'ahu	Water resources	High	Mod
Resistance	Increase biosecurity measures	Coordinate inspections happening by different agencies	O'ahu	Invasive species management		
Resistance	Improve fire prevention and response	Create a system of water storage tanks to support rapid fire response	Maui	Dry forest	High	Mod
Resistance	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	Create an app to track location of fire risk zones and increase public reporting of fires	O'ahu	Land-use planning		
Resistance	Integrate invasive species management into societal operations	Create invasive species management guidelines for homeowners and land owners	Kaua'i	Invasive species management		
Resistance	Reduce human pressure on native ecosystems and species	Create tourism caps to reduce or spread impacts	Kaua'i	Native ecosystems and rare species conservation		
Resistance	Reduce invasive plants across the landscape in areas not being managed as weed-free	Decrease sale of invasive species by nurseries	Hawai'i	Invasive species management		
Resistance	Improve water conservation efforts	Develop a water budget to account for all water sources, connectivity, uses/withdrawals, and disposal/discharges	Maui	Water resources	Low	Mod
Resistance	Maintain water availability	Encourage landowners to bank water and create new reservoirs	Kaua'i	Water resources	High	Mod
Resistance	Improve fire prevention and response	Enhance public awareness of the risks and consequences of wildfire to native plant ecosystems	Maui	Native ecosystem conservation	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Manage invasive species	Erect fencing to protect subalpine areas from feral ungulates	Maui	Alpine/subalpine	High	Mod
Resistance	Improve fire prevention and response	Establish fuel breaks where needed to protect priority areas within native ecosystems	Maui	Native ecosystem conservation	High	Mod
Resistance	Manage invasive species	Expand fencing to lower elevations, focusing on incipient sites or most vulnerable areas throughout the forest	Maui	Mesic/wet forest	Mod-high (high)	High
Resistance	Manage invasive species	Expand the use of fencing in and remove invasive ungulates and plants from remnant native habitats and corridors between protected habitats	Maui	Dry forest	Mod	Mod
Resistance	Reduce the impacts of non-climate stressors on remnant dry forest	Fence high-quality habitat areas (e.g., areas with intact canopy and good structure) and remove invasive ungulates	Hawaiʻi	Dry forest	Mod	High
Resistance	Manage invasive species	Fence priority areas to exclude invasive species within intact forest	Oʻahu	Mesic/wet forest & upland wetlands	Moderate (mesic) to high (wet) (mod)	Mod
Resistance	Anticipate potential shifts in invasive species distributions	Identify and protect areas (e.g., use fencing) with the least invasive species and where preventing new introductions is most critical	Oʻahu	Invasive species management	High	Mod
Resistance	Maintain some weed-free areas around areas of identified concern	Identify buffer areas for different invasive species in relation to management areas	Hawaiʻi	Invasive species management	Mod	Mod
Resistance	Maintain and protect existing dry forest habitat	Improve biosecurity controls to prevent the introduction of invasive insects, pathogens, plants, and animals	Oʻahu	Dry forest	Low	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Reduce non-climate stressors that limit water supply	Improve water conservation efforts (e.g., fix leaks)	O'ahu	Water resources	Mod	High
Resistance	Reduce non-climate stressors that limit water supply	Incentivize rainwater capture for local irrigation	O'ahu	Water resources	Mod	High
Resistance	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	Incorporate climate materials into fire management education (e.g., fire departments visiting schools)	O'ahu	Land-use planning		
Resistance	Improve water conservation efforts	Increase agricultural water conservation (i.e. promote soil moisture management, capture rain water)	Maui	Water resources	High	Mod
Resistance	Improve fire prevention and response	Increase and then enforce penalties for starting fires	Hawai'i	Native ecosystems and rare species conservation		
Resistance	Manage invasive species	Increase biosecurity	Kaua'i	Coastal	Mod	Low
Resistance	Maintain and protect existing dry forest habitat	Increase biosecurity to prevent fire-adapted species introductions	O'ahu	Dry forest	High	Mod
Resistance	Manage invasive species	Increase early detection and rapid response measures	Kaua'i	Native ecosystems and rare species conservation		
Resistance	Increase education and outreach to increase public engagement and stewardship in conservation	Increase education and outreach on invasive species risks and specific actions the public can take to reduce introduction and spread (e.g., sterilize recreation equipment)	O'ahu	Invasive species management	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Maintain and protect existing dry forest habitat	Increase fencing and invasive plant and ungulate removal at high elevations to increase continuity between dry and mesic/wet forest habitats	Oʻahu	Dry forest	High	High
Resistance	Reduce the impacts of non-climate stressors on remnant dry forest	Increase fire prevention and fuel management (e.g., grazing, fuel breaks) in most intact dry forest habitats	Hawaiʻi	Dry forest	High	Mod
Resistance	Improve fire prevention and response	Increase fuel reduction efforts in Wildland-Urban Interface, common ignition sites, and areas of high conservation value	Maui	Dry forest	High	Mod
Resistance	Improve fire prevention and response	Increase funding for support of fire response agencies and Community Wildland Protection Plans	Maui	Native ecosystem conservation	High	Mod
Resistance	Increase biosecurity measures	Increase inspections (boats, planes, military) on all goods between islands and overseas	Oʻahu	Invasive species management	High	Low
Resistance	Improve water conservation efforts	Increase public and private water system conservation (i.e. alter rate structure, use low-flow fixtures, detect and fix leaks)	Maui	Water resources	High	Mod
Resistance	Improve fire prevention and response	Increase public awareness of fire-related issues	Hawaiʻi	Native ecosystems and rare species conservation		
Resistance	Manage invasive species	Increase regulations and broaden policy options	Kauaʻi	Native ecosystems and rare species conservation		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Maintain and protect existing dry forest habitat	Increase research on strategic firebreak placement and change placement if necessary to improve fire prevention	Oʻahu	Dry forest	Mod	Mod
Resistance	Reduce the impacts of non-climate stressors on remnant dry forest	Increase the number of fuel breaks below restoration and reforestation sites, and use non-native, non-invasive, drought-tolerant species when possible	Hawaiʻi	Dry forest	High	Mod
Resistance	Manage invasive species	Increase upfront investment in ungulate and mammalian predator removal through hunting/shooting and snares	Maui	Mesic/wet forest	Mod-High	High
Resistance	Increase biosecurity measures	Integrate climate change into forthcoming state biosecurity plan	Oʻahu	Invasive species management		
Resistance	Increase public education on current and projected fire risk (e.g., zones and public fire reporting)	Integrate climate change into Wildland-Urban Interface designations and future landscape development, particularly for areas that are dry or projected to become drier	Oʻahu	Land-use planning	High	Mod
Resistance	Maintain/improve water quantity and quality	Investigate and reduce non-point source pollution	Hawaiʻi	Water resources	High	High
Resistance	Increase streamflow	Investigate engineering solutions (e.g., bulkheading tunnels) within existing tunnel systems with insufficient flow	Oʻahu	Aquatic (streams)	High	High
Resistance	Increase local food security	Limit development on agricultural land	Oʻahu	Land-use planning		
Resistance	Preserve water supplies by increasing water use efficiency	Maintain aquifers by ensuring native forest cover	Hawaiʻi	Water resources	Mod	Mod
Resistance	Improve fire prevention and response	Maintain fuel breaks below power lines and on roadsides	Maui	Dry forest	Mod	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Integrate invasive species management into societal operations	Make invasive species removal required as part of home or property sales	Kauaʻi	Invasive species management		
Resistance	Restore and conserve native shoreline and estuary habitat	Nourish beaches in areas where habitat retreat is not an option	Oʻahu	Shorelines & estuaries	Low	Moderate-high (Waikiki and other tourist areas) (Mod) Low (County Beach Park, similar places)
Resistance	Reduce non-climate stressors that affect water quality	Practice strategic watershed fence placement from mauka to makai to best enhance water quality	Oʻahu	Water resources	Moderate	Moderate
Resistance	Increase food security to build resilient cultural communities	Preserve cultural foods	Kauaʻi	Cultural resources and practices	High	Mod
Resistance	Increase food security to build resilient cultural communities	Preserve salt making and taro production	Kauaʻi	Cultural resources and practices	Mod	Mod
Resistance	Manage invasive species	Prevent introduction of new diseases and pathogens by increasing biosecurity controls (e.g., quarantines, intraisland policies, optional vs. mandatory restrictions)	Kauaʻi	Native ecosystems and rare species conservation	Mod	Low
Resistance	Improve fire prevention and response	Prevent off-road vehicle and pedestrian activity in high recharge areas, sensitive watersheds, and core native habitats through education and access limits	Maui	Mesic/wet forest	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Prepare for sea level rise impacts	Prioritize coastal areas for protection	Kauaʻi	Native ecosystems and rare species conservation	Mod	High
Resistance	Preserve, restore, and increase resilience of native ecosystems	Protect and preserve remnant habitat, and include a diversity of sites	Oʻahu	Native ecosystems and rare species conservation	Mod	Mod
Resistance	Protect cultural practices (e.g., fishing, gathering, farming, fiber collection and processing)	Protect water rights and public access to the shoreline and forest	Maui	Cultural resources and practices	High	Mod
Resistance	Protect cultural practices (e.g., fishing, gathering, farming, fiber collection and processing)	Protect/create dedicated spaces for cultural practices	Maui	Cultural resources and practices	High	Mod
Resistance	Maintain/improve water quantity and quality	Provide incentives for Hawaiian field systems to not be developed or grazed by cattle	Hawai'i	Water resources	High	Mod
Resistance	Integrate invasive species management into societal operations	Provide tax rebates for invasive species removal	Kauaʻi	Invasive species management		
Resistance	Reduce non-climate stressors that affect water quality	Reduce pollutant and sediment runoff (e.g., revegetate slopes with native plants, reduce acreage of fallow agricultural land)	Oʻahu	Water resources	High	High
Resistance	Manage invasive species	Reframe, revise, and update invasive species lists: identify invasiveness level and potential ecological impacts, identify different vectors for introduction, and add prioritization layer or numerical risk value to help influence permitting and inform acceptable imports	Kauaʻi	Invasive species management		

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Restore coastal habitats	Remove and control invasive and alien species in wetlands	Maui	Coastal	Mod	High
Resistance	Manage invasive species	Remove feral ungulates through aerial eradication, ground hunting, or snares	Maui	Alpine/subalpine	High	High
Resistance	Manage invasive species	Remove hau and mangroves	Kauaʻi	Coastal	Low	Mod
Resistance	Manage invasive species	Remove invasive plants (e.g., Miconia)	Maui	Aquatic	Mod	Mod
Resistance	Manage invasive species	Remove invasive plants through biological, chemical, or mechanical treatments	Maui	Mesic/wet forest	Mod	Mod
Resistance	Manage invasive species	Remove invasive species in priority native ecosystems from mauka to makai	Kauaʻi	Native ecosystems and rare species conservation	High	Low
Resistance	Restore and conserve native shoreline and estuary habitat	Remove mangroves and other invasive vegetation	Oʻahu	Shorelines & estuaries	Mod-high (mod)	Mod-high (mod)
Resistance	Manage invasive species	Remove small mammals inside fences, as well as within a buffer around the fence	Maui	Alpine/subalpine	Mod	High
Resistance	Minimize the impacts of non-native species (e.g., cats, rodents, mongoose, arthropods [Argentine ant])	Remove ungulates and erect fencing to protect subalpine habitats	Hawaiʻi	Alpine/subalpine	High	Mod
Resistance	Reduce non-climate stressors that limit water supply	Remove water diversions	Oʻahu	Water resources	High	Mod
Resistance	Reduce the impacts of non-climate stressors on remnant dry forest	Remove weeds, including invasive grasses, in all remnant dry forest habitat and areas that will likely remain dry under a changing climate	Hawaiʻi	Dry forest	Low-mod (mod)	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Reduce invasive plants across the landscape in areas not being managed as weed-free	Reshape landscape management to more sustainable/diverse landscapes, beginning with small parcels	Hawai'i	Invasive species management		
Resistance	Improve water conservation efforts	Retrofit existing infrastructure to reduce water losses	Oʻahu	Aquatic (streams)	Mod	High
Resistance	Increase biosecurity measures	Support implementation of existing biosecurity plans	Hawai'i	Invasive species management	Mod	Mod
Resistance	Manage invasive species	Target nurseries to decrease harmful plant introductions	Kauaʻi	Invasive species management	Mod	High
Resistance	Manage invasive species	Use agriculture as a tool to combat invasive species (e.g., goats for rent for weed control)	Kauaʻi	Invasive species management		
Resistance	Manage invasive species	Use biocontrol measures to reduce invasive plants that are expected to thrive under climate change	Kauaʻi	Mesic/wet forest	Mod	Low-Mod (low)
Resistance	Manage invasive species	Use fencing in critical watersheds to exclude ungulates from upland forested areas	Maui	Aquatic	Mod	Mod
Resistance	Reduce non-climate stressors that limit water supply	Use gray water for irrigation by implementing wastewater and rain water recycling	Oʻahu	Water resources	High	Mod
Resistance	Improve fire prevention and response	Use managed grazing and fuel treatments to limit potential fire spread and severity	Maui	Dry forest	Mod	Mod
Resistance	Promote technical and cultural practices to reduce stream flashiness and associated invasive species transport	Use rain gardens and other landscape tools (e.g., retention basins, check dams) in riparian areas to prevent or minimize the movement of invasive species	Maui	Invasive species management		
Resistance	Restore coastal habitats	Utilize exclusion fencing and restoration in upland areas to enhance erosion control	Maui	Coastal	Mod	High

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Resistance	Restore coastal habitats	Provide erosion control by using fencing to exclude invasive species from upland habitats	Maui	Food & fiber	Mod	High
Resistance	Maintain and protect existing dry forest habitat	Widen firebreaks and increase maintenance in the Wildland-Urban Interface	Oʻahu	Dry forest	Low-mod (mod)	Low-mod (mod)
Resistance	Protect natural cultural resources and native ecosystems	Work with cultural groups to identify the best way to protect cultural sites (e.g., to use or not use signs to mark places)	Oʻahu	Cultural resources and practices	Mod	Mod
Resistance/ Resilience	Ensure no new development occurs in areas that will likely be inundated in the future	Change permitting rules to limit development along the shoreline and floodplain to higher elevations above the 100-year sea level rise projections	Maui	Land-use planning	High	Mod
Response	Increase ecosystem resilience, connectivity, and integrity	Acquire land for mauka migration in anticipation of sea level rise, increasing temperatures, and precipitation changes	Maui	Water resources	Mod	Low
Response	Anticipate and facilitate habitat migration	Acquire property with high future ecosystem value (i.e. less developed, less exposed/vulnerable sites)	Oʻahu	Shorelines & estuaries	High	Mod
Response	Anticipate and facilitate habitat migration	Identify and protect currently vulnerable areas and areas of possible habitat migration based on available data, including existing infrastructure lifetime	Maui	Coastal	High	High
Response	Anticipate and facilitate habitat migration	Amend shoreline setback rules to take climate change into account	Maui	Land-use planning	Mod	Mod
Response	Prepare for sea level rise impacts	Assisted migration of rare species	Kauaʻi	Native ecosystems and rare species conservation	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Response	Facilitate transition of species into new areas as climate regimes shift	Create test plots to determine where habitat may shift along ecotone boundaries and identify potential unintended consequences	Maui	Mesic/wet forest	Mod	High
Response	Engage developers, real estate, and insurance companies on climate-related risk and response for coastlines	Engage on long-term but complex solutions (e.g., managed retreat)	O‘ahu	Land-use planning	Mod	Low
Response	Manage invasive species	Erect fences across biome and habitat borders to allow for potential habitat and species range shifts	Maui	Mesic/wet forest	Mod-High	High
Response	Protect current and future habitat	Establish shoreline setbacks	Hawai‘i	Shorelines, aquatic, tidally-influenced habitats	Mod High (for beaches)	Mod
Response	Anticipate and facilitate habitat migration	Facilitate managed retreat of infrastructure and human communities	Kaua‘i	Coastal	High	Low
Response	Create new wetlands to buffer climate-related habitat change	Factor in climate changes in wetland acquisition planning and examine risk involved in managing new wetlands	O‘ahu	Lowland freshwater wetlands	High	Low-mod (mod)
Response	Use assisted colonization to restore rare species (e.g., corals, turtles, birds)	Identify and prioritize suitable habitat based on factors that suggest long-term ecological sustainability	Maui	Rare species conservation	High	Mod
Response	Protect current and future habitat	Identify and protect low-lying areas where wetlands or anchialine pools can migrate	Hawai‘i	Shorelines, aquatic, tidally-influenced habitats	High	High
Response	Anticipate and facilitate habitat migration	Identify critical infrastructure that needs to be protected or relocated	O‘ahu	Shorelines & estuaries	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Response	Improve resilience of key dry forest species/communities	Identify key species that are most adapted to future climate conditions	Maui	Dry forest	High	Mod
Response	Facilitate transition of species into new areas as climate regimes shift	Identify and protect possible refugia based on precipitation modeling	O'ahu	Mesic/wet forest & upland wetlands	Mod	Low
Response	Facilitate transition of species into new areas as climate regimes shift	Identify, prioritize, and protect areas that may transition to dry forest in the future	O'ahu	Dry forest	Mod	High (identification) to low (protection) (mod)
Response	Anticipate and facilitate habitat migration	Implement living shorelines and green infrastructure	Kaua'i	Coastal	High	Mod
Response	Preserve, restore, and increase resilience of native ecosystems	Increase incorporation of existing modeling studies and GIS analyses and conduct new modeling to help identify future habitat areas for protection	O'ahu	Native ecosystems and rare species conservation		
Response	Facilitate transition of species into new areas as climate regimes shift	Increase research and modeling on species needs and potential range shifts	O'ahu	Mesic/wet forest & upland wetlands	Mod	Low
Response	Maintain/improve water quantity and quality	Integrate climate projections into Water Commission planning efforts	O'ahu	Water resources	High	High
Response	Anticipate and facilitate habitat migration	Investigate the utility of maintaining mangroves if they can effectively buffer sea level rise and flooding impacts	Kaua'i	Coastal	Mod	High
Response	Anticipate and facilitate habitat migration	Limit development in inland/upland areas where coastal habitats may migrate	Kaua'i	Coastal	High	Low
Response	Implement climate-informed coastal zoning protections	Limit development in most vulnerable sites	Maui	Coastal	High	Mod

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Response	Identify and promote climate-adapted species composition	Map transitional areas between dry and mesic habitat to identify and prioritize protection for areas of mesic habitat that may transition to dry habitat	Hawai'i	Dry forest	Mod-high (mod)	Mod
Response	Maintain and restore existing dry forest habitat	Outplant native species in microrefugia and at different elevations	Hawai'i	Dry forest	Low-mod (mod)	Mod
Response	Anticipate and facilitate habitat migration	Plan for and facilitate inland/upland habitat migration	Kaua'i	Coastal	High	Low
Response	Maintain and augment native species populations	Plant a variety of species adapted to different salinities	O'ahu	Lowland freshwater wetlands	Mod	High
Response	Prepare for sea level rise impacts	Plant salt- and flood-tolerant vegetation	Kaua'i	Native ecosystems and rare species conservation	High	High
Response	Anticipate and facilitate habitat migration	Prioritize key native habitats for conservation	O'ahu	Shorelines & estuaries	Mod	High
Response	Facilitate transition of species into new areas as climate regimes shift	Prioritize the planting of native species that thrive in a wide variety of conditions (e.g., generalists, resilient native/endemic species)	Maui	Mesic/wet forest	High	Mod-high (high)
Response	Use assisted colonization to restore rare species (e.g., corals, turtles, birds)	Protect and prepare habitat for rare species release by increasing habitat quality and reducing threats (e.g., predators, invasive species, human disturbance)	Maui	Rare species conservation	Mod	Low
Response	Anticipate and facilitate habitat migration	Protect upland areas for mauka migration in anticipation of sea level rise	Hawai'i	Cultural resources	Mod	Low

Adaptation Approach	Adaptation Strategy	Specific Action	Workshop Origin	Habitat/ Conservation Activity	Effectiveness	Feasibility
Response	Use assisted colonization to restore rare species (e.g., corals, turtles, birds)	Release rare species into suitable habitat and monitor survival, dispersal, reproductive success, abundance, and genetic diversity	Maui	Rare species conservation	Mod	Low
Response	Maintain and restore existing dry forest habitat	Shift timing of planting to take advantage of rainfall	Hawai'i	Dry forest	Mod	Mod
Response	Create new wetlands to buffer climate-related habitat change	Use climate models to manage water levels and surface water pumping regimes for freshwater wetland assisted migration, reclamation, and management	O'ahu	Lowland freshwater wetlands	High	Low
Response	Identify and promote climate-adapted species composition	Use common garden experiments to outplant along elevational/moisture gradients and identify species applicability under changing conditions	Hawai'i	Dry forest	Mod-high (high)	High

Appendix C. Current and Future Management Tables for Habitats

The following tables present transcribed worksheets from small group work on habitats at each adaptation workshop.

Climate-Informed Evaluation and Revision of Current Management Actions
Workshop participants identified current management goals for focal habitats. For each goal, participants identified potential risks using the results of the vulnerability assessment, and evaluated whether actions in their current form help to reduce vulnerabilities and/or how they could be modified. For each current management action, participants evaluated its effectiveness (likelihood of reducing climate vulnerability) and feasibility (likelihood of implementation), identified necessary modifications regarding where and how to implement actions given climate vulnerabilities, and evaluated the ease of reversibility in case of unintended consequences. Lastly, participants evaluated whether there were potential conflicts with or benefits to other resources from action implementation.

Potential Future Management Goals and Adaptation Actions
Workshop participants identified potential future management goals and adaptation strategies for focal habitats. Participants identified more specific adaptation actions to reduce vulnerabilities or increase resilience. For each adaptation action, participants evaluated where, when, and how to implement those actions as well as collaboration and capacity needs. Action effectiveness (likelihood of reducing vulnerability), feasibility (likelihood of implementation), and reversibility were also evaluated.

Maui Nui
Coastal Habitats (beaches, estuaries, anchialine pools)

Table 1. Current management goals, potential vulnerabilities, and current management actions for coastal habitats on Maui Nui (e.g., beaches/shorelines, estuaries/tidal wetlands, anchialine pools).

Current Management Goal: Restore coastal habitats

Potential climatic and non-climatic vulnerabilities:

- *Dunes and coastal strand habitats*: sea level rise and storm surge, seawalls, coastal hardening, infrastructure (roads), development
- *Wetland habitats*: precipitation changes, storm events (including increased erosion), wildfire, sea level rise, soil changes, changes in invasive species, inability for habitat migration
- *Upland habitats*: little mid-level restoration, increased impervious surface development

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Dune and coastal strand restoration	Moderate	High	**Where**: Existing and known (historic) dunes; select sites based on potential for success and migration opportunities **How**: Identify site and associated conditions (permitting, funding, protection needed, existing management plans, consider long-term management issues, plan for migration); increase community education and involvement; support community groups and volunteers; develop and save MOUs as needed; develop landowner agreements	Easy	**Other resources action benefits**: Sand beaches; coral reefs; wetlands; coastal infrastructure; endangered species; native plants **Other resources with potential conflicts**: Roads (due to migrating sand), aesthetics (blown sand blocks views from buildings)
Remove and control invasive and alien species in wetlands, and then outplant native wetland species	Moderate	High	**Where**: Protected areas; critical areas where restoring one habitat can protect another (e.g., upstream of reef); select sites based on potential for success **How**: Identify site and associated conditions (permitting, funding, protection needed, existing management plans, consider long-term management issues, plan for migration); utilize exclusion fencing; increase community education and involvement; support community groups and volunteers; develop and save memorandums of understanding (MOUs) as needed; develop landowner agreements; enhance interagency coordination; plan for new wetlands (blue line); use land acquisition/conservation easements	Moderate	**Other resources action benefits**: Endangered species; native plants and habitats; coral reefs; biodiversity; pollution reduction; flood storage; water quality; human communities (buffers from storm events) **Other resources with potential conflicts**: Kanaha Pond State Wildlife Sanctuary vs. airport traffic; development; infrastructure
Utilize exclusion fencing	Moderate	High	**Where**: Protected areas; streams; wetlands;	Easy to	**Other resources action**

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
and restoration in upland areas to enhance erosion control			fallow agricultural areas; highly erosive areas; areas critical for connectivity (migration) or native habitat **How**: Include watershed planning; increase acreage/effort; increase coordination between mauka/makai	Moderate	**benefits**: Erosion control; watershed protection; freshwater capture; native flora and fauna; biodiversity **Other resources with potential conflicts**: Hunters and gatherers; land access; development interests; landowner conflicts

Current Management Goal: Protect coastal habitats: Āhihi-Kīnaʻu Natural Preserve/Makena State Park (coastal zone protection), Nuʻu (conservation easement)

Potential climatic and non-climatic vulnerabilities:

- Sea level rise, storm surge, flooding, erosion
- Invasive species
- Coastline development, including public and private infrastructure
- Trespassing into protected areas
- Lack of public support, funding, management, and action implementation
- Push back from landowners, active opposition

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Identify areas that need protection based on specific criteria (Gap Analysis Planning)	High	Moderate	**Where**: Select sites based on criteria: existing dune and wetland habitat, highly eroding areas, adjacent to significant aggregate reef, areas with connectivity or areas adjacent to undeveloped area, areas with willing landowners **How**: Integrate climate considerations (particularly habitat migration); occur faster, stay relevant, and be adaptable; identify people/agencies to be involved; convene a fast-track process; utilize data & GIS resources; increase public involvement; develop forecasting models; investigate gray to green infrastructure; species improvement districts	Easy to ignore, Hard to delete plan	**Other resources action benefits**: Adjacent ecosystems; makes places livable (green) **Other resources with potential conflicts**: Property rights; water use rights; insurance; liability
Implement zoning protections: • Modify formula of erosion control • Include setback lines for sea level rise • Adapt management of special management	Moderate to High Depends on how many, confidence in data, and political considerations	Low to Moderate Depends on litigation, politics, and consistent	**Where**: County-wide; highly eroding areas; all coastlines; consider priority infrastructure and where there will be hazards to buildings **How**: Use data incorporating effects of climate change (e.g., sea level rise, storm surge); move special management areas; identify and fill data gaps; engage in a public process; change county code	Hard	**Other resources action benefits**: Improves coastal water quality; reduces damages to human communities; reduces real estate vulnerabilities; may help decrease insurance rates **Other resources with potential**

areas (SMAs)		implementation			**conflicts**: Property owners; infrastructure; property rights
Conduct climate-informed public education and outreach about protected areas	High If done well	Moderate Influenced by funding and the economy	**Where**: Mandatory education for council and county planning commissioners, realtors, community associations, and adjacent landowners; protected areas **How**: Integrate climate change messaging into existing programs; enhance cooperation and information sharing between groups (local and state-wide); develop partnerships to supplement what government cannot do; develop a climate awareness month; integrate into public uses of protected areas	Moderate	**Other resources action benefits**: Support for protection, ecological services, and adaptation measures; management funding **Other resources with potential conflicts**: None

Table 2. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for coastal habitats on Maui Nui (e.g., beaches/shorelines, estuaries/tidal wetlands, anchialine pools).

Future Management Goal: Develop strategies to support habitat migration, incorporating Blue Line Project data to prioritize sites for protection

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
Identify currently vulnerable areas and areas of potential habitat migration based on available data, including existing infrastructure lifetime	High	High	Near-term (<5 yrs)	**Where**: All coastal habitats on Maui, Lānaʻi, and Kahoʻolawe **How**: Do comprehensive assessment and then narrow down based on prioritization and vulnerability assessment	Easy to ignore Hard to undo	**Collaboration**: Government, non-profit organizations, research groups, private landowners, community groups **Capacity needed**: Data, staff, funding, a convening individual with the capacity to bring people together
Conduct a cost/benefit analysis of a range of management alternatives	High	High	Near-term (<5 yrs)	**Where**: All coastal habitats on the Maui, Lānaʻi, and Kahoʻolawe **How**: Do comprehensive assessment and then narrow down based on prioritization and vulnerability assessment	Easy to ignore Hard to undo	**Collaboration**: Government, non-profit organizations, research groups, private landowners, community groups **Capacity needed**: Data, staff, funding, a

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
						convening individual with the capacity to bring people together
Future Management Goal: Develop strategies to support habitat migration, incorporating Blue Line Project data to prioritize sites for protection						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Conduct a cost/benefit analysis of a range of management alternatives	High	High	Near-term (<5 yrs)	**Where**: All coastal habitats on the Maui, Lānaʻi, and Kahoʻolawe **How**: Do comprehensive assessment and then narrow down based on prioritization and vulnerability assessment	Easy to ignore Hard to undo	**Collaboration**: Government, non-profit organizations, research groups, private landowners, community groups **Capacity needed**: Data, staff, funding, a convening individual with the capacity to bring people together
Future Management Goal: Build support for coastal habitat protection with climate-informed coastal habitat public education and advocacy						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Engage community groups, develop constituencies, align interest groups, and mobilize people to demand action from the government	High Depends on individual group capacity	Moderate to High	Near-term (<5 yrs) and continue into future	**Where**: Where resources are at risk; where opportunities exist (e.g., areas with community interest, recent land acquisition, shovel-ready projects) **How**: Build partnerships and develop coordination; identify issues and solutions; compile best available data; develop outreach materials; utilize social media; promote direct actions and events	Hard	**Collaboration**: Government, private entities, community groups, Department of Transportation, county, city council, mayor, representatives (need to reach decision makers) **Capacity needed**: Data, staff, funding, people, community associations

Aquatic Habitats (streams, groundwater, seeps, and springs)

Table 3. Current management goals, potential vulnerabilities, and current management actions for aquatic habitats (i.e. streams, groundwater, seeps, springs) on Maui Nui.

Current Management Goal: Increase streamflow to protect habitat and water supply (goal of maintaining 64% median flow & 90% of habitat)

Potential climatic and non-climatic vulnerabilities:

- Forest pests and disease
- Decreased water quality and increased sedimentation
- Variable mean flow
- Fewer, but bigger, storms
- Higher-intensity flow
- Changes in precipitation
- Funding

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Control ungulates using fencing and animal removal	Moderate Lower effectiveness if focused just on quantity; higher effectiveness if focused on both quality and quantity	Moderate Dependent on funding	**Where**: Prioritize pristine forests first (will require funding), but also consider downstream needs (e.g., watersheds with intact coral reefs needing protection); expand to lower forest areas **How**: Continue existing efforts	Easy If no fences or funding, invasive plants and ungulates would come back	**Other resources action benefits**: Fresh water recharge, habitat diversity, cultural resources, and many others **Other resources with potential conflicts**: Hunters, recreational use, land access
Increase data collection and stream monitoring	Low Support management changes	Moderate (without funding) High (with funding) Consider shifting to automated data collection and increasing citizen science/ community involvement	**Where**: Island-wide; intermittent streams; Lahaina; 4 Rivers – Nā Wai ʻEha **How**: Legislation; litigation; education/universities; create vector diagrams of water inputs/outputs; add indicator species for drying, warming, and species composition; utilize rain, temperature, and salinity gauges; increase stream monitoring (more monitoring points/increased monitoring frequency); standardize how flow data is gathered and agree upon flow standards; create flexible and comprehensive monitoring system (what's being taken out, why, and by who); encourage non-extractive uses (e.g., taro agriculture); utilize citizen science and place-based education and monitoring	Easy Will stop if research stops	**Other resources action benefits**: Mauka to makai ecosystems **Other resources with potential conflicts**: Development; water/flood control; conflicts over enforcement of public trust doctrine
Engage in collaborative	High	High	**Where**: Island-wide	Easy	**Other resources action benefits**:

efforts to support streams and watersheds	If funded	If funded	**How**: Legislation		Many **Other resources with potential conflicts**: Collaboration reduces likelihood of conflicts
Current Management Goal: Protect and maintain groundwater quality and quantity					
Potential climatic and non-climatic vulnerabilities: • Increased or decreased precipitation • Increased wildfire leading to erosion and sedimentation					
Current Management Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Where/How to Implement Given Vulnerabilities**	**Reversibility of Action**	**Other Resource Considerations**
Monitor point and non-point source pollutants: • Industrial agriculture (e.g., fertilizers, insecticides, byproducts) • Development (e.g., insecticides) • Manage drill permits • Monitor/manage salinity in wells and groundwater	Low Reducing pollutants requires significant shift at policy level Monitoring shows change in recharge and increased salinity over time due to aquifer over withdrawal; monitoring important for policy but not always taken into consideration	Low Requires manpower and funding; policy change requires enhanced monitoring, staff, funds, and political will	**Where**: Legislature; education; elections; county council; Congress **How**: Increase training for community monitoring; work with environmental lobbying groups; increase funds/funding; tie more closely with permitting; increase enforcement and land use controls; enhance political will/support for monitoring; collaborate with EPA and Department of Health	Easy	**Other resources action benefits**: Interconnectedness of everything; monitoring groundwater health important for human health, ecosystem health, and healthy aquatic and coastal habitats; agriculture **Other resources with potential conflicts**: Access (need permission to enter areas); conflict between recharge for environmental health and economic/ developmental uses (both interested in the monitoring data, but want different outcomes and have different priorities); societal willingness to pay; competing interests with development, traditional agriculture, and other off-stream uses
Increase regulation and monitoring of wells and groundwater	No information given Must be well designated	No information given	**Where**: No information given **How**: Utilize available information (e.g., USGS studies, EPA monitoring, precipitation records and projections); maintain science-based sustainable yields; develop a water quality model; improve analysis of well impacts	Easy	**Other resources action benefits**: Fresh water **Other resources with potential conflicts**: No information given

Table 4. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for aquatic habitats (i.e. streams, groundwater, seeps, and springs) on Maui Nui.

Future Management Goal: Increase watershed protection to maintain streamflow volumes that maintain 90% habitat and 64% median flow

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
Expand watershed conservation to lower elevations	High	Moderate	Mid-term (5-20 yrs)	**Where**: All windward streams and watersheds **How**: Legislative changes at state and local levels; expansion of watershed partnerships through new partners and expanded boundaries	Easy	**Collaboration**: Hawaiian Association of Watershed Partnerships **Capacity needed**: Funding, collaboration
Place-based education	High	Moderate Must convince Department of Education	Mid-term (5-20 yrs)	**Where**: State-wide **How**: Work with Department of Education; collaborate with Office of Hawaiian Affairs; work with Hawaiian Language Immersion teachers and the Hōʻike o Haleakalā curriculum	Easy	**Collaboration**: Department of Education, Office of Hawaiian Affairs, Hōʻike o Haleakalā teachers, County, Department of Land and Natural Resources, Maui College, Hawaiian Language Immersion teachers, local science/STEM programs, community groups **Capacity needed**: Teachers – training and resources; policy changes; curriculum changes/adaptations
Establish and enforce mandated in-stream flow standards	High	Moderate	Mid-term (5-20 yrs)	**Where**: State-wide **How**: Increased enforcement and litigation	N/A	**Collaboration**: Commission on Water Resources Management, U.S. Geological Survey **Capacity needed**: Staff; data
Future Management Goal: Maintain and enhance water quality						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Utilize new technologies: • Install automatic sensors that monitor streams 24/7 • Extract sodium to increase fresh water	High	High	Near-term (<5 yrs)	**Where**: Diversion gates for all stream diversions (excludes taro diversions); perennial streams; automated sensors in as many streams as possible **How**: Mandate acquisition of new technologies; support innovative and environmentally	Easy	**Collaboration**: Private firms, U.S. Geological Survey, Commission on Water Resources Management, National Oceanic and Atmospheric Administration, private land owners (manage discharge), wetland

• Diversion gates				concerned leadership; work with developers to encourage monitoring; investigate what to do with brine when sodium is extracted		managers, Office of Hawaiian Affairs, county **Capacity needed**: Funding; policy change, including accountability policy (so landowners are accountable for what comes off their land); technology and land access
Develop and implement well source protection ordinances	High	High	Near-term (<5 yrs)	**Where**: Maui County **How**: Adopt and implement ordinance	Easy	**Collaboration**: Agricultural community, Department of Health, developers **Capacity needed**: Staff, funding

Dry Forest

Table 5. Current management goals, potential vulnerabilities, and current management actions for dry forest habitats on Maui Nui.

Current Management Goal: Increase habitat resilience through revegetation with native species

Potential climatic and non-climatic vulnerabilities:

- *Invasive plant/ungulate removal:* Vulnerable to fire, drought, animal ingress, disease, storms, fire, lapses in funding, increased air temperature, flooding, insect/pathogen introduction
- *Seed collection/revegetation:* Vulnerable to seed set, limitations in seed source, rodents, drought, precipitation, disease, propagator vulnerabilities, low germination rates, difficult to know assisted migration protocols
- *Fire prevention & response:* Lack of fresh water to fight fires, increased drought, wind, increased fuel loads, severe weather

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fencing, invasive plant and ungulate removal	Moderate Must outpace native revegetation with invasive plant colonization Staffing, funding constraints	Moderate Funding/other resources, safety constraints	**Where**: Remaining native habitat, corridors/gaps between protected habitat **How**: Secure approval and funding, build and maintain fence, remove invasive species	Easy (open the gate and/or stop managing invasive species)	**Other resources action benefits**: Reduces erosion, increases watershed function (increases aquifer recharge, slows flow downslope), decreases vulnerability to ROD, plants, disease, and humans **Other resources with potential conflicts**: Increased transpiration if colonized by invasive species, decreased hunting and perceived reduction in wild meat availability
Seed collection and revegetation	Moderate Limited seed sources,	Moderate Lack of water,	**Where**: Riparian corridors, eroded sites and disturbed areas, pockets of diversity, expanding mauka and connecting habitats	Moderate (fence breaches,	**Other resources action benefits**: Cultural resources, fog drip capture **Other resources with potential

	resources, high risk of loss due to drought, lack of pollinators/ dispersers	vegetation availability constraints (i.e., lack of plants for use in revegetation), competition from invasives	**How**: Secure resources, identify protected areas and address gaps, collect and propagate seeds, propagate, involve the public, monitor and adapt Select species that are drought- and wind-tolerant, create canopy, secure soils, seed prolifically, and are ethnobotanically important	fire)	**conflicts**: Species selection?
Fire prevention and response (e.g., fuel reduction, greenbreaks, fire breaks, managed grazing, seed banking, education)	Moderate Cooperative, resources, seed availability	Moderate Resources, arson/public awareness, landowner restrictions/ zoning	**Where**: Wildland-urban interfaces, areas of high conservation value, common ignition sites **How**: Maintain fuel breaks below power lines and roadsides; involve the public	Easy	**Other resources action benefits**: Public safety, property safety, ecosystem services, erosion reduction, coastal resource protection **Other resources with potential conflicts**: Population growth, resistance to controlled burns, lack of maintenance, increased access to sensitive areas, land ownership conflicts

Current Management Goal: Raise public awareness and community support for dry forest resource protection

Potential climatic and non-climatic vulnerabilities:

- Trying not to get discouraged (need to stay positive)
- Retaining historic knowledge
- Fire/storm devastation in remaining area
- Cuts in funding -> cuts in educational funds

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Highlight the importance of dry forests to the public and emphasize what is at risk from climate change (e.g., culture, economy, ecosystem services) through a comprehensive media campaign	Moderate-high Money, reaching all audiences, knowledge gaps	Moderate Defining limits, money	**Where**: Schools, social media, public events, news, parks, PSAs, video Engage Hawaiian community and agricultural producers **How**: Develop prints and use digital media; communicate the monetary value of forests; get groups involved (schools, cultural, woodworkers, etc.) Communication example for decreased precipitation: Restored forests will utilize limited precipitation more effectively, be more resilient to tropical storms, enhance soil moisture, reduce erosion, be more	Moderate	**Other resources action benefits**: Reduced costs of labor, long term costs of protection due to community support, increased general awareness – benefit to many partners and other areas **Other resources with potential conflicts**: Differing values systems and economic interests, development vs. conservation

			resilient to disease and resistant to wildfire; shade from canopy cover decreases ambient temperature Create language that links past forest benefits and cultural and community resources to dry forest, highlighting what's at stake from further loss of dry forest habitat		

Table 6. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for dry forest habitats on Maui Nui.

Future Management Goal: Increase capacity for dry forest restoration

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
Increase knowledge – think tanks, fill gaps in cultural and technical knowledge, peer review	High	Moderate	Near-term (<5 yrs) to mid-term (5-20 yrs)	**Where**: In-situ (restoration trials), front country – research, think tanks **How**: Identify gaps and prioritize research needs, invite experts, complete a facilitated process with outcome summaries and next steps, seek legislative sponsorship	Easy	**Collaboration**: University of Hawaiʻi (UH), government agencies, engineers, scientists, cultural practitioners, conservation groups, schools, planners, landowners **Capacity needed**: Money, public relations, access to sites, economic incentives, multi-stakeholder benefits
Create a work force to implement restoration in a timely manner	High	High Past examples include past ex. environmental work force, Americorps	Near-term (<5 yrs)	**Where**: State-wide, areas with safe access, in historic dry forest, high-priority sites (depends on training of group) **How**: Non-profits, private volunteer programs, schools, legislative action, state, prisoners?, cultural groups	Easy	**Collaboration**: University, prisons, schools, at-risk youth, UH Maui College, charter schools, cultural groups **Capacity needed**: Training, safety, transportation, restrooms, supervisors, admin, waivers, restoration plan
Improve technologies to increase survival and long-term restoration success (e.g., fog drip, irrigation, invasive	High	Moderate	Near-term (<5 yrs) to mid-term (5-20 yrs)	**Where**: Within the cloud belt **How**: Work with community to create access to water for fire, community, agriculture, restoration; create a system of storage tanks and water delivery system	Easy	**Collaboration**: Landowners, UH **Capacity needed**: Funding, access, infrastructure, monitoring, interest

species, biomimicry, nanobots)						
Future Management Goal: Improve resilience of key dry forest species/communities						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Identify key species that are most adaptive Identify and prioritize dry forest biomes for protection and restoration and create strategy to expand protection	High	Moderate Strategy is easy (relatively), implementing is hard because requires many resources and landowners/ cooperators	Plan – Mid-term (5-20 yrs) Beginning to protect areas – Mid-term (5-20 yrs) Implementation – Long-term (>20 yrs)	**Where**: Protect all remaining dry forest habitat, connect protected areas mauka to makai **How**: Use mapping and remote sensing, expert consultation, collaborate, create long-term management plans	Moderate (once forest is established) Long-term support is needed	**Collaboration**: Funders, landowners, experts, resource managers; need to identify new funding sources that care about diversity, culture **Capacity needed**: Fencing, long-term managers for the site, geospatial analysts, field crews, volunteers, cultural and community engagement
Create a digital and physical genetic database to protect remaining species (in situ [outplanting] and ex situ [seed storage] with context and/or reference to role in ecosystem)	High Cryogenics, long term preservation of habitat, seed sources, and genetic data	Moderate Constraints: High costs (reduce over time), required technical training; planting and seed collection is feasible	Mid-term (5-20 yrs)	**Where**: Sample from all dry forests in Hawaiʻi (genetics vary from site to site) **How**: Collect, store, and propagate seeds, plant in appropriate areas, identify locations and collaborators for seed bank storage	Easy	**Collaboration**: State, Lyon Arboretum, UH, other construction orgs **Capacity needed**: Storage sites (temperature- and humidity-controlled), geneticists, lab capacity, protected areas for planting
Explore genetic engineering for increased resilience	Moderate	Moderate	Mid-term (5-20 yrs)	**Where**: Look for isolated areas where spread could be limited **How**: Research, pilot study, expansion,	Moderate	**Collaboration**: UH, public **Capacity needed**: Money, technical knowledge base,

(e.g., drought tolerance)				monitoring		facilities, planning

Mesic and Wet Forest

Table 7. Current management goals, potential vulnerabilities, and current management actions for mesic and wet forest habitats on Maui Nui.

Current Management Goal: Maintain integrity of native-dominated ecosystems

Potential climatic and non-climatic vulnerabilities:

- Forcing/facilitating mammal movement into new areas
- Severe weather impacts to fences (e.g., tree fall, washouts)
- Limited availability of tools due to legal/bureaucratic issues (e.g., no snaring, aerial shooting, lethal traps)
- Funding
- Limited effectiveness of tools – not all transferable (e.g., pig fence does not work for deer, snares do not work for cats)
- Stochastic weather events will impact effectiveness of outplanting/invasive removal (e.g., soil moisture)
- Drought and wildfire – affect all actions/objectives, impact effectiveness of tools (e.g., conditions for effective biocontrol)
- Temperature and precipitation changes affecting habitat suitability for vegetation
- Unpredictable seasonal patterns (impacts planning)
- Drier conditions (increased pigs and rats, may limit planting to wet season for dry and mesic areas)

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fencing and ungulate/ mammalian predator removal by shooting/hunting and snares	Moderate-high Important as precursor to invasive removal and outplanting/ assisted migration; highly effective to enable biome shifts; important to have native seed bank	High Cost and funding are important but well-established	**Where**: Across biome and habitat borders to allow migration/biome shifts; throughout all forest locations Put fences at lower elevations and dip into non-native habitat; put exclosures around threatened/endangered species; focus on incipient areas or those most vulnerable to invasion by specific species **How**: Think about leaving room to move/expand, site-specific gear/ biosecurity, targeting different species in different areas; erect higher fences and use rodenticide; may need to do more stringent pest protection; increase up-front investments	Easy to stop maintenance and allow fence damage Difficult but doable to totally remove fences (expensive, logistically challenging)	**Other resources action benefits**: Reducing erosion, benefitting alpine/subalpine habitats, aquatic environment protections/water quality, marine/ocean ecosystem, aesthetic improvements, cultural benefits, forest products Pollinators, seed dispersers, food change/ecological, water, erosion **Other resources with potential conflicts**: Recreation, cultural interests (e.g., hunters, subsistence hunts); fence strikes, impacts outside fence (e.g., erosion, destruction of natives though they grow back quickly), erosion, biosecurity, concentrated ungulates inside fences, conflicts with herbicide and invasives with groundwater recharge and water quality

Invasive plant removal of priority species with biological, mechanical, and chemical treatments	Bio: Moderate to high (depending on timing, control and effectiveness) Mechanical: Low (resources and scale) Chemical: Moderate (can do larger areas) Highly effective to enable biome shift and outplanting	Bio: Low (requires time to develop it and testing) Mechanical: Low (requires lots of money) Chemical: Moderate to high (must be sprayed from helicopter, limitations due to human dimensions, non-target effects, toxicity)	**Where**: Throughout; target sites based on distribution and density; protect core habitat, edges; target rapid-spreading invasives, incipient species **How**: Identify core areas/priorities (determine how to define core areas, watersheds, etc.), select proper tool to use, acquire permits and approvals (e.g., public notice, partner and landowner coordination), increase volunteer and community participation	Bio: Low (tough to stop once implemented) Mechanical: High (can stop easily) Chemical: Moderate (potential for killing non-target species)	**Other resources action benefits**: Prevents spread to other areas and ecosystems thus protecting pristine native habitats; mitigates spread through recreation; increases groundwater recharge and stream health, reduces fire risk, enhances cultural/aesthetic values **Other resources with potential conflicts**: Herbicide can conflict with wildlife, groundwater, and social resistance for pesticides and biocontrol (e.g., water toxin, impacts to non-target species); potential to spread invasions by not properly cleaning materials
Outplant native species to create habitat and increase resilience; encourage biome shifts	High (depending on species and location) If survival is high, effectiveness is high; if survival is low, effectiveness is low Highly effective to facilitate vegetation shifts	Low-moderate Depends on spatial scale, correct methods, seed sourcing/ genetic integrity, location, propagation ,	**Where**: Areas where passive restoration is not possible (due to slope, soil moisture, seed bank availability); areas with access to sites **How**: Seed collection and propagation, genetic tests, herbicides to remove invasives, establish nursery, volunteers/workers to outplant, monitor planting sites for success	High (stop planting) Discontinue treatment/ stop management activities such as ungulate removal	**Other resources action benefits**: Providing more habitat for threatened and endangered wildlife; increases resistance to climate factors and invasives; mitigates spread due to recreation; increases seed sources for natural dispersal to other locations; cultural/aesthetic benefits **Other resources with potential conflicts**: Genetic make-up of the species based on seed collection/source; impacts for anthropogenic disturbances such as trails (e.g., bringing in invasives)

		seed viability			

Current Management Goal: Maintain and restore water quality and quantity by controlling erosion and sedimentation					
Potential climatic and non-climatic vulnerabilities: • Storms • Drought • Pathogens (can wipe out ground cover) • Fire • Rainfall (success of control plantings) • Limited area of impact • Potential for erosion control plants to become invasive/problematic					
Current Management Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Where/How to Implement Given Vulnerabilities**	**Reversibility of Action**	**Other Resource Considerations**
Plant erosion control plants (e.g., vetiver)	Moderate (site-specific)	Low-moderate Requires time for plants to grow (cannot implement quickly, effects delayed)	**Where**: Very targeted, important to be in the right place **How**: Carefully target vulnerable locations For this to be an effective strategy, downhill ordinances must also be in place to regulate agricultural/residential runoff and erosion	Easy (vetiver is sterile)	**Other resources action benefits**: Marine and nearshore habitats (e.g., coral reefs, ocean quality), stream life, water for human consumption **Other resources with potential conflicts**: Herbivore food sources (potential), takes up space for natives
Mechanical erosion control (e.g., check dams, retention basins)	Moderate For this to be an effective strategy, downhill ordinances must also be in place to regulate agricultural/residential runoff and erosion	Moderate Check dams have to be cleared; can be implemented more quickly than planting	**Where**: Very targeted, important to be in the right place **How**: No answer given	Moderate	**Other resources action benefits**: Marine and nearshore habitats (e.g., coral reefs, ocean quality), stream life, water for human consumption **Other resources with potential conflicts**:

Current Management Goal: Prevent and suppress fires					
Potential climatic and non-climatic vulnerabilities: • Fire					
Current Management	**Effectiveness in Reducing**	**Feasibility**	**Where/How to Implement Given**	**Reversibility**	**Other Resource Considerations**

Action	Vulnerabilities		Vulnerabilities	of Action	
Prevent ORV (off-road vehicle) and pedestrian activity - Rules - Education	High Natural regeneration of native and non-native vegetation cover is fast in wet/mesic forests	Moderate Requires enforcement, regulatory tools (challenging), may encounter social resistance	**Where**: Prioritize high recharge areas, sensitive watersheds, areas near water collection, areas with high erosion impacts to water resources, high-angle slopes, core native habitat **How**: Establish regulations, community outreach, physical barriers, signage, enforcement	Easy (stop management / enforcement)	**Other resources action benefits**: All habitats downhill, reduces vectoring of invasive plants, decreases collateral damage on rare plants/wildlife and fire risk **Other resources with potential conflicts**: Increases fire risk where roads no longer provide firebreaks; social resistance; damage/vandalism

Table 8. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for mesic and wet forest habitats on Maui Nui.

Future Management Goal: Development and innovation of new/more efficient technologies and tools (for habitat restoration and invasive species control						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Tech capacity - herbicide delivery (decreased regulations) - detection - seed balls	Mod-High	High	Near-term (<5 yrs)	**Where**: Test on high and low densities of targets; focus on high quality core habitat **How**: Decreased regulations (permits more accessible)	Hard	**Collaboration**: Government agencies – Federal Aviation Administration/U.S. Fish and Wildlife Service/National Oceanic and Atmospheric Administration/state, enthusiasts, private companies (need mechanical abilities), Department of Defense, agricultural sector **Capacity needed**: Need mechanical abilities beyond conservation, policies change, imagery
Biocontrol/ biotech	High Some tools exist, others in development	High Regulatory timeframe challenge	Near-term (<5 yrs)	**Where**: Test on high and low densities of targets **How**: Decreased regulations (permits more accessible)	Hard Regulations take a long time	**Collaboration**: Facilitate existing relationships (U.S. Forest Service-U.S. Department of Agriculture, U.S. Geological Survey, universities, Department of Defense), grant competitions (innovation), agricultural sector **Capacity needed**: Funding (no profit connection), tools that are

						effective enough without collateral impacts
Native species propagation (for all taxa, including plants, birds, inverts)	High	High	Variable	**Where**: Focus on high quality core habitat **How**: No answer given		**Collaboration**: Zoos, nurseries, schools **Capacity needed**: For difficult species, need money and partnerships
Future Management Goal: Facilitate transition of species into new areas as climate regimes shift						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Assessment/ test plots of current conditions - Where is there habitat? - What are unintended consequences?	Moderate	High	Target goal is long-term (>20 yrs)– assessment portion could be near-term (<5 yrs)	**Where**: Areas projected to transition along ecotone boundaries **How**: Regulatory changes/approval	Easy	**Collaboration**: All interested agencies, managers (public/private) **Capacity needed**: Data, policy, staff time, communication
Prioritize planting of species which thrive in wide variety of conditions (stress generalist/ resilient species that are native/ endemic)	High	Moderate to High	Near-term (<5 yrs) implementation, long-term (20 yrs) to complete	**Where**: Areas projected to transition along ecotone boundaries **How**: Information transfer, best management practices	Easy	**Collaboration**: No answer given **Capacity needed**: No answer given

Alpine/Subalpine

Table 9. Current management goals, potential vulnerabilities, and current management actions for alpine and subalpine habitats on Maui.

Current Management Goal: Remove and/or control invasive species

Potential climatic and non-climatic vulnerabilities:

- Decreased soil moisture
- Increased wildfire potential
- Changes in precipitation
- Changes in plant communities

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Invasive plant/weed removal	High Sparse vegetation at high elevations makes it easier	Moderate Species-dependent	**Where**: Both inside and outside fence, focusing on areas with high diversity or "clumps" of rare species; however, the alpine area is small enough to target the entire area	Easy Will grow back quickly	**Other resources action benefits**: Limited chance of being a vector of invasive species to other habitats, but needs to be reciprocal – public

	to have an impact	(e.g., high for pine, moderate for gorse)	**How**: Set clear priorities and improve techniques by species; use critical habitat and DLNR species recovery plans as guidance No changes necessary for wildfire (does not have a "season") Difficult to predict precipitation – target removal during drought periods so resources are not wasted		perception is mixed but there are good attitudes about some native communities at the alpine level **Other resources with potential conflicts**: Public perception (e.g., some people are attached to the presence/aesthetics of pine forests)
Small mammal removal	Moderate	High Few issues with access, transport, etc. Need more landscape-level measures	**Where**: Inside fences and in a buffer area around fences **How**: Transect survey Avoid placing traps in drainages or depressions where they could get washed away	Easy	**Other resources action benefits**: Cultural benefit **Other resources with potential conflicts**: Concerns about animal cruelty and rodenticide, possible increase in non-native invertebrates (observed elsewhere)

Current Management Goal: Restore native species

Potential climatic and non-climatic vulnerabilities:

- Changes in precipitation
- Increased air temperature
- Increased drought
- Changes in wind patterns (impact seed dispersal, cloud patterns, & moisture)
- Altered wildfire regimes

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Passive restoration	Moderate Depends on site and existing seed bank	High Very low cost	**Where**: Areas with a good seed bank (look at the neighboring areas and use historical information to pick optimal locations) **How**: Same as above; do a vegetation survey once a year	Easy	**Other resources action benefits**: Increases vegetation growth, increases erosion prevention for downslope habitats, improves water quality and storage, provides carbon sequestration **Other resources with potential conflicts**: Social perception of "passive" work, risk of new invasions
Active restoration	Moderate Unforeseen challenges may impede success	Moderate Requires money, seeds,	**Where**: Inside fences, in high priority areas for investment and likelihood of success Warmer, drier air/soil and strong winds will negatively impact success **How**: Select appropriate species community	Hard It is expensive and	**Other resources action benefits**: Increases vegetation growth, increases erosion prevention for downslope habitats, improves water quality and storage, provides carbon

	Faster benefits than passive restoration	crews, good conditions	FIRST (historic/original species, possibly a drought- or precipitation-tolerant surrogate); use good silvicultural practices (e.g., spacing, composition, seed collection, nurseries)	unpopular to backtrack once you've committed to these actions	sequestration **Other resources with potential conflicts**: Goldilocks complex (nobody happy); issues with setting priorities and selecting plants, possibility of contamination/biosecurity, maintaining genetic integrity Assisted migration has pros and cons depending on who you talk to

Current Management Goal: Remove feral ungulates

Potential climatic and non-climatic vulnerabilities:

- Increased precipitation -> more ungulates at higher elevations
- Decreased precipitation -> reduced high-elevation pressure
- Increased storm and fire damage to fences
- Increased erosion
- Upslope animal movement

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Erect fencing	High	Moderate Financial limitations ($27/foot)	**Where**: All subalpine areas (above 6,800 ft.), which are compressed/restricted due to topography **How**: Funding, contractors, installation	Very hard Very expensive	**Other resources action benefits**: Keeps animals below subalpine areas and within hunting range; keeps ecosystem intact when combined with ungulate removal; helps filtration for downslope ecosystems (the first line to prevent Kihei-like runoff) **Other resources with potential conflicts**: Access restrictions for hunters
Aerial eradication and ground hunting	High (in open areas)	High	**Where**: Within all fenced areas **How**: Get permission/buy in from adjacent landowners; do public outreach; use trained personnel and aircraft Aerial hunting is easiest, no changes related to climate/storms	Easy Just stop	**Other resources action benefits**: Supports natural regeneration, slows erosion, improves water storage, increases available seabird nutrients **Other resources with potential conflicts**: Social issues (e.g., negative public perception of removal of food source), increases fire potential
Removal with snares	High (especially in dry conditions)	High	**Where**: Within all fenced areas **How**: Transects, surveys, and hotspotting OR gridding	Depends on the implementati	**Other resources action benefits**: Supports natural regeneration, slows erosion, improves water storage,

				on method	increases available seabird nutrients **Other resources with potential conflicts**: Social/animal cruelty issues

Table 10. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for alpine and subalpine habitats on Maui.

Future Management Goal: 1) Increased landscape-level protection and restoration using the "Mauna Lei" approach (i.e., trees acting as a "lei around the mountain" to protect lower ecosystems, like an erosion filtration sock); 2) Research and development to support adaptive policies and technology						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Research and development for small predator control	High (as seen in NZ)	High (if conflicts can be overcome)	Near-term (<5 yrs) (post-ungulate removal)	**Where**: Inside and outside fences **How**: Establish new research partnerships, obtain funding, do community outreach	Hard Requires large investment, outcome not guaranteed	**Collaboration**: Yes, all conservation groups at the landscape level **Capacity needed**: Data, experiences from other islands, technical reports
Research and development for weed control	High	High (if conflicts can be overcome)	Near-term (<5 yrs) Mid-term (5-20 yrs) for biocontrol	**Where**: Everywhere (landscape scale), targeting areas with weeds and Dept. of Land and Natural Resources species recovery areas; identify the areas that are most likely threatened and in which weed control can be achieved **How**: Funding and expertise, smart students; look for new ways to eradicate ginger and rubus (not currently feasible)	Hard Requires large investment, outcome not guaranteed	**Collaboration**: Yes, all conservation groups at the landscape level **Capacity needed**: Data, experiences from other islands, technical reports, propagation for planting
Future Management Goal: Improved silvicultural practices for priority species (because we already did the research!)						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Improved seed storage capacity *(leads to next action)*	High	High	Near-term (<5 yrs) for some species, >5 yrs for others	**Where**: Practices should be island-based **How**: Create standardized protocols for all facilities, improve communication and collaboration	Easy Turn off the lights!	**Collaboration**: Universities; all agencies **Capacity needed**: Improved inter-agency trust; facilities; funding; less federal involvement (though helps with endangered species listings)

Improved methodology for seed propagation *(leads to next action)*	Low to High (depends on R&D results)	Moderate	Mid-term (5-20 yrs)	**Where**: Depends on the plant **How**: Identify the right staff/people with the specific knowledge	Easy	**Collaboration**: Universities; all agencies; need more trust (only effective if everyone is involved) **Capacity needed**: Data and information sharing – Lyon Arboretum, Hawaiʻi Volcanoes National Park demonstration, extension agent and training
Silvicultural planting methods	Moderate	Moderate (could be a failure in some places)	Mid-term (5-20 years)	**Where**: Depends on the plant, needs to be in protected areas **How**: No answer provided	Hard	**Collaboration**: Identify good labor, public support **Capacity needed**: Funding, data management, policy guidance, field staffing
Future Management Goal: Manipulate the system (pie-in-the-sky ideas!)						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Automated cloud seeding technology	High	High	Mid-term (5-20 years): depends on the military and regulations	**Where**: Entire habitat range **How**: Need military operations, aerospace engineering, etc.	Hard	**Collaboration**: Department of Defense **Capacity needed**: Giant dome (size of the entire island?)
GMO everything	High	Not at all	Long-term (>20 yrs)	**Where**: Entire habitat range **How**: Need field expertise, genetic engineers, shady companies	Hard to impossible	**Collaboration**: Corporations; big pharmaceutical companies **Capacity needed**: Money; technology; policy changes
Predator behavioral modification (e.g., Pavlov's dog, sheep and Christmas berry)	High (if it works…)	Very low	Long-term (>20 yrs)	**Where**: Entire habitat range **How**: Ask an expert	Hard (or could kill them all)	**Collaboration**: Individuals and corporations testing new methods **Capacity needed**: Testing facilities; unlimited funding

Oʻahu

Coastal Habitats (shorelines, estuaries)

Table 11. Current management goals, potential vulnerabilities, and current management actions for shoreline and estuarine habitats on Oʻahu.

Current Management Goal: Restore and conserve native shoreline and estuary habitat
Potential climatic and non-climatic vulnerabilities: • Sea level rise • Reef degradation • Wind

- Waves
- Storm surge
- Foot traffic on dune systems
- Urban development
- Sand availability

- Invasive species
- Shoreline erosion
- Low streamflows
- Increased salinity
- Increasing stream temperature
- Increasing sea surface temperature

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Beach nourishment	Low Limited current application (only occurring at a few select beaches); high cost; environmental externalities	Variable (location specific) Moderate-High (Waikiki or other tourism areas) Low (County Beach Park and other places) Location-based; requires funding; sand availability	**Where**: Places where benefits outweigh costs (consider economics, politics, existing infrastructure, and environmental impacts); areas with appropriate beach dynamics (mostly where existing projects are - systems are already highly engineered); areas where retreat is not an option; areas with cultural implications **How**: More T-groins	Hard for T-groins Easy for beach nourishment	**Other resources action benefits**: Fish recruitment **Other resources with potential conflicts**: Sand impacts on live rock, rocky shorelines, and coral reef; temporary impacts on erosion control, turbidity, and near-shore habitats with initial erosion pulse; alters natural sediment and sediment regime (volume and timing)
Remove mangroves and other invasive vegetation	Moderate-High Requires continuous effort and many volunteers; uncertain effects on natives; mangrove removal can increase sedimentation	Moderate-High Cost; labor intensive; requires continuous monitoring	**Where**: Areas with strong upland restoration; areas with important cultural resources; areas where benefits outweigh costs **How**: Monitor and practice adaptive management; practice ahupuaʻa based management; combine with upland and stream restoration and native species planting; combine with removal of	Easy	**Other resources action benefits**: Fiber (can use mangrove wood for other purposes); cultural knowledge and heritage and traditional practices (e.g., promotes fishpond recovery, restores access) **Other resources with potential conflicts**: Increased access to cultural sites; potential increased sedimentation and

			California grass		turbidity with mangrove removal; loss of carbon sink; reduces storm buffer

Table 12. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for shoreline and estuarine habitats on Oʻahu.

Future Management Goal: Facilitate managed retreat and prepare for inevitable and serious landscape change						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Identify critical infrastructure that needs to be protected (hard or green) or relocated	High Cost; land ownership; engineering and technology logistics; essential services (e.g., critical roads for fire and emergencies; sewage infrastructure)	Moderate Public demand for protection; need for critical infrastructure; political will	No answer given	**Where:** No answer given **How:** No answer given	No answer given	**Collaboration:** No answer given **Capacity needed:** No answer given
Acquire property with high future ecosystem value	High Geology; development	Moderate Development status of land (e.g., not possible in developed areas like Waikiki); political will; land purchase cost; location dependent (e.g., geology)	Near-term (<5 yrs) for planning Mid-term (5-20 yrs) to long-term (>20 yrs) for action	**Where:** Priority areas (see criteria below) **How:** Identify exposed and vulnerable areas (e.g., look at sea level rise modeling data); identify priority areas (less developed, high ecosystem value, low elevation/vulnerable areas, areas hit by repeat disasters); conduct localized assessments and cost-benefit analyses; begin discussions regarding retreat and mitigation to build community buy-in; identify policy and financing options (see what has worked in other states); examine legal and insurance aspects (e.g.,	Moderate	**Collaboration:** Hawaiʻi Tourism Authority; legislature and elected officials; land trusts; local communities; private land owners; County Council; Department of Transportation; Department of Land and Natural Resources; State and County Planning Departments; other agency heads; private partnerships; grassroots organizations; foundations; transit-oriented development process; Interagency Climate Adaptation Committee legislators **Capacity needed:** Money; education; public support; communication visualizations and data; blue line approach

				what was used for Hurricane Sandy); develop post-disaster protocols; investigate creative funding (e.g., carbon tax, mitigation bank, pooling money)		

Lowland Freshwater Wetlands

Table 13. Current management goals, potential vulnerabilities, and current management actions for lowland freshwater wetland habitats on Oʻahu.

Current Management Goal: Maintain and increase native plant and animal species

Potential climatic and non-climatic vulnerabilities:

- Precipitation changes
- Sea level rise and coastal flooding
- Salinity changes
- Increased drought
- Competition with invasive species
- Increased herbivory
- Reduced recruitment (for a variety of reasons)

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Invasive species removal: • Control invasive plants • Control/suppress invasive predators (dogs, cats, rats, mongoose, ants, frogs, cattle egrets)	High	Moderate Predators, plants	**Where**: Areas with more fresh water; smaller, more manageable areas **How**: Public outreach and education to build awareness and understanding; use school groups to test invasive species thresholds	Easy	**Other resources action benefits**: Waterbirds; biodiversity; water quality; flood control; aesthetics; cultural knowledge & significance; overall resilience and function **Other resources with potential conflicts**: Public issues with plants, cats, and herbicide; public perception of animal rights (potential backlash)
Native outplantings to add and relocate plants and animals	Moderate	High	**Where**: Test plots and adaptive management; potentially use newly acquired small wetlands to grow native species (e.g., sedges) that can then be transplanted elsewhere; new wetlands **How**: Look at ENSO seasonal projections to inform planting time (i.e., is it likely to be wetter or drier); plant a diversity of different species adapted to different conditions (e.g., different salinities) and use monitoring to see what's successful;	Easy	**Other resources action benefits**: Waterbirds; biodiversity; water quality; flood control; aesthetics; cultural knowledge & significance; overall resilience and function **Other resources with potential conflicts**: Potential short-term decrease in water quality depending on environmental conditions

			practice adaptive management		

Table 14. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for lowland freshwater wetland habitats on Oʻahu.

Future Management Goal: Create new wetlands to buffer changes in habitat and climate, and improve overall resilience						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Improve science-management communication and partnerships about new climate models and tools to increase accessibility to information	High Allows more informed decisions and increases partner access to funding, etc.	Moderate	Near-term (<5 yrs) and on-going	**Where**: Region-wide meetings every other year, with individual island meetings in-between years; technical support help desk for managers and the public **How**: Use Pacific Coast Joint Venture meeting and Hawaiʻi Conservation Conference as a model; convene annual meeting with scientists and managers to share information about respective activities; create community of practice; something between Hawaiʻi Conservation Conference and Pacific Cost Joint Venture	Easy	**Collaboration**: Pacific Coast Joint Venture; non-profit organizations; Matt Sherman (native nursery, Hui Ku Maoli Ola); federal and state agencies; academia **Capacity needed**: Staff time and interest; partner time and interest; funding; upper level management support; public support
Factor in climate changes in wetland acquisition planning and examine risk involved in managing new wetlands	High	Low-Moderate	Near-term (<5 yrs) planning Mid-term (5-20 yrs) acquisition	**Where**: Island-wide planning **How**: Monitor to determine habitat thresholds; increase communication between different agencies; develop action implementation plan for different acquired properties, including who does what	Easy	**Collaboration**: Non-profit organizations (e.g., The Nature Conservancy); universities; communities; federal, state, and local agencies; stakeholders **Capacity needed**: Staff time and interest; partner time and interest; funding; upper level management support; public support
Surface water pumping and water level management for freshwater wetland assisted migration,	High	Low Funding; need water pump; less	Near-term (<5 yrs): existing locations with pumping abilities Mid-term (5-20 yrs)	**Where**: Target and expand areas where infrastructure and pumps already exist; expand to new areas depending on on-the-ground conditions	Easy Water easily evaporates	**Collaboration**: U.S. Army Corps of Engineers; state or federal management agency; Department of Health

reclamation and management		feasible in new areas	and long-term (>20 yrs): expanding to new areas	**How**: Use climate models to inform pumping regime that's most suitable for maintaining habitat; integrate flood contingency planning	Removing pumping structures more difficult	**Capacity needed**: Funding; water pump truck for one-time water transfers

Streams

Table 15. Current management goals, potential vulnerabilities, and current management actions for stream habitats on Oʻahu.

Current Management Goal: Restore "mauka to makai" streamflows to facilitate connectivity, stream quality, and native species movement and re-establishment

Potential climatic and non-climatic vulnerabilities:

- Reduced precipitation and streamflows
- Increased water and flow diversions
- Lower streamflows
- Increasing air temperatures
- Flooding
- Increasing temperature

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Modify diversions to allow flow to pass (e.g., metal plates over grates); gather baseline information on the state of current diversions	High	Moderate Not physically expensive, but takes years of legal action	**Where**: Prioritize diverted streams under development pressure with high use and climate stress; possibly target leeward vs. windward **How**: Improve data availability to target appropriate areas; develop partnerships and negotiate to avoid litigation (e.g., Waimea Kauaʻi 2017)	Physically easy to remove	**Other resources action benefits**: Estuaries; cultural practices; wetland restoration; watershed health; fisheries; recreation; aesthetics **Other resources with potential conflicts**: Artificial habitat created by diversions (e.g. artificial wetlands for birds); potential land use impacts with higher streamflow, but unlikely since diversions minimize streamflow in the first place
Establish and enforce in-stream flow standards	High If enforced	Moderate (establishment) Low (enforcement) Depends on personnel	**Where**: Areas with existing conflict and competition; streams with high diversions **How**: Conduct more monitoring and data collection; find lower cost ways to gather data via citizen science and observation networks	Easy	**Other resources action benefits**: Estuaries; cultural practices; wetland restoration; watershed health; fisheries; recreation; aesthetics; improved social understanding and awareness of water availability, which will enable smart planning **Other resources with potential conflicts**: Economic development; offstream water uses; water banking

		and funding			
Restore fish passage by modifying stream crossings to enhance connectivity	Moderate Invasive fish may reduce available habitat	High Technically easy and does not affect human uses	**Where**: In streams with large potential habitat above barriers; where there are no climbing catfish; shaded vs. open **How**: Rainfall and streamflow projections have high uncertainty so focus on no-regrets strategies (e.g., modify culverts in other areas to accommodate extreme flooding); develop better monitoring for suitable habitat and update stream classifications	Easy	**Other resources action benefits**: Estuaries; cultural practices; wetland restoration; watershed health; fisheries; recreation; aesthetics **Other resources with potential conflicts**: Potential invasive species introduction to new ranges
Current Management Goal: Improve water conservation efforts					
Potential climatic and non-climatic vulnerabilities: • Increased precipitation • Increased temperatures • Increased wildfire					
Current Management Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Where/How to Implement Given Vulnerabilities**	**Reversibility of Action**	**Other Resource Considerations**
Increase outreach and education (e.g., mauka to makai event at aquarium)	Moderate-High	High	**Where**: Start with keiki because in-school education is critical; agricultural users (focus on better practices, since agriculture is biggest surface water user); ditch system operators (improve systems); residential and military users **How**: Use ENSO/short-term impacts to sensitize people to potential climate impacts, combined with climate products tailored to specific users; increase water bills; inform best practices taken by water users	Easy	**Other resources action benefits**: Recreation; aesthetics; ecological literacy **Other resources with potential conflicts**: None identified

Table 16. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for stream habitats on Oʻahu.

Future Management Goal: Increase streamflow						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Practice holistic management by eliminating watershed	High	Low Many constituents	Long-term (>20 yrs)	**Where**: Target rural areas with multiple uses, existing partnerships, indigenous cultural populations, and areas where cultural practices are more in place; avoid urban areas	Hard	**Collaboration**: Watershed residents; water diverters; native Hawaiian practitioners; government agencies; end water

transfers and restoring traditional decision-making		using diverted water; potential economic impacts; needs funding		**How**: Identify key stakeholders; outline benefits; develop management framework; form a managing entity for stewardship; monitor stream conditions before and after; develop a system to offset financial losses, at least temporarily		users; Hawaii legislature **Capacity needed**: Water quality data; policy changes; a new entity to take ownership and garner trust
Investigate engineering solutions (e.g., bulkheading tunnels)	High Requires effective management and funding for installation	High Requires funding to install and operate	Mid-term (5-20 yrs)	**Where**: Existing tunnel systems where there is insufficient flow and community concern **How**: Obtain system operators and land owner permission and right of entry; develop engineering plan and design to control bulkhead; fund acquisition; monitor before and after for streamflow and biota	Easy Do not have to remove, just open them up	**Collaboration**: Land owners; system operators; community; U.S. Army Corps of Engineers; Commission on Water Resources Management; Division of Aquatic Resources; U.S. Fish and Wildlife Service **Capacity needed**: Data and monitoring; funding; management capacity to operate
Artificially enhance streams by using wastewater	High (low elevation streams) Limited effectiveness at higher elevations with native fish	Low Public resistance; lack of supporting research in ecosystem	Long-term (>20 years)	**Where**: Areas with lots of wastewater; urban areas; near streams with reduced flow; areas with a willing, receptive community (windward side?) **How**: Evaluate sites; conduct a public education campaign; engage experts and give examples (Lake Wilson gets R1); infrastructure design and completion; build higher elevation treatment plants (has to be done regardless)	Hard	**Collaboration**: City and County; Department of Health; federal agencies; U.S. Army Corps of Engineers **Capacity needed**: Funding; policy change; research and development

Dry Forest

Table 17. Current management goals, potential vulnerabilities, and current management actions for dry forest habitats on Oʻahu.

Current Management Goal: Restore degraded dry forest habitat
Potential climatic and non-climatic vulnerabilities: • Rainfall • Drought and drying effects • Storms • Fire • Seed availability and access • Seed predation • Phenological shifts (pollinator mismatch)

- Tree mortality
- Pathogens

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Seed collection and storage	Low-moderate Depends on storage facility	Low-moderate Capacity, funding	**Where**: Oʻahu, Hawaiian Islands **How**: Determine and utilize species storage requirements for temperature and humidity; create common native seed orchards on Oʻahu; increase number of seed labs on Oʻahu and throughout Hawaiian Islands	Easy Requires equipment purchasing	**Other resources action benefits**: Mesic forests; research and development applicable to all habitats **Other resources with potential conflicts**: Infrastructure cost for refrigeration; space for storage capacity
Revegetation by outplanting smaller plants	Moderate-high Maintenance, time	Moderate Number of clean plant growers	**Where**: Dry forest edges; Wildland-Urban Interface; higher elevations to increase survival; native-dominant areas to expand patches **How**: Consider climate in timing and seasonality of planting to promote natural recruitment; obtain better predictions and integration of fire outlooks (North Ops Predictive Services)	Hard	**Other resources action benefits**: Carbon sequestration/credit; wildlife habitat; community wildfire protection; erosion control; water recharge; increased watershed value; cultural corridors for collection and use **Other resources with potential conflicts**: Public attachment to invasive plants; cultural resources (surface features, artifacts)

Current Management Goal: Maintain and protect existing dry forest habitat

Potential climatic and non-climatic vulnerabilities:

- Increased temperatures (guinea grass, increased ignition risk)
- Storms
- Wind
- Small remnant habitat area
- Habitat and species range shifts (e.g., rain shifts can move habitat out of fenced areas)
- Ungulate grazing on native and invasive species
- Grazing pressure release post-fencing
- Invasive plants replacing native species
- Increased invasive grass density and abundance
- Erosion
- Vandalism
- Increased wildfire
- Change in rainfall (drought, pulse rainfall)

- Increased fuel loads
- Change in wind patterns (increased ignition risk)
- Increased tree death due to insect and disease outbreaks
- Significant change in habitat type (e.g., dry to wet/mesic forest) or species assemblages
- Water access for firefighters
- Insufficient and ineffective laws
- Disease-stressed forests more susceptible to invasion

Current Management Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Where/How to Implement Given Vulnerabilities**	**Reversibility of Action**	**Other Resource Considerations**
Fencing and invasive plant and feral ungulate control	High Costly; labor intensive; uncertainties with human potential; may increase vulnerability to fire; staffing/time to maintain treated areas	High Fencing expensive due to steep terrain; overgrowth of vegetation makes plant removal expensive; site access; cost	**Where**: Higher elevations to increase continuity between dry and mesic/wet forest habitat areas that are generally more intact; sites with better overall quality (as opposed to those with rare species); dry forest-human interface; fence range connected **How**: Increase access to fences; coordinate with adjacent landowners; create vegetative buffer near communities outside the fence; create firebreaks; consider fire management as a part of planning; managed grazing; develop tree fall protocols for storm impacts on fences (i.e. removing trees at risk of falling before storms, rapid response to fix fences after storms); increase funding for fence repair post-storm events; active canopy restoration for shading to prevent invasive understory; possibly fence animals into game management areas or other desired areas	Easy (can reopen to ungulate access) Hard (fence removal) Expensive if have to install fences again	**Other resources action benefits**: Mesic forest; streams; wetlands; near-shore and ocean habitats; erosion control **Other resources with potential conflicts**: Perceived conflict with hunting; other land uses (military, development)
Firebreaks and fire prevention	Low-moderate Depends on conditions; growing fuel breaks takes time and must be done right	Low-moderate Depends on location and conditions; need more research on revegetation species	**Where**: Close to human communities (integrate into comprehensive plans); place at Wildland-Urban Interface instead of at disturbed forest edge/native-alien forest boundary; green corridors alongside highways; develop large urban buffers (including highways) **How**: Widen fuel breaks and increase maintenance; develop more water catchments; increase research on strategic fuel break placement and change placement	Hard Labor-intensive, but self-reversing without maintenanc e	**Other resources action benefits**: Cultural heritage and values; community and property protection; recreational area protection; erosion control; native wildlife habitat; insect corridors; education and outreach **Other resources with potential conflicts**: Available area for housing; land owner values;

			if necessary; change native species assemblages used in fuel breaks; increase public engagement; enhance biosecurity to prevent fire-adapted species on O'ahu		conflicting organization and agency mandates; aesthetic considerations
Biosecurity control (insects, pathogens, plants, animals)	Low Huge potential but not being implemented	Moderate Seeing nothing is the ideal outcome, so hard to confirm	**Where**: Ports; landscaping industry; agriculture; trails, roads, and access points **How**: Monitor dynamics of invasion potential; public access to new sites (trails, roads)	Easy If/when happens	**Other resources action benefits**: Agriculture; tourism; human health; watershed health; rat lung worm (slugs) **Other resources with potential conflicts**: Industry; nursery trade; tourism trade; military supply and movement of goods

Table 18. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for dry forest habitats on O'ahu.

Future Management Goal: Increase and improve public education on importance of dry forest habitats						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Increase layperson knowledge of dry forest-related ecosystem services (e.g., cultural resources, air quality, drinking water, wildlife habitat, erosion control) and linkages between dry forests and coral reefs	Low-moderate Need experts at messaging	High	Near-term (<5 yrs)	**Where**: Communities near dry forests; schools; social media; cultural practitioner representatives; community centers; first Fridays **How**: Need communication intermediary; look to other successful campaigns; distribute pamphlets; use cultural messengers; evaluate knowledge absorption; encourage behavior change	Easy Need to be wary of wrong messaging	**Collaboration**: Bishop Museum; Merrie Monarch; airports; kiosks; tourism industry; National Botanical Gardens **Capacity needed**: "People who like people"; funding; materials; accessible sites or site visits
Future Management Goal: Increase research efforts to increase capacity and management tools in dry forests						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Conduct controlled fuel break trial burns (e.g., test mulch types, types and planting arrangements /structure of native	Low-moderate Needs to be done; effectiveness of grazing is high at small scale	High Controlled burns have higher risk; needs	Near-term (<5 yrs)	**Where**: Low-risk/controlled sites; Wildland-Urban Interface (not too close to property); previously burned areas (i.e., Makua); fallow agricultural land **How**: Consider structure and arrangement of vegetation in fuel break;	Moderate to Hard Depends on location	**Collaboration**: Local counties, cities, and communities; State Department of Agriculture; ranchers; agricultural entities; Pacific Fire Exchange **Capacity needed**: Funding;

and alien (non-invasive) plants, goat grazing, greenbreaks, seed spurs, seed orchards)		research		map existing and potential fuel break locations; create list and map water sources; provide fuel breaks and water sources to fire fighters; integrate and test with National Wildlife Refuge annual burns		permits; training; researchers; Hawaii Fire Department wildland fire training and expertise
Identify, prioritize, and protect potential dry forest habitat	Moderate Land ownership; existing boundaries and limited connectivity with mesic forest that may become dry forest in the future	High (habitat identification) Low (habitat protection) Funding	Near-term (<5 yrs): Identification and prioritization Mid-term (5-20 yrs): Protection	**Where**: Adjacent to and connecting to existing habitat patches; areas that will increase connectivity between dry and mesic forest **How**: Increase knowledge of potential new habitat and coordination between land owners; develop necessary infrastructure that can accommodate future needs (e.g., production nursery and staff); document carbon storage potential (forest vs. grassland)	Easy	**Collaboration**: Habitat identification experts (e.g., Jon Price, Tom Gillespie, Lucas Fortini); network of landowners; school kids; Pacific Fire Exchange; agricultural industry; Trust for Public Land; Community Land Trust; military; Kamehameha Schools **Capacity needed**: Data on biome shifts; funding; volunteers; policy change; tax credits/incentives; tourism taxes

Mesic and Wet Forest and Upland Wetlands

Table 19. Current management goals, potential vulnerabilities, and current management actions for mesic/wet forest and upland wetland habitats on Oʻahu.

Current Management Goal: Maintain and restore native mesic and wet forest habitat

Potential climatic and non-climatic vulnerabilities:

- Storms, precipitation, flooding, and wildfire (may damage fencing)
- Recreation
- Ability to fence appropriate species
- Reduced native forest regeneration
- Storms (invasions facilitated by disturbed conditions, spread or killing of biocontrol agents)
- Climate unsuitable for biocontrol agents
- Creation of new or unexpected habitat for invasive species (e.g. due to precipitation shifts) and increased invasive species range and vigor (most can tolerate a wide range of conditions)
- New invasive species introductions (whether intentional or accidental) via enhanced trade and globalization
- Military activities
- Development and population growth (development creates disturbance and increases ornamental plant; risk may be exacerbated if current dry forest buffer area is lost)
- Increased air temperature
- Impacts of moisture changes and drought on plant survivorship

- Change in suite of native species
- Disease
- Predation
- Competition with invasive species

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fencing priority areas (determined by rainfall, amount/intactness of native forest, and presence of rare plants or other specific species)	Moderate (mesic forest) High (wet forest) Invasive plants can still get into fenced areas via other mechanisms; some predators can still get through fence (e.g., rats); requires funding and maintenance to maintain effectiveness; vandalism; limited life-span of fences	Moderate Depends on funding; terrain; land ownership; jurisdictional overlaps and competing interests; compliance and permitting requirements; public opposition	**Where**: Higher elevations (or full elevational range) to accommodate migration; easy-access areas that have greater habitat extent (strategic vs. continuous fencing lines); priority watersheds **How**: Consider topographic features in deciding placement (e.g., use natural barriers to reduce fencing cost); consider adding predator-proof fencing material and explore ways to make predator-proof fencing more affordable (e.g., possible for state to purchase directly from manufacturer for cheaper?); increase eradication efforts (e.g., rats, invasive plants); create island-wide fencing prioritization list and consider other factors in prioritization scheme (e.g., downstream/marine impacts of fencing, potential to gain access to funding associated with carbon sinks, stakeholder and funder values, climate-resilient areas, crew- and public-accessible areas); capitalize on data currently being gathered for other projects to help inform fencing placement decisions (e.g., GIS data being gathered for the Effective Conservation Program could potentially be combined with climate data); learn from efforts on other islands (e.g., Kauaʻi had fence fabricated in China but assembled on-island to reduce costs); increase state leadership, coordination, and engagement with different organization and stakeholders (e.g., watershed partnerships); use education and outreach to reframe purpose of fencing and increase public support, focusing societally important issues (e.g., fencing to protect drinking water)	Moderate Hard/expensive to remove fencing, but easy to allow forest access by cutting holes in fence; however, there is danger of losing public support and funding if agencies have to admit to putting fence in the wrong place	**Other resources action benefits**: Groundwater supply (for drinking water); hunting (creates travel corridors and can funnel ungulates and other species to desired locations); educational opportunities around restoration/climate change; refugia creation for rare plants, birds, and cultural practices **Other resources with potential conflicts**: Recreation/aesthetics; hunting (perception that fencing may reduce access in some areas); could increase invasives depending on how fence line is managed (e.g., could introduce new invasives during construction and cleared fence line could increase pig /cat use and invasive plant establishment); may push invasive species to undesired locations; could impact downstream restoration activities in coastal areas if no communication is built into process
Manage invasive species via 1) removal of ungulates, predators, and plants with a high rate of spread, and 2) biocontrol	Moderate (removal) Unknown (biocontrol) Treatment	Moderate Funding and capacity issues; invasion	**Where**: High quality fenced forest areas (both existing and predicted); lowlands (to prevent upward invasive movement); areas with small invasive populations that can be eliminated; accessible areas where public interaction could be increased **How**: Create a decision matrix to help prioritize areas for treatment (include presence of threatened and endangered	Easy (invasive removal) Hard (biocontrol)	**Other resources action benefits**: Cultural services; fresh water recharge/supply; fire prevention **Other resources with potential conflicts**: Nursery industry and hula and lei plants if imports decrease; perceived decreased

	effectiveness varies by species; access issues and lack of planting rules on private land; lack of mesic forest regeneration and/or native planting efforts allows re-invasion	occurring at large scale, but current treatment is patchy and small-scale due to limited resources; need repeat application	species, habitat quality [current and future], accessibility); target high impact invasive species; increase eradication efforts - potentially engage hula and lei groups to steward places and resources; share information and lessons learned on effective treatments; prevent new invasive introductions by increasing biosecurity, decreasing ornamental plant use, and increasing public and legislature education to prevent invasive plant sale and purchase (consider using legislation and/or incentive programs); increase in-state capacity to identify and conduct research on pests and pathogens; collaborate with universities to conduct research projects relevant to management (e.g., develop technologies to treat hard-to-reach invasives, compare native vs. invaded forest water yields and ecosystem services, monitor abundance of native vs. invasive forest as temperature and precipitation changes)		access for hunting, food provisioning, and cultural uses (e.g., if ungulates and guava removed); invasive removal may impact existing native/invasive pollinator interactions or damage native vegetation; herbicide use may mar public perception of management activities
Restore common and rare native species	High (if paired with fencing and invasive removal) Moderate (if not paired with fencing and invasive removal) Greenhouse capacity and manpower to produce volume of native species needed; disease; needs to be paired with fencing and invasive removal	Low-moderate Manpower and forest access to find and collect rare species; breeding technologies; terrain requires helicopter or hiker access	**Where**: Areas with fencing and invasive species control; areas where native system is degraded or missing; areas with existing projects (to create refugia and corridors); accessible areas (to allow access and education opportunities) **How**: Select resilient common species (consider natural regeneration vs. scatter, conduct genetic testing); increase propagation and knowledge of how to propagate additional common and rare species; investigate new methods for mass seed collection; increase planting volume and investigate new technologies (e.g., consider slurries for areas with bare ground, seed balls, aerial seeding); consider assisted migration; improve seed storage and nursery protocols; restructure local ornamental market (either voluntarily or legally) to use and grow native species instead of exotic; conduct weed workshops	Easy	**Other resources action benefits**: Groundwater recharge; biodiversity; downstream and coastal habitats by decreasing erosion; tourism; cultural uses; forest products (e.g., koa); carbon storage; co-evolved pollinators **Other resources with potential conflicts**: In-breeding risk (genetic integrity and material may be compromised – currently need funding for genetic research); some native species have evolved to utilize invasive species
Conduct outreach and education	Variable Hard to	High, if messaging coordinate	**Where**: State-wide **How**: Hire a state communication and outreach staff person to lead collaborative outreach and promote consistent	No answer given	**Other resources action benefits**: Groundwater recharge; biodiversity; tourism; cultural

	measure impact and prove utility; hard to engage people and find appropriate communication method; limited volunteer project opportunities; variable volunteer experiences	d state-wide Depends on staffing (including differences between agencies)	messaging; coordinate across different state agencies for consistent messaging (e.g., reframe fencing to "fencing for climate adaptation and protecting drinking water"); link forest conservation messaging with public values (e.g., drinking water, healthy reefs); engage and have strategic conversations with non-profits and private landowners that will promote word-of-mouth sharing and neighbor storytelling (the most effective communication method); increase media stories (e.g., Hana Hou Magazine); develop an Adopt-a-Forest program to engage youth; expand upon and increase volunteer program in a strategic and well-planned way to avoid bad volunteer experiences; increase community engagement opportunities in planning and project design (builds buy-in and creates foundation for policy and funding change); develop methods to measure impact		uses; carbon storage **Other resources with potential conflicts**: Increased engagement with natural landscapes could have unintended consequences (e.g., love it to death); may encounter conflicting community priorities

Table 20. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for mesic and wet forest and upland wetland habitats on Oʻahu.

Future Management Goal: Increase outreach and education to support native forest restoration and management						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where & How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Increase education of the legislature and public engagement with natural resource decisions made by the legislature (e.g., have the public comment on bills)	High Depends on funding	Low Competing social interests; apathetic public; hard to equate environmental measures to economic benefits	Near-term (<5 yrs)	**Where**: Target education and prioritize community projects in the respective communities of Senate and House chairs and other legislature leaders **How**: Change agency communication and language (e.g., preserving cultural heritage in the face of climate change, fencing for climate change); develop a suite of public communication strategies to target different audiences; train state staff in effective communication methods (e.g., storytelling); create slideshow to teach public how to comment on bills; get environmentally-minded individuals into government positions (e.g., budget, finance); hire a public relations staff member to communicate climate change threats to legislature in understandable	Hard Hard to reverse a strong public message	**Collaboration**: Environmental groups; community leaders; cultural groups; non-traditional partners (e.g., industry); national level support and education **Capacity needed**: Public relations/legislature liaison; increased data collection and synthesis (e.g., data on restoration effectiveness); increased community and cultural involvement (including materials and personal stories)

				ways (e.g., economics); conduct economic analyses to show native forest value (e.g., generate a dollar value that can be understood); target communities and community representatives that will be visible and meaningful to decision-makers; conduct site visits with decision-makers; improve data sharing within and between agencies; increase education/outreach in the summer (hot weather and hurricane season may help generate more public interest)		
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where & How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Assisted migration	Unknown Can do this action on a species level, but no experience at a diverse habitat level; limited area for upward movement on Oʻahu, particularly for wet forest species; timelines (differences between planting vs. actual climate change may decrease establishment); lack data on historic and	Low Suitable land area limited; hybridization issues; differences between conserving species vs. ecosystems	Experiment: Near-term (<5 yrs) Larger-scale implementation: Mid-term (5-20 yrs)	**Where**: New mountain ranges or other islands (need to consider genetic risks); on-island refugia predicted by models **How**: Increase research and modeling on potential range shifts; conduct precipitation modeling to help identify refugia; research species' needs (e.g., required soil components and temperatures for plant survival and health); create a working group to look into habitat-level migration (e.g., possibilities, genetic risks)	Small scale: Moderate Large scale: Hard	**Collaboration**: Engage universities and PICCC for needed research **Capacity needed**: Data; modeling; policy updates to allow native animal movement

	projected range conditions					

Hawaiʻi

Coastal, Aquatic, and Tidally-Influenced Habitats (beaches, estuaries, anchialine pools, etc.)

Table 21. Current management goals, potential vulnerabilities, and current management actions for coastal, aquatic, and tidally influenced habitats on Hawaiʻi.

Current Management Goal: Reconnect and enhance connections of people to place

Potential climatic and non-climatic vulnerabilities:

- Introduced foods (original purpose of food security) presents risk to native species, especially in aquaculture
- Change in relationship of people to place and resources
- Disconnection from food, water, shelter
- Sea level rise
- Development
- Sedimentation
- Migration of anchialine pools
- Roads/travel corridors
- Disease outbreaks
- Change in access and where certain activities can occur
- Change in water quality – salinity, increasing water temperatures, decreasing dissolved oxygen
- Loss of species that are core reasons for why people engage in areas
- Human migration due to climate change
- Loss of ecosystem services
- New people coming in that do not have the long-term connections to resources and/or different world views

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Building local experience of landscapes and seascapes into science	High Depends on program design, network strength and relationships between managers, scientists, and community members	Moderate-High Communities are very strong on island; funding is limited and funding cycles are too short; political will; policy/legal	**Where**: Areas with drought (i.e. leeward environments); lowland, most disturbed areas; select communities that are already doing the work and use as a model for other communities **How**: Sharing examples through in-person, side-by-side engagements; use watershed approach to increased connection to places; examine whole watershed threats and prioritize what and how to address; coordinate with upland management to allow for more holistic approach	Easy	**Other resources action benefits**: Waterbirds; coastal plants; non-marine aquatic species; nearshore marine species; some benefits to tourism and economic development **Other resources with potential conflicts**: Conflicts between native ecosystem protection and local food production/agriculture; lack resources already but increased conflict because these actions could allocate resources to

		constraints			certain areas over others (i.e. more active, participatory communities may get more attention than others); interview fatigue – capacity-limited communities; attracting tourism vs. protecting places that tourists are impacting
Building capacity of local communities through restoration projects, on-the-ground action, involvement in policy decisions, and genealogy exercises	High Depends on program design, network strength and relationships between managers, scientists, and community members	Moderate-High	**Where**: Areas with drought (i.e. leeward environments); lowland, most disturbed areas; select communities that are already doing the work and use as a model for other communities **How**: Sharing examples through in-person, side-by-side engagements; use watershed approach to increased connection to places; examine whole watershed threats and prioritize what and how to address; coordinate with upland management to allow for more holistic approach	Easy	**Other resources action benefits**: Waterbirds; coastal plants; non-marine aquatic species; nearshore marine species; some benefits to tourism and economic development **Other resources with potential conflicts**: Conflicts between native ecosystem protection and local food production/agriculture; lack resources already but increased conflict because these actions could allocate resources to certain areas over others (i.e. more active, participatory communities may get more attention than others); interview fatigue – capacity-limited communities; attracting tourism vs. protecting places that tourists are impacting
Building local economy to support ecosystem conservation and protection, and enhance sustainability (i.e. create jobs, preserve human needs, preserve natural and cultural heritage)	High Depends on program design, network strength and relationships between managers, scientists, and community members	Moderate-High	**Where**: Areas with drought (i.e. leeward environments); lowland, most disturbed areas; select communities that are already doing the work and use as a model for other communities **How**: Sharing examples through in-person, side-by-side engagements; use watershed approach to increased connection to places; examine whole watershed threats and prioritize what and how to address; coordinate with upland management to allow for more holistic approach	Easy	**Other resources action benefits**: Waterbirds; coastal plants; non-marine aquatic species; nearshore marine species; some benefits to tourism and economic development **Other resources with potential conflicts**: Conflicts between native ecosystem protection and local food production/agriculture; lack resources already but increased conflict because these actions could allocate resources to certain areas over others (i.e. more active, participatory communities may get more attention than others); interview fatigue – capacity-limited communities; attracting tourism vs.

					protecting places that tourists are impacting

Table 22. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for coastal, aquatic, and tidally influenced habitats on Hawaiʻi.

Future Management Goal: Change laws/policies to protect and promote current and future community response to climatic change impacts

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
Expand Ecological Effects of Sea Level Rise (EESLR) model to cover rest of the island	Low	High	Near-term (<5 yrs)	**Where**: Entire island **How**: Beta testing with communities; determine whether to add other components; determine how it can be used to inform policy decisions	Hard Most areas have been mapped	**Collaboration**: The Nature Conservancy; National Oceanic and Atmospheric Administration; individual communities **Capacity needed**: Funding
Engage larger community to discuss climate impacts and co-develop climate-informed policies and plans	High Depends on community	Low-Moderate	Near-term (<5 yrs)	**Where**: Target low-lying areas already impacted; communities with strong voices **How**: Engage key community spokespeople	Easy	**Collaboration**: Homeowners; community organizations; county planners; NGOs; tourist organizations; local community leaders; local, respected kupuna; elected officials; Professional Human Dimensions group **Capacity needed**: Dedicated staff member with community contacts
Create a network of expertise (e.g., natural and cultural resource managers, students, etc.) to be a resource for local communities	High Depends on community	High	Near-term (<5 yrs)	**Where**: Target low-lying areas already impacted; communities with strong voices **How**: Investigate existing networks that may be able to assist	Easy	**Collaboration**: University of Hawaii; National Park Service; Bishop Museum; Historical Society; area users **Capacity needed**: Staff with expertise and community contacts
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Increase education and involvement of	High	High	Near-term (<5 yrs)	**Where**: Throughout the island **How**: Engage with charter and non-	Easy	**Collaboration**: Schools; National Park Service;

students (K-12, college) in conservation work				charter schools		University of Hawaii **Capacity needed**: Staff; curriculum
Increase citizen science efforts to gather data to support climate-informed decision making	Low-Moderate	High	Near-term (<5 yrs)	**Where**: Low-lying communities; most vulnerable communities **How**: Engage universities to train community members	Easy	**Collaboration**: Students; communities; universities; Makai Watch **Capacity needed**: Funding; established and standardized monitoring protocols
Create strategic communications campaign to implement policy changes	High	High	Near-term (<5 yrs) to mid-term (5-20 yrs)	**Where**: Throughout the island **How**: Work with a communications expert to help design messaging; develop communications/marketing and outreach plan to communities	Easy	**Collaboration**: Communications organization **Capacity needed**: Funding; staff

Dry Forest

Table 23. Current management goals, potential vulnerabilities, and current management actions for dry forest habitats on Hawaiʻi.

Current Management Goal: Maintain and restore existing dry forest habitat

Potential climatic and non-climatic vulnerabilities:

- Drought
- Increased wildfire
- Soil moisture
- Decreased water availability
- Decreased recruitment
- Ungulates
- Lack of protection from development pressures
- Invasive species
- Pests
- Lack of dispersal and pollinators for re-establishment
- Regulatory barriers (i.e. not allowed to move species outside of historic range; Department of Land and Natural Resources cooperative agreement with U.S. Fish and Wildlife Service)
- Funding

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fuels reduction and	High	Moderate	**Where**: Most intact habitat; along highways; in	Moderate	**Other resources action benefits**:

fire/fuels management	Labor-intensive; time for crew; funding; human ignitions; amount of herbicide	Access to sites; fire season; keeping up - no professional firefighting force on island	presence of threatened and endangered species; upper elevations; smaller scale sites – prioritize fuel break placement (fuel breaks above most flammable areas); place restoration/reforestation sites above fuel break; with fuel breaks, pay attention to water limitations of moist vegetation **How**: Vegetation of fuel breaks may need to change – challenge of natives vs. invasives; use drought-tolerant species in fuel breaks; use morning glory; regional comprehensive management; better education on fire risk to public; increase number of fuel breaks; decrease arson if possible; use non-native, non-invasive species; green fire breaks; Department of Transportation vegetation free roadsides	If you bulldozed something to create habitat, it will be challenging to reverse	Everything mauka; mesic/wet forest; increased air quality; increased watershed health; habitat for birds; limiting spread of invasive species along roadside **Other resources with potential conflicts**: Tree tobacco (endangered species) – manduka; use of herbicide; social perception; losing some habitat by creating fuel breaks; opening up some areas to invasion; time it takes away from restoration and other efforts – general opportunity cost
Ungulate control through fencing	Moderate Challenged by ungulate ingress; continuous maintenance; needs to be coupled with management	High High cost but doable	**Where**: Higher elevation sites; canopy, overstory areas; sites with high soil content; most vulnerable areas **How**: Pest-proof fencing (rats); perhaps augment fencing with chemical control to decrease seed predation; most to least threatened sites	Moderate	**Other resources action benefits**: Increased habitat for birds and pollinators; better forest health; decreased erosion; increased cultural resources; increased opportunity for public to see wildlife **Other resources with potential conflicts**: Perceived decreased hunting access; increased ungulates in inhabited areas; different weed issues – may be trading one for another; maintenance costs
Weed removal and outplanting of natives • Includes community involvement and labor Effort-dependent	Low-moderate Requires constant planting; species, site, and year dependent; fire risk	Moderate Depends on scale; depends on fire and fuels management and fencing success	**Where**: All remnant dry forest habitat**;** where management regime already in place (state and federal lands)**; a**reas that will remain as dry forest habitat even with climate change **How**: Identify species composition across time and ranges; test trials of species in different areas to see what's most effective (i.e. move species upland); shift timing of planting to take advantage of rainfall; plant in microrefugia; mulching; supplemental watering through irrigation	Easy (weed removal) Moderate-Hard (outplanting)	**Other resources action benefits**: Decreased fire; increased moisture; increased habitats for birds and insects; increased water; increased seed production of rare species; decreased erosion **Other resources with potential conflicts**: Herbicide use; cultural resources – resistance to removing silver oak and panini, kiawe, olive trees; once you introduce a

					species assemblage, it's difficult to change to another assemblage
Current Management Goal: Community and cultural engagement, education, and outreach on the importance of dry forest habitat					
Potential climatic and non-climatic vulnerabilities: • Loss of dry forest habitat and species of cultural concern • Loss of accessible sites • Decreased time for outreach, locations shut down due to wildfire risk • Decreased community education because less inherent value • Loss of reference ecosystem					
Host volunteer planting days (i.e. weed removal, nursery)	High All happens because of volunteers	High	**Where**: Easily accessible areas; trails and roads; areas with canopy for shade; areas where volunteers can see progress (i.e. restored sites); story about history and culture; sites with good views; mauka sites **How**: Increase access to best sites; aina-based education; programming should always be biocultural; access to and knowledge of culturally important sites; transportation and substitute teachers; more outreach staff (i.e. Division of Forestry and Wildlife has limited staff capacity); increase communication with the public; change timing of work days	Easy	**Other resources action benefits**: Increased bird and insect habitat; more informed voters; increased community buy-in; frees up manager time; creates more scientists **Other resources with potential conflicts**: Volunteer time; volunteers potentially spreading rapid ʻōhiʻa death and invasive species; people may take plants; accidental trampling; non-staff planting plants not the best from U.S. Fish and Wildlife Service perspective
Preserving access to gathering of important cultural species (plants, rocks, timber) and stewardship (ʻōhiʻa, alii, mint [kupa], lei materials)	High	Moderate Need more staff time for remote areas	**Where**: Less threatened areas vs. more vulnerable areas; need to preserve access to threatened and endangered species to maintain knowledge; diversity of ecosystems **How**: Allow people in strategic sites; tiered access for kupuna; more community-based regulation of access - konohiki	Moderate	**Other resources action benefits**: Increased number of people that care about the land; increased visibility of species outside of forest; increased knowledge of plants; sharing observations of change; increased planting at residential houses **Other resources with potential conflicts**: Weed and disease introductions; increased fire; perception that ungulate hunting is reduced
Host outreach events (Wiliwili Festival, Biocultural Blitz, Run for the Dry Forest, hunting	High	Moderate-High Requires time and funding	**Where**: More accessible sites of larger size; hunting community areas **How**: Increase ability to track success of events (repeat customers, etc.); experts demonstrating	Easy	**Other resources action benefits**: More volunteers; increased interest from schools; press coverage; social cohesion; overlap

tournaments)			importance – makahiki – lei making, hunting; integrate climate change; demo plant species use under changing climate conditions; lei competition with different climate-adapted (and not climate-adapted) species		between groups (managers, scientists, community); science and monitoring data; decreased number of pigs **Other resources with potential conflicts**: Large footprint (carbon, rubbish); trampling

Table 24. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for dry forest habitat on Hawai'i.

Future Management Goal: Identify and promote climate-adapted species composition						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Outplanting common garden along elevational/ moisture gradients to identify species applicability under changing conditions	Moderate-High	High	Near-term (<5 yrs) to mid-term (5-20 yrs)	**Where**: Pu'u Wa'awa'a; Mauna Kea through the saddle; Pōhakuloa Training Area **How**: Institutional support; grants; identify species to test (uhei, halapepe, wiliwili, ahaya - all lowland dry at edge of transition zone); identify current threatened and endangered list of plants; build fences; remove weeds; build firebreaks; demonstration education project; test at different points around the island	Hard	**Collaboration**: Dry forest hui; Department of Defense; University of Hawaii; Pacific Islands Climate Change Collaborative; Pacific Islands Climate Science Center; Division of Fish and Wildlife; U.S. Fish and Wildlife Service; The Nature Conservancy; U.S. Geological Survey; Kamehameha Schools **Capacity needed**: Funding; people; data management; continuity; long-term agreement
a) Identify transitional areas between dry and mesic habitat through mapping b) Find areas of mesic habitat likely to transition to dry to target for protection	Moderate-High	Moderate	Near-term (<5 yrs)	**Where**: Computer-based efforts **How**: Funding, organization to convene (i.e. PICCC); bring people along with the idea; do the modeling	Easy	**Collaboration**: National Park Service, U.S. Geological Survey; Department of Defense; Natural Resources Conservation Service; University of Hawaii; U.S. Fish and Wildlife Service **Capacity needed**: Funding; staff; policy change

Regulatory policy change (i.e. historic range issue, streamlining a landscape approach)	High	Moderate-High	Near-term (<5 yrs)	**Where**: U.S. Fish and Wildlife Service; between state and federal entities **How**: Communicating science effectively to policymakers; advocate and lobby for change; demonstration of impending failure of current plan	Hard	**Collaboration**: Hawaiʻi Rare Plant Restoration Group; Plant Extinction Prevention Program; National Park Service, U.S. Geological Survey; Department of Defense; Natural Resources Conservation Service; University of Hawaii; U.S. Fish and Wildlife Service **Capacity needed**: No answer given

Mesic and Wet Forest

Table 25. Current management goals, potential vulnerabilities, and current management actions for mesic and wet forest habitats on Hawaiʻi.

Current Management Goal: Maintain intact, native-dominant, self-perpetuating ecosystem

Potential climatic and non-climatic vulnerabilities:

- Canopy loss due to drought (more for mesic than wet), opening space for invasives
- Rapid ʻōhiʻa death
- Invasive species
- Development
- Increased storm frequency
- Change in dominant canopy vegetation
- Climate-driven habitat migration
- Loss of dispersers and decreased recruitment
- Invasive species – ungulates, plants, rats – decreased self-perpetuation and recruitment
- Flammable grasses
- Increased wildfire
- Loss of forest structure
- Increased temperatures causing increased stress and tree mortality
- Active lava flow that can eliminate forests

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fencing and ungulate removal	High Depends what you start with in an intact system; less	Moderate Community opposition; depends on	**Where**: Areas more resilient to invasion (aʻa lava flows); higher elevations; Special Ecological Areas (SEA), but add climate considerations to this classification system; climate refugia; balance of presence vs. density – only a few land owners at	Moderate May create vector for invasive	**Other resources action benefits**: Decreased erosion; increased regeneration **Other resources with potential conflicts**: Perception of decreased

	effective in degraded system – must pair with other system activities such as plant control; helps increase both native and non-native vegetation which needs to be managed	terrain; funding; fence life to install and maintain (10-30 years)	high elevations **How**: Identify new areas in addition to SEA; differences in type of ungulates (identify what fences needed for which type of species); increase hunter engagement – currently fencing not effective enough to decrease animal numbers; work with partners in Watershed Alliance; identify climate refugia across boundaries; manage for changing communities (shifts in native dominance); conduct comprehensive mapping of habitat; identify clearing and clustering requirements that affect fragmentation in lowlands; use different kinds of materials for fences; more frequent checks; improve materials to be more resilient to VOG	species in intact areas; increase rapid ʻōhiʻa death introduction in fence creation/ tree removal along fence; increase invasive plant species with ungulate removal	hunting access; increased bat and petrel mortality; increased invasive species and rapid ʻōhiʻa death
Native species augmentation: • Outplanting • Seed scattering/seeding (typically post-fire) Adding new individuals	Low-Moderate Small scale currently; not effective at larger scales; plantings can die; some experimentation with non-natives that can outcompete invasives but co-exist with natives	Moderate (small scale) Low (large scale) Funding; manpower; access – limited scale; volunteer capabilities; monitoring	**Where**: Post-disturbance sites; consider patch size and connectivity – how big to decrease invasive-ability?; increase in buffer areas **How**: Plant during wet season; proactive plantings – consider modeled future envelopes; move birds (last remaining seed disperser – omano) to new areas; use drought or temperature tolerant species; increase experimental to management scale (novel hybrid systems, allow for native species regeneration); large-scale seeding with planes; select different seed sources to increase adaptive capacity; work at watershed scale to build flexibility across jurisdictions; protect land for planting opportunities; potentially water seedlings if planting in dry season; look into genetics and new siting of plants to increase survivability	Depends on scale Hard – if large/establis hed planting area Easy – if small area	**Other resources action benefits**: Decreased erosion; increased water recharge; increased regeneration **Other resources with potential conflicts**: Could introduce ants, rapid ʻōhiʻa death, or other problematic species without proper sanitation; hybridization and genetic issues; if change in species composition, could affect existing wildlife or species use of habitat

Table 26. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs mesic and wet forest habitats on Hawaiʻi.

Future Management Goal: Create a forest that is self-sustaining (in terms of cost, time, need for management) with no or limited on-the-ground human management						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**

Increase education and outreach to instill community conservation ethic: • Urban forestry • Emphasize and elevate awareness of biocultural and ecosystem services • Evaluate communication methods	High Rethink conservation psychology/ how to account for human behavior	Moderate Available science; funding; motives; scale; need social science integration	Near-term (<5 yrs)	**Where**: Increase urban forestry; integrate in K-12 curriculum consistently (e.g., Konuku program, visiting stewards, kupuna) **How**: Evaluate communication methods and conservation ethic changes over time; emphasize biocultural and other ecosystem services; capitalize on opportunities (e.g. rapid ʻōhiʻa death/biosecurity); leverage other education opportunities (Aloha+ dashboard); use different communication venues	Easy	**Collaboration**: Industries (hotels, airlines); existing initiatives; new partners – agriculture, industry, horticulture; tourism industry; Hawaiʻi Education Alliance; promote state/federal/local/non-profit collaboration; identify and engage stakeholders **Capacity needed**: Data on whether and how ethics have changed; funding; appropriate communication methods; school transportation and access to natural areas
Examine use of unmanned aerial systems to aid management • Fence checks • Seed scattering • Monitoring and mapping canopy cover • Herbicide application • Ungulate detection and control	Moderate-High More efficient, but not necessarily effective due to decreased manpower needed on the ground increased human safety	Low-Moderate Policy currently restricts use; need specialized personnel; Federal Aviation Administration regulations; design/ technology use for altitude; viewed as a "toy"; may not work at high altitudes	Near-term (<5 yrs)	**Where**: Anywhere if politically palatable**;** **c**annot use in wilderness **How**: Increase education and outreach; change policy to allow use	Easy	**Collaboration**: Cross-jurisdictional collaboration (e.g., currently using helicopter on federal land, but drones on state/county lands); use management boundaries for monitoring effectiveness **Capacity needed**: Technology improvements; trained staff; policy changes

Alpine/Subalpine

Hawaiʻi workshop participants did not evaluate current management actions. Please see Maui alpine and subalpine current management action tables.

Table 27. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for alpine and subalpine habitats on Hawaiʻi.

Future Management Goal: Increase public understanding of alpine and subalpine habitats to decrease stress on these systems						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Increase stewardship of local conservation lands within other nearby habitats	Low-Moderate	High	Near-term (<5 yrs)	**Where**: Island-wide; where there is interest in alpine controversy (i.e. observatories) **How**: Collaborative vision; Rapid ʻŌhiʻa Death (ROD) crews; find complementary education programs; communicate that the mountain cannot handle too much stress; work with tour companies to communicate stress; identify and communicate acceptable risks vs. thresholds of vulnerability	Easy	**Collaboration**: Natural Area Reserve System; existing environmental educators; National Park Service; Department of Land and Natural Resources; Kamehameha Schools; Department of Hawaiian Home Lands; tour companies that target the summit **Capacity needed**: Funding; capacity/staffing
Create remote sites and viewpoints with sightlines of alpine/ subalpine habitats, and public signage of natural and cultural importance of habitats	Moderate	Moderate-High	Mid-term (5-20 yrs)	**Where**: Imiloa; Mauna Kea County Park; National Oceanic and Atmospheric Administration lab on Mauna Loa; Kona; Waimea **How**: Communicate bi-directional flow of impacts; communicate soundscape (silence) benefits; need to communicate local examples	Easy-Hard Hard once constructed	**Collaboration**: County; National Oceanic and Atmospheric Administration; Parker Ranch; Waikoloa Village; Pōhakuloa Training Area Environmental **Capacity needed**: Funding; permission for private lands
Increase awareness of invasive species risk and spread	Low	High	Near-term (<5 yrs)	**Where**: Remote interpretation sites; airports; malls; car rental offices; shoe stores; nurseries; hotels; hunter check-in stations **How**: Rapid ʻŌhiʻa Death (ROD) crews; all invasive species; Wash Your Boots campaign; people have a role to play (i.e. maintain your yard); think local, act island-wide	Easy	**Collaboration**: Environmental education groups; airports; visitor and rental entities; outdoor gear shops; tire centers; horticultural entities; hunting community **Capacity needed**: Funding; relationships with different sectors

Kauaʻi

Coastal Habitats (beaches, estuaries)

Table 28. Current management goals, potential vulnerabilities, and current management actions for coastal habitats on Kauaʻi.

Current Management Goal: Protect coastal habitats

Potential climatic and non-climatic vulnerabilities:

- Ocean acidification and impacts on coastal invertebrates
- Sea level rise
- Saltwater inundation and impacts on wetland vegetation and habitats
- Salinity and tolerance of limu
- Upland, non-point source pollution
- Changes in precipitation on fresh/saltwater mix
- Political will
- Diseases

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Non-native and invasive species management: a) Biosecurity b) Predator control (cats, rates, mongoose, snakes) c) Hau and mangrove removal	a) Moderate b) Low c) Low	a) Low b) Moderate c) Moderate	**Where**: a) Ports, harbors, Nawiliwili, Pacific Missile Range Facility b) Cat colonies in coastal areas, mauka to makai for all others, trees, coastal riparian for ants c) River mouths, coastal riparian, estuaries **How**: a) More capacity, broader scope, Pacific Missile Range Facility, education from dock to managers b) Integrate into other plans, poisoning if needed c) Chainsaw, replant with natives, pesticide placed around based of mangroves and hau; however, may want to investigate utility of maintaining mangroves if they can help buffer sea level rise and other impacts – will be a tough decision	a) Easy b) Hard c) Hard	**Other resources action benefits**: a) All other habitats b) Native species, all habitats c) Improved hydrology, opportunity for natives to reestablish, canoeing, cultural/socioeconomic values **Other resources with potential conflicts**: a) None – tourism industry scared of trapped mongoose pictures b) Chemicals, people who love cats c) People like how it looks, loss of visual/hazard buffers
Watershed management planning	Low-Moderate	High	**Where**: Biggest development impacts, largest rivers, areas of highest water content (Nawiliwili, Waimea), pristine areas (Limahuli) **How**: Prioritize watersheds; identify impaired waterways	Easy	**Other resources action benefits**: Recreation, quality of life, flood control, fisheries **Other resources with potential conflicts**: Private property owners
Runoff management • Stormwater	Moderate	High	**Where**: Areas that are developed – parking lots, commercial/residential development; farms and	Easy	**Other resources action benefits**: Public health, habitat quality, wildlife

• Nutrients • Wastewater			agricultural lands **How**: Restore native plants; green infrastructure as part of stormwater ordinance; upgrade treatment plans		health, flood control **Other resources with potential conflicts**: Non-compliant developers; funding; government regulations

Table 29. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for coastal habitats on Kauaʻi.

Future Management Goal: Allow for retreat of priority coastal habitats in light of climate change						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Implement living shorelines and green infrastructure (e.g., living shorelines: dunes, reefs, natural plantings; green infrastructure: permeable pavement, green roofs)	High	Moderate Political will	Near-term (<5 yrs)	**Where**: State and county property to do first demo (e.g., Green infrastructure: Kakaako; Living shorelines: Huleia mangrove removal and replanting, Lydgate, Black Pot, Ponakai, areas near river mouth estuaries, Kapaʻa Beach Park) **How**: Written into county codes/ required; take out jetties at Kapaʻa Beach Park and put in plants; take out ironwoods; put in sand catchment plants; allow naupaka to establish	Moderate	**Collaboration**: Look at other models in the state, country; funding of living shorelines; schools; local governments **Capacity needed**: Public-private partnership; native seed nurseries
Facilitate habitat migration mauka (build habitat first then communities can move)	High	Low	Near-term (<5 yrs)	**Where**: Areas with significant coastal plan; areas likely to flood; state-owned upland areas **How**: Limit development in further inland/upland areas where habitat may be suitable; model habitat migration zones; allow low-lying lands to be set aside to maintain ecosystem function; create habitat through Natural Resources Conservation Service or others	Hard	**Collaboration**: Communications strategy (i.e. building habitat to protect communities from flooding); intergovernmental coordination **Capacity needed**: Research, maps, policy change
Managed retreat of infrastructure and communities (e.g., Kalihiwai post tsunami)	High	Low	Mid-term (5-20 yrs)	**Where**: Most vulnerable, low-lying areas/habitats (Kapaʻa, Hanalei, Waimea, Kekaha, Moloaa, Anahola, Lihue); prioritize communities that have space upland (i.e. Hanalei, Kapaa); in places already doing hazard planning **How**: After next hurricane – map out most vulnerable areas to identify potential future risks; integrate flood risk into realtor and insurance disclosures (climate risk disclosure);	Hard	**Collaboration**: Realtors; insurance entities; landowners; schools; state agencies; county agencies; Surfrider; FEMA; community associations **Capacity needed**: FEMA Community Rating System; policy change; community-based implementation;

				strict setback rule implementation; transfer development rights		change in governance support

Streams and Lowland Wetlands

Table 30. Current management goals, potential vulnerabilities, and current management actions for stream and lowland wetland habitats on Kaua'i.

Current Management Goal: Reduce invasive species

Potential climatic and non-climatic vulnerabilities:

- Precipitation – impacts on plant distribution (e.g., albizia)
- Increased evapotranspiration – water availability effects
- Bait and trapping effectiveness
- Increased disease (avian botulism, new/novel diseases)
- Increased water temperature – changing food availability
- Increased reproduction of rates
- Range shifts of invasive species
- New invasive species
- Increased salinity may reduce native propagation

Current Management Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Where/How to Implement Given Vulnerabilities**	**Reversibility of Action**	**Other Resource Considerations**
Trapping for predator control	Moderate-High Not enough hunters; continued predator influx; different land use values (i.e. promotion of cat colonies in some areas)	Moderate Mobility of predators; size dependent; varies by species; not feasible for rats; labor intensive; weather dependent; funding dependent; location/placement; bycatch (i.e. mice in cat traps)	**Where**: Prioritize within critical habitat areas; areas less vulnerable to flooding (avoids trap loss); areas with vulnerable bird species (need to track birds as they move); areas where predators are coming in (if these change) **How**: Increase trap effort during dry periods or during dry stretches in wet season; combining A24 with live cat traps (avoids issue with increased precipitation, increased seed availability); use dogs for mongoose scenting	Easy	**Other resources action benefits**: Decreases toxo/disease spread, benefiting downstream systems; benefits other native birds aside from wetland waterbirds; decreases taro and native seed consumption, which may increase plant propagation **Other resources with potential conflicts**: May increase other invasives (e.g., by decreasing chicken control by cats); unintended/unknown trophic consequences; incidental trapping of listed species (i.e. moorhen, nene, shearwater)
Mechanical and chemical invasive plant removal	Moderate-High Jurisdictional challenges –	Low-Moderate Labor intensive; can work at small scale,	**Where**: Control in new areas if streamflow decreases and more invasives present; maintain in existing areas; possibly in areas resilient to SLR	Easy	**Other resources action benefits**: Maintains streamflow; reduces sedimentation; maintains water filtration/downstream benefits

	neighboring land uses	harder island-wide	**How**: Adaptive management: track responses to actual change (i.e. rates of spread, ranges); identify thresholds where new management interventions are needed; research thresholds/tipping points for native species; need central clearinghouse of information		**Other resources with potential conflicts**: May damage nests; could reduce habitat availability/increase predator exposure over short term; increased erosion; chemical application may negatively affect larvae, algal productivity, etc.; potential fuel spills; accidental transfer of invasive/non-native species

Table 31. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for stream and lowland wetland habitats on Kaua'i.

Future Management Goal: Increase citizen outreach, education, and science to increase awareness and support for managing systems in light of climate change

Adaptation Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Implementation Timeframe	Where/How to Implement	Reversibility of Action	Collaboration & Capacity
Develop multiple avenues to increase local education (i.e. schools, public story events, kids vs. adults, tourists vs. locals, movies, climate change exhibits, fur vs. feather competitions, etc.)	High Depends on scale	Moderate-High Do not always know how best to reach people; funding; personnel turnover	Near-term (<5 yrs)	**Where**: Times/locations that will increase local community exposure; free events (i.e. Lighthouse days); museum – central island location; newspapers; social media; outreach videos; game cameras to capture species and share in classrooms **How**: Identify different venues (i.e. museums, kids summer camp, hunter safety trainings); create survey to identify how different people process information; identify opportunities for continued engagement vs. one-day events; link with other permitting actions (i.e. hunter safety/licensing courses); emphasize native species, climate-informed conservation; standardize climate change message and develop	Easy	**Collaboration**: Multiple agencies (develop consistent messaging); Garden Island Resource Conservation District; schools; hunting entities; videographers; educators **Capacity needed**: Staffing; Kauai Conservation Association; Kauai Community College; diversified funding sources; business partners

				baseline acceptable conditions		

Mesic and Wet Forest and Upland Wetlands

Table 32. Current management goals, potential vulnerabilities, and current management actions for mesic and wet forest and upland wetland habitats on Kauaʻi.

Current Management Goal: Protect watersheds by increasing water capture and groundwater recharge (e.g., maintaining ground/shrub cover, planting native species)

Potential climatic and non-climatic vulnerabilities:

- Increased invasive species
- Changing species composition
- Decreased precipitation
- Increased wildfire
- Increased temperatures
- Hunting/recreation activities
- Increased parasites/pathogens
- Increased storms
- Human activities: ignitions, land use, ecotourism

Current Management Action	Effectiveness in Reducing Vulnerabilities	Feasibility	Where/How to Implement Given Vulnerabilities	Reversibility of Action	Other Resource Considerations
Fencing and ungulate removal (snares, hunting, trapping, monitoring before and after)	High Large scale more effective	Moderate-High Funding is barrier; Political ambivalence may help increase feasibility	**Where**: Continue to implement in high elevation watersheds/areas which serve as refugia and work down; restore areas mostly degraded below planning; fencing to serve as buffer **How**: Install taller fences for deer; plan for more maintenance funds per year; increase hunting opportunities (access and timing); increase user fees; leverage recreational hunting to improve conditions in buffer zones; re-evaluate feasibility of different landowner relationships	Easy	**Other resources action benefits**: Water supply, water quality, filtration and storage, native species, recreation/hunting opportunities, new/unusual opportunities for partnerships **Other resources with potential conflicts**: Perceived decreased access to hunting areas that are important for specific hunters; invasive plants; wildfire; vandalism
Control invasive plants through biocontrol measures	Moderate Scaling issue, neighboring lands	Low-Moderate Maintenance/ continual control/ funding	**Where**: Continue to keep out of priority areas; expand outward into larger buffers where species are moving **How**: Shift target species (e.g., prioritize those likely to do better under climate change); monitoring and evaluation of invasive plants to determine what to prioritize; biocontrol methods investigation	Easy	**Other resources action benefits**: Maintain water supply, biodiversity, reducing sedimentation **Other resources with potential conflicts**: Pesticide/herbicide use with pollinators and insects

Ex situ conservation (seed banking, captive breeding)	Moderate Rarely implemented	Moderate	**Where**: Target at-risk species for collection; sample as many populations/locations as you can; potentially target areas of persistence of species; collect pioneer species **How**: Representation of genetic diversity and habitat diversity; pre-plan (plant species likely to do better in drier conditions); restore to what the conditions are projected to be and monitor to determine if changes are occurring; prepare for fire and storms; collect and plant disease-resistant varieties; provide corridors for species movement over time	Easy (plants) Hard (birds)	**Other resources action benefits**: Native species, biodiversity, pollinators, increasing resilience overall **Other resources with potential conflicts**: Takes away funding from other projects; genetic manipulation (inbreeding/outbreeding); altered water capture/recharge rate; increased diseases/pests

Table 33. Potential future management goals, adaptation actions, and action implementation details including where and how to implement and collaboration and capacity needs for mesic and wet forest and upland wetland habitats on Kaua'i.

Future Management Goal: Increase community outreach to increase public awareness and value of mesic and wet forest habitats						
Adaptation Action	**Effectiveness in Reducing Vulnerabilities**	**Feasibility**	**Implementation Timeframe**	**Where/How to Implement**	**Reversibility of Action**	**Collaboration & Capacity**
Increase K-12 education: • School programs • Community-based restoration projects • Pick a specific site to focus on for combined education/ restoration project	Moderate	Moderate	Near-term (<5 yrs)	**Where**: Koke'e as restoration site **How**: Working group; business plan; funding; land; Department of Energy buy-in	Moderate	**Collaboration**: Cultural practitioners, educators, scouts, Department of Energy, churches, farmers, hunters, fishermen, state parks, conservationists, YWCA, Hui Olaka, storybook theater **Capacity needed**: Community engagement, corporate/private funding, carbon sequestration funding

Citation

Gregg, R.M., editor. 2018. Hawaiian Islands Climate Vulnerability and Adaptation Synthesis. EcoAdapt, Bainbridge Island, WA.

For more information on this report and other products, please contact Rachel@EcoAdapt.org and visit http://bit.ly/HawaiiClimate.

Produced in cooperation with the Pacific Islands Climate Change Cooperative with funding from the U.S. Fish and Wildlife Service