The Pacific Islands Climate Science Center Five-Year Science Agenda, 2018–2022

David A. Helweg, Dan A. Polhemus, and Bonnie J.E. Myers

FRONT COVER IMAGE: The Hawaiian voyaging canoe Hawai‘iloa, seen here along the windward shores of Moloka‘i, was built in the early 1990s in the traditional way, but using two Sitka spruce trees given by the Tlingit and Haida tribes of Alaska instead of the massive native koa trees, now depleted in Hawai‘i’s forests. Maritime traditions of Native Hawaiian and Pacific peoples are strong and deep in community and cultural identity and reflect complex linkages between society, land, sea, and sky. Photograph © Monte Costa/Photo Resource Hawaii.

Contents

Figures

Tables

Abbreviations

CONUS	Continental U.S.
DOI	Department of the Interior
EEZ	Exclusive Economic Zone
ENSO	El-Niño Southern Oscillation
NCCWSC	National Climate Change and Wildlife Science Center
NOAA	National Oceanographic and Atmospheric Administration
PI-CSC	Pacific Islands Climate Science Center
RISA	Pacific Regional Integrated Sciences and Assessments Program
SAC	Stakeholder Advisory Committee (PI-CSC)
SON	Resource Management Statement of Need
USAPI	U.S. Affiliated Pacific Islands
USCRTF	U.S. Coral Reef Task Force
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey, DOI

Acknowledgements

Dan Polhemus participated in development of this document through Inter-Agency Agreement G17PG00088 from the U.S. Geological Survey to the U.S. Fish & Wildlife Service, Pacific Islands Office. Bonnie Myers (National Climate Change and Wildlife Science Center) participated while on detail to the Pacific Islands Climate Science Center as the Research Manager. We thank the Stakeholder Advisory Committee and Science Advisory Panel, who gave us many days of their time to develop and approve the resource management climate adaptation priority needs and the science framework to address those needs. Jonathan Likeke Scheuer facilitated the Stakeholder workshops (USGS contract G16PX01458), providing his unique leadership navigating towards this statement of the climate adaptation needs of our region.

Citation

Helweg, David A., Polhemus, Dan A., and Myers, Bonnie J.E. (2017). *The Pacific Islands Climate Science Center Five-Year Science Agenda, 2018–2022*. https://doi.org/10.21429/C9HG9R.

Executive Summary

The Department of the Interior (DOI) Pacific Islands Climate Science Center (PI-CSC) is one of eight CSCs in the National Climate Change and Wildlife Science Center (NCCWSC) managed by the US Geological Survey (USGS). The Mission of the NCCWSC enterprise is to "deliver science to help fish, wildlife, water, land, and people adapt to a changing climate". The PI-CSC serves Hawai'i and the US Affiliated Pacific Islands (USAPI)[1]. The PI-CSC supports adaptation by producing new knowledge and tools through research, by working with resource managers and community planners to include environmental knowledge in adaptation decision making, and by building capacity in the next generation of resource managers and scientists through education and training.

The PI-CSC uses a 5-year science plan, called a Science Agenda, to guide investment in research and training for climate adaptation in the region. The PI-CSC works with a Stakeholder Advisory Committee to identify natural and cultural resource management priorities, and aligns those with national priorities. In this Science Agenda, we describe the priorities for climate adaptation science for 2018-2022.

Environmental Change from a Pacific Island Perspective. From the snowy heights of Mauna Kea on Hawai'i Island to the depths of the Mariana Trench, from densely populated cities and US military installations to sparse rural communities and uninhabited sandy atolls, the Pacific region encompasses diverse associations of peoples and places that are directly affected by changes to the atmosphere, ocean, and land. Changing climate impacts society in three fundamental ways, through changes in (1) ecosystem goods and services (the amount and dependability of nature's contributions to people), (2) ecosystem function and wildlife populations, and (3) intensity, duration, and predictability of damaging natural events. Each of these has costs to society.

In the Pacific Islands region, over 500 Endangered Species and other vulnerable biota exist in a complex set of landscapes and seascapes. These plants and animals have shared these islands with generations of indigenous peoples, a rich biocultural environment with over 20 spoken languages and thousands of cultural sites and features. The PI-CSC interprets climate adaptation from this "biocultural" context. People, built environments, natural heritage, agriculture, economies – all are interwoven in a patchwork compressed onto small land areas. The holistic biocultural approach integrates climate adaptation in human communities and natural areas. It has the greatest promise for success because it maximizes engagement of the people and organizations that are needed for adaptation to succeed.

The PI-CSC Stakeholder Advisory Committee and Scientific Advisory Panel identified high priority climate adaptation needs for resource managers and contributed to transforming the priorities into the final science framework. Intuitive for an island region, there is substantial concern for science and support for adaptation in the coastal zone.

[1] The US Affiliated Pacific Islands (USAPI) include the Territories of American Samoa and Guam, Commonwealth of the Northern Mariana Islands, and the Freely Associated States of the Republic of Palau, Federated States of Micronesia, and Republic of the Marshall Islands.

Islands also allow us to visualize and make quick connections between the coast and inland/ upland areas, and the framework also describes substantial concern for science and support for adaptation in the precious natural and cultural heritage of island forest systems. Described by the biocultural context, people and their natural and cultural heritage are links in the chain of adapting to changing conditions.

Working with the Stakeholder Advisory Committee and Science Advisory Panel, the PI-CSC developed a science framework based on five Themes.

- *THEME: Drought in the Pacific Islands.* Managers seek to understand drought tolerance of species and forest community structures that might stabilize dry and wet ecosystems, and seek to understand how the human dimensions of drought will support efforts to prevent fires and increase resilience that will sustain biodiversity and society.
- *THEME: Coastal Adaptation & Planning.* Managers of coastal communities and natural areas seek to develop adaptation strategies that address the impact of sea level rise, wave inundation, salt water intrusion, coastal hazards and changes to terrestrial hydrology. Managers seek to ensure that adaptation strategies or plans are consistent (spatially and temporally) with the planning horizons and jurisdictional purview of organizations addressing climate change.
- *THEME: Forest Conservation in a Changing Environment.* To manage terrestrial protected areas and species, biocultural resources and practices, ecosystems, and sensitive/important species in coming decades, managers seek to understand how forest resource abundance, distribution, and ecological interactions could be affected by changes in environmental drivers.
- *THEME: Core Questions for Resource Managers.* Grappling with climate change poses a challenging set of questions for managers of fish, wildlife, and habitat. In Hawai‘i and USAPI, there is only limited understanding of the processes that control change in forest and woodland plant communities and food webs. Moreover, there are complex issues that compete with climate change for attention because of their immediate impact. Thus, managers seek to include climate change as a new, additional stressor in their framework for resource management.
- *THEME: Adaptation and Survival in Low Islands and Atolls.* For human communities and living resources in low islands or atolls, climate impacts are so immediate and extensive that adaptation is essentially equal to survival. Government officials seek to better understand and anticipate potential or actual human population displacement as a result of climate-related ocean inundation that will affect food security, freshwater security, and livelihood, to develop programs to transition the displaced and develop means to preserve cultural identity.

The framework described here portrays a wide and complex spread of issues, not surprising given the communities, infrastructure, and natural and cultural heritage of this vast region. The challenges to implementation are chronic – limited funds and the logistics of working with partners across millions of square miles of ocean. The Science Agenda was developed in collaboration with resource managers, community planners, and cultural practitioners. Extent of implementation will depend on levels of funding and partnerships available.

Introduction

The Department of the Interior (DOI) Pacific Islands Climate Science Center (PI-CSC) is one of eight CSCs in the National Climate Change and Wildlife Science Center (NCCWSC) managed by the US Geological Survey[2] (USGS). The Mission of the NCCWSC enterprise is to "deliver science to help fish, wildlife, water, land, and people adapt to a changing climate". The PI-CSC serves Hawai'i and the US Affiliated Pacific Islands (USAPI)[3], spread across a vast expanse of the Pacific covering an area larger than the North American continent between the southern tropics northwards across the equator to the northern Tropic of Cancer, and spanning five time zones and the International Date Line (Figure 1, top panel). This region is peppered with National Parks and National Wildlife Refuges (Figure 1, bottom panel).

In 2013, the PI-CSC developed its first 5-year science plan spanning 2014-2018, described as a Science Agenda[4]. The Science Agenda is aligned with agency and department priorities, and is central to informing investment in research and training for climate adaptation in the region. The PI-CSC has subsequently continued to work with its stakeholders, science advisors, and agency guidance to update its priorities, which are presented in this new Science Agenda for 2018-2022.

Environmental Change from a Pacific Island Perspective

From the snowy heights of Mauna Kea on Hawai'i Island to the depths of the Mariana Trench, from densely populated cities and US military installations to sparse rural communities and uninhabited sandy atolls, the Pacific region encompasses diverse associations of peoples and places that are directly affected by changes to the atmosphere, ocean, and land (reviewed in Helweg et al., 2014; Keener et al., 2012; Keener et al., 2013; Marra et al., 2017). Changing climate impacts society in three fundamental ways, through changes in (1) ecosystem goods and services (the amount and dependability of nature's contributions to people), (2) ecosystem function and wildlife populations, and (3) intensity, duration, and predictability of damaging natural events. Each of these has costs to society. Warming conditions, now and in coming decades, will create heat-related stress for human communities, agricultural systems, infrastructure, and for native plant and animal species. Intensified drought-related cycles make water shortage one of the most important climate-related risks in the region. Invasive species and land use change are likely to amplify the adverse effects of climate change on habitats and species. Coastal zones and resources are threatened by flooding and intrusion of seawater into infrastructure and aquifers. Fisheries are threatened by warmer ocean temperatures and ocean acidification. Widespread coral reef bleaching, caused by ocean warming, is contributing to lower fisheries yields. Cumulatively, changing climate is a factor in loss of goods and services that range from coastal protection, habitat, and economic gains from tourism based on healthy ecosystems on land and in the ocean.

---

[2] Visit NCCWSC and the PI-CSC online at https://nccwsc.usgs.gov/ and https://nccwsc.usgs.gov/pacificislandscsc, respectively

[3] The US Affiliated Pacific Islands (USAPI) include the Territories of American Samoa and Guam, Commonwealth of the Northern Mariana Islands, and the Freely Associated States of the Republic of Palau, Federated States of Micronesia, and Republic of the Marshall Islands.

[4] PI-CSC 2014-2018 Science Agenda available for download at https://pubs.usgs.gov/of/2014/1075/

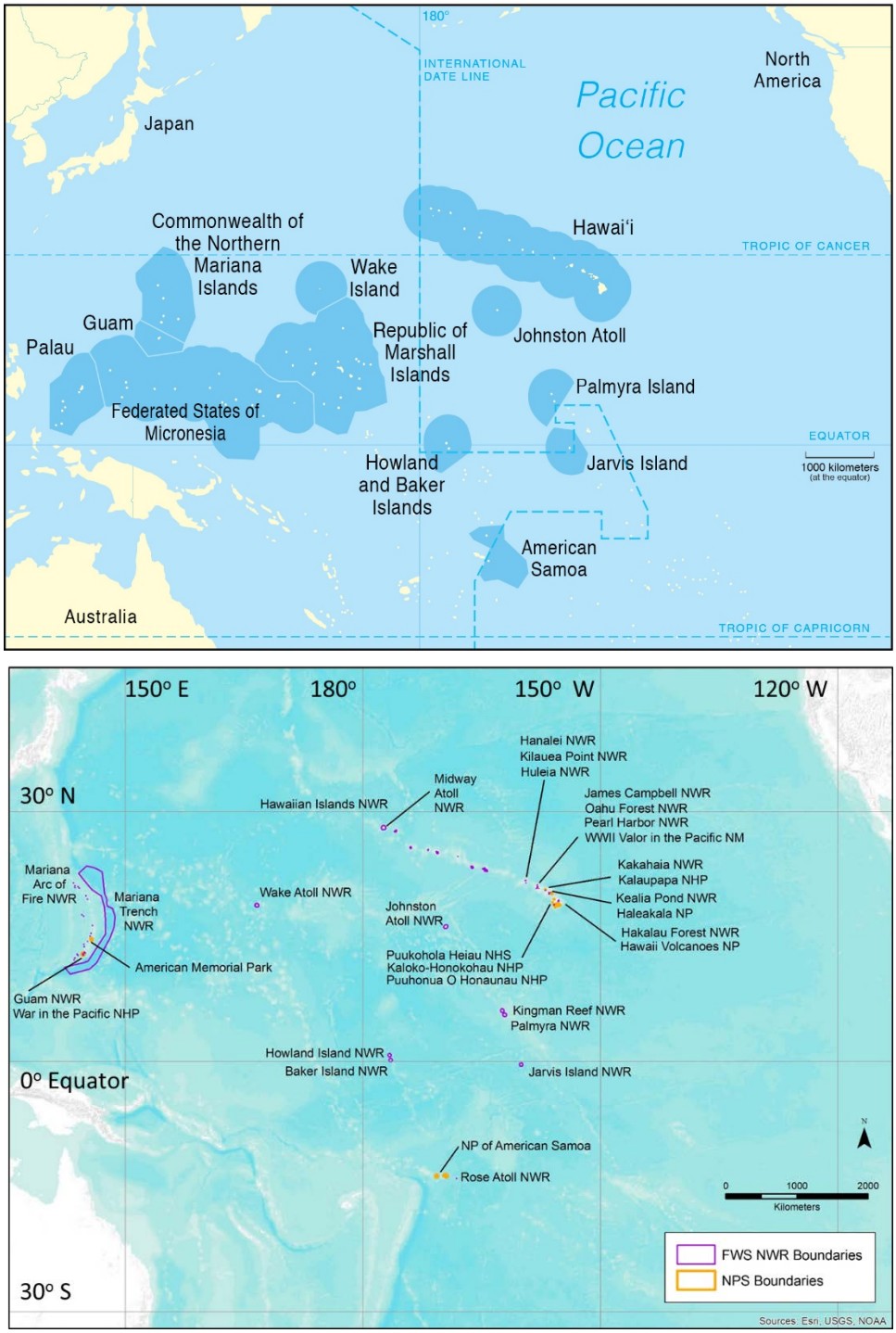

Figure 1. The PI-CSC REGION. The top panel illustrates the U.S. and U.S.-Affiliated jurisdictions using EEZ. The bottom panel depicts locations of National Parks and Fish & Wildlife Service Refuges.

Seasonal Variability and Long-Term Change. Due to their location close to the equator, the most prevalent cause of year-to-year changes in Pacific Island climate patterns is the El Niño-Southern Oscillation (ENSO) phenomenon. Regional impacts from the El Niño and La Niña phases of ENSO vary with season and strength, and can dramatically affect precipitation, air and ocean temperature, sea surface height, storminess, wave size, and trade winds. The strength of these ENSO-related patterns in the short term can make it more difficult to observe the more gradual, long-term trends of climatic change. However, understanding and anticipating ENSO effects is important for planning for shorter-term climate impacts on island communities and natural resources. Some of these shorter-term impacts may have more significant implications for resource managers than multi-decadal long-term climate changes. Therefore, climate adaptation must consider the time frames of ENSO and climate variability (seasonality, and several years to a decade out) as well as long-term climate change over many decades.

A Biocultural Context for Climate Adaptation

In the Pacific Islands region, over 500 Endangered Species and other vulnerable biota exist in a complex set of landscapes and seascapes. Perhaps surprising to those who envision these islands as tropical beaches, a large portion of land cover is in fact forest[5], although these small land areas are surrounded in substantial oceanic Exclusive Economic Zones (EEZs; Table 1). While vulnerability of native biodiversity in the past has been quantified in terms of endangered species (Table 1), it can also be understood in the context of its richness and uniqueness as a whole, and is a natural heritage requiring wise and forward-looking stewardship legacy goals. These plants and animals have shared these islands with generations of indigenous peoples, a rich biocultural environment with over 20 spoken languages and thousands of cultural sites and features. Each culture's beliefs and societal structure, as well as their relationship with the environment, is unique and closely connected with the land, sea and the locally unique plants and animals of each island group.

The Pacific Islands CSC interprets climate adaptation from this "biocultural" context. From the perspective of resource management, a biocultural resource is "the tangible and intangible cultural heritage relating to human interaction with the natural environment, and the organisms, ecosystems, and geophysical components within that environment which are essential to such cultural heritage". People, built environments, natural heritage, agriculture, economies – all are interwoven in a patchwork compressed onto small land areas. Thus, it is important to combine the study of adaptation with the practice of adaptation. The holistic biocultural approach integrates climate adaptation in human communities and natural areas. It has the greatest promise for success because it maximizes engagement of the people and organizations that are needed for adaptation to succeed.

[5] USDA Forest Service land cover maps are online at https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046690

Island Jurisdiction	EEZ (Sq Mi)	Land Area (Sq Mi)	Percent Forest	Protected Species
States				
Hawai'i (main islands)	345,695	6,365	35%	502
Commonweath & Territories				
American Samoa	156,136	76	50%	6
Guam	85,523	230	40%	33
Northern Mariana Islands	289,294	179	50%	26
Sovereign Freely-Associated States				
Marshall Islands	768,548	70	n/a	n/a
Federated States of Micronesia	1,156,924	271	85%	n/a
Palau	233,197	165	81%	n/a

Table 1. Descriptions of the PI-CSC jurisdictions by square miles of EEZ, land area, percent acreage in forest, and ESA-listed species. Land area and percent forest are approximations. Protected species numbers online at https://ecos.fws.gov/ecp0/reports/species-listed-by-state-totals-report.

Science Priorities 2018 – 2022

In this section, we describe the priorities for climate adaptation science in the next five years. The PI-CSC has limited funds and must invest them carefully. To accomplish this, our funding is aligned, strategic, and leveraged. First, we must identify climate-related needs most aligned with the missions of the Department of Interior (DOI) and USGS programs. Second, we must set aside issues that are covered well by other agencies or for which science or management have little traction. Finally, we seek to accomplish as much as we can by collaboration with regional climate programs, resource managers, cultural stewards, community leaders, and existing research/management collaboration networks.

The PI-CSC supports adaptation by producing new knowledge and tools through research, by working with resource managers and community planners to include environmental knowledge in adaptation decision making, and by building capacity in the next generation of resource managers and scientists through education and training. Two types of research are needed. One is called "actionable science"[6], designed to be quickly useful to resource managers. It starts with a resource management decision that needs to be made. Actionable science is most reliably co-produced by scientists working in concert with decision makers or resource managers. Importantly, in order to deliver actionable science it may be necessary to build a foundation of knowledge first. An example of a foundational product would be a high-resolution coastal map, which is needed to predict how far inland sea level rise would go and thence to mapping out community vulnerability. The Pacific Islands have very few foundational products

[6] Actionable science is defined at https://nccwsc.usgs.gov/sites/default/files/files/ACCCNRS_Report_2015.pdf

compared to the CONUS, and thus PI-CSC actionable science often has to start nearly from scratch. A second type of science is motivated by scientists' understanding of the need for research at a time when resource managers aren't yet ready for co-production. That said, this is not pure or basic research. Instead, scientists may detect changing conditions and strive to understand the system to help inform management questions or needs. We must understand the resource in order to manage it.

The Science Agenda update process started in April 2016. The PI-CSC Stakeholder Advisory Committee (SAC; see Table 2) was charged with identifying ways in which changing environmental conditions may impact resource management. The SAC met in two 2-day workshops in October 2016 and May 2017, during which they developed and agreed upon a set of Resource Management Statements of Need (SONs; described in Appendix 1). The PI-CSC convened a working group of regional science leaders, a Scientific Advisory Panel, who participated in SAC meetings and assisted in transforming the resource management SONs into a set of scientific questions and the final science framework.

PI-CSC Stakeholder Advisory Committee	
Participating Organization	**Invited to Participate**
EPA Pacific Islands Office	American Samoa
Guam	DOI Office of Hawaiian Relations
Hawaii Commission on Water Resource Management	DOI Office of Insular Affairs
Hawaii State Office of Conservation and Coastal Lands	Hawaii State Department of Agriculture
Kamehameha Schools Natural and Cultural Resources Group	Hawaii State Division of Forestry and Wildlife
National Park Service CESU Office	Hawaii State Office of Planning
National Park Service Pacific West Region	The Federated States of Micronesia
NOAA Pacific Islands Regional Office	The Nature Conservancy -- Micronesia
NOAA Pacific Regional Integrated Sciences and Assessments	USDA Forest Service Regional Office
Pacific Birds Habitat Joint Venture	
Pacific Islands Climate Change Cooperative (USFWS LCC)	
Secretariat of the Pacific Regional Environment Programme	
The Commonwealth of the Northern Mariana Islands	
The Nature Conservancy – Hawai'i	
The Republic of Palau	
The Republic of the Marshall Islands	
USDA Natural Resources Conservation Service	
USDA Pacific Climate Hub	
USFWS Pacific Islands Fish & Wildlife Office	

Table 2. The PI-CSC Stakeholder Advisory Committee who worked together to formulate Resource Management Statements of Need for this Science Agenda.

Filters and Exclusions. Some issues are covered well by other programs and were set aside. For example, commercial fisheries by NOAA, commercial crops by USDA, pollutants by EPA, municipal water by the Pacific RISA and USGS Water centers, and coral reef conservation by the US Coral Reef Task Force (USCRTF). The full list of exclusions and down-selecting to aligned focal areas is described in Appendix 2.

After aligning the PI-CSC to agency and departmental priorities, the SONs developed by the Stakeholder Advisory Committee were transformed into a framework of climate adaptation issues and focal areas within those issues, presented in Table 3. Progress and learning in the first cycle of the PI-CSC Science Agenda (2014 – present) were synthesized and included in developing the science framework, summarized in Appendix 3. The science framework represents the SONs and also connects and provides continuity with the existing set of priorities in the current Science Agenda (Helweg et al., 2014). This crosswalk is provided in Appendix 4. Some of the concepts that emerged during stakeholder dialogues were related more to the structure and content the CSC should seek in future projects, rather than specific scientific questions. These implementation issues are documented in Appendix 5.

Intuitive for an island region, there is substantial concern for science and support for adaptation in the coastal zone. The framework also describes substantial concern for science and support for adaptation in the precious natural and cultural heritage of island forest systems. Consistent with the biocultural context, the science framework connects natural and cultural resources and the lifeways of contemporary human communities in the region. People and their natural and cultural heritage are links in the chain of adapting to changing conditions.

	SCIENCE THEMES				
	Drought in the Pacific Islands	Coastal Adaptation & Planning	Forest Conservation in a Changing Environment	Core Questions for Resource Managers (1)	Adaptation and Survival in Low Islands and Atolls
Theme Focal Areas	Ecohydrology and Watershed Services	Coastal Cultural Heritage Sites	Changing Plant Communities in Forests and Woodlands	Adaptation Decisions for Low Likelihood – High Risk Future Scenarios	Coastal Flooding / Infiltration and Freshwater Security
	Drought, Fire, and Landscape Change	Effective Community Adaptation Planning	Managing Wildlife in Forest Habitats	Testing and Evaluating Model Predictions	Timelines for Critical Habitability Decisions
	Indigenous Agroforestry and Aquaculture Systems	Ridge-to-Reef and Brackish Systems	Indigenous Stewardship of Forests and Woodlands	Assessing Risk Across Multiple Time Frames – What Must Happen Now?	Adapting Agroforestry to Projected Future Conditions
	NOTE (1): "Resource Managers" includes both Natural and Cultural Resources				

Table 3. Climate adaptation themes and focal areas within those themes.

THEME: Drought in the Pacific Islands. Hawai'i and the Pacific Islands are home to unique wildlife and plants arrayed across a remarkable range of ecosystems. Drought has the potential to affect us all in many ways, reducing quality of life and impacting agriculture and native ecosystems. Early Oceanic voyaging societies adapted to regular climate variations, including periods of extreme drought. Today, as drought events become more severe, contemporary communities must also learn to adapt. Managers seek to understand drought tolerance of species and forest community structure that might stabilize dry and wet ecosystems, and seek to understand how the human dimensions of drought will support efforts to prevent fires and increase resilience that will sustain biodiversity and society.

- Focus: Ecohydrology and Watershed Services. Freshwater hydrologic systems will be affected as climate and humans modify vegetation in forested areas that receive substantial rainfall. Improved understanding of how different watershed tree species affect the hydrologic cycle are important for developing effective land-management decisions designed to address the interaction between climate change and freshwater production. PI-CSC will work with land managers to identify strategies to enhance water resources and reduce runoff, including implications of eliminating non-native watershed plant species that transpire at high rates.
- Focus: Drought, Fire, and Landscape Change. In Pacific Islands, cycles of wet and dry conditions increase the likelihood of wildfire, which kills native plants while spreading invasive weeds. Denuded landscapes elevate potential for erosion, which delivers sediment into streams and nearshore areas. PI-CSC will work with land and water managers to identify and prioritize locations and watersheds vulnerable to increases in drought-related wildfire and erosion and provide tools to help managers develop informed adaptive management strategies to reduce the adverse impacts of drought on native plant communities and watersheds.
- Focus: Indigenous Agroforestry and Aquaculture Systems. Throughout the Pacific, climate change will alter ecosystem goods and services provided by agroforestry (the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits) and aquaculture (production or harvesting of seafood and seaweeds). PI-CSC will seek to work with resource managers and stewards of indigenous agroforestry and aquaculture in a place-based context to understand how predicted changes in wind conditions, freshwater availability, substrate chemistry, and sea level height may impact systems and to identify mechanisms for increasing resilience in these systems to maintain ecosystem services.

THEME: Coastal Adaptation & Planning. Managers of coastal communities and natural areas seek to develop adaptation strategies that address the impact of sea level rise, wave inundation, salt water intrusion, coastal hazards and changes to terrestrial hydrology. Managers seek to ensure that adaptation strategies or plans are consistent

(spatially and temporally) with the planning horizons and jurisdictional purview of organizations addressing climate change.

- Focus: Coastal Cultural Heritage Sites. Coastal environmental impacts of changing sea levels and wave regimes include inundation, erosion, flooding, storm surge, wave impacts, and loss of coral and other habitat. The PI-CSC will work with stewards of coastal cultural sites, landscapes, and seascapes (e.g. sacred sites and burials, communal sites, archeological sites, littoral indigenous harvest zones), associated cultural practices, and traditional/indigenous knowledge systems in Hawai'i and the U.S. affiliated Pacific Islands to understand vulnerability or thresholds of change to help them prioritize sites, practices, or knowledge for co-production of adaptation and resiliency strategies.
- Focus: Effective Community Adaptation Planning. Planners and regulatory managers of coastal communities seek to develop strategies that consider multiple risks, including the implications of changing climate. Strategic thinking can include consideration of natural infrastructure (e.g., coral reefs to counter wave impact, vegetation to counter erosion) and built infrastructure, as well as the implications of climate-related coastal flooding and infiltration on ecosystem goods and services. Managers could immediately benefit from analyses that seek to understand how exposure to climate change is predicted to affect essential services. Strategic options may include the spatially-explicit economic impacts arising from extreme climate events, annual and decadal variability, and long-term shifts. PI-CSC will work with community managers to provide knowledge or tools for their adaptation decisions, which may seek to balance benefits from successfully managed ecosystem goods and services with potential for regulatory and non-regulatory approaches.
- Focus: Ridge-to-Reef and Brackish Systems. Nearshore habitats, including littoral ecosystems, lagoons, and brackish systems such as mangroves (where they are native), fish ponds, and coastal wetlands, will experience climate impacts related to coastal flooding or changes in rainfall patterns. PI-CSC will work with managers of nearshore resources to understand how predicted changes in climate and land cover stressors may affect structure and function of nearshore and coastal ecosystems, and how changing climate will affect ecosystems services provided by nearshore habitats.

THEME: Forest Conservation in a Changing Environment. To manage terrestrial protected areas and species, biocultural resources and practices, ecosystems, and sensitive/important species in coming decades, managers seek to understand how forest resource abundance, distribution, and ecological interactions could be affected by changes in environmental drivers. Managers also seek to explore and identify adaptation and resilience strategies appropriate for individual sites and/or suitable for larger-scale applications.

- Focus: Changing Plant Communities in Forests and Woodlands. Climate change threatens native forest ecosystems by shifting optimal conditions for native plant species, and by expanding ranges of invasive weeds. PI-CSC will work with

managers to identify areas with high potential to change from native to non-native plant communities, and seek ways to build resilience to future weed invasion into management programs.

- Focus: Managing Wildlife in Forest Habitats. Changing climate will affect populations of native and introduced wildlife and their ability to provide essential ecosystem services. PI-CSC will work with wildlife managers to understand how climate change will alter non-game and game wildlife populations and the ecosystem services provided, especially in non-native areas for services such as grazing to defend native-dominated areas from forest stand-replacement events (e.g., fire) and to reduce invasive grasses, while also providing opportunities for recreational and subsistence hunting.
- Focus: Indigenous Stewardship of Forests and Woodlands. Pacific island communities have an inseparable connection to, and derive their sense of identity from the lands, waters, and biocultural resources of their islands. Environmental change over time threatens this familial relationship with ancestral resources and is disrupting the inter-generational continuity that is required for the health and well-being of these communities. Indigenous stewards, practitioners and resource managers seek to find ways to respectfully acknowledge, share, understand and manage the resources well enough that society can sustainably interact with them into the future, including anticipating and preparing for changing environmental conditions. PI-CSC will contribute to gathering knowledge through communities of practice and place-based management of the resources (in this case, forest ecosystems) in combination with adaptation science, which will contribute to resilience and sustainable resources that are an integral part of human communities.

THEME: Core Questions for Resource Managers. Grappling with climate change poses a challenging set of questions for managers of fish, wildlife, and habitat. In Hawai‘i and USAPI, there is only limited understanding of the processes that control change in forest and woodland plant communities and food webs, including natural succession, succession following wildfire, storms, or land-use change, invasive species spread and impact, and alteration of forest stand structure (the mix of tall and short plant species). Moreover, there are long-standing and complex management practices, plus many issues that compete with climate change for attention because of their immediate impact (e.g., invasive weeds, predation on protected species). Thus, managers seek to include climate change as a new, additional stressor in their framework for resource management. Managers are much more likely to consider and use something they have been actively engaged in developing and therefore have some understanding of. Climate science, ecological science, and resource management seek to get on the same page with time scales, spatial scales, and the ecosystem factors most vulnerable to climate change.

- Focus: Adaptation Decisions for Low Likelihood – High Risk Future Scenarios. Modeling of future environmental conditions includes prediction of average conditions but also produces predictions of conditions that would be considered

extreme. An example might be the "once-in-a-century flood" or sudden spread of an invasive weed or disease in response to a change in environmental conditions or storm event. They are by definition low in likelihood, but risks to natural resources or human communities are high. PI-CSC will work with resource managers to understand whether predicted environmental change is affecting likelihoods and intensities of high-risk conditions, as well as to identify potential management options.

- Focus: Testing and Evaluating Model Predictions. In order to anticipate and manage for climate-related factors, it must be possible to predict, detect, and track climate-related change. Model verification and improvement requires environmental data collected with scale-dependent design and deployment of sensors, plus an assessment of baseline conditions and evaluation through repeated sampling over time. PI-CSC will work with resource managers, climate modelers, and scientists, practitioners and communities to collect relevant environmental data that will be used to verify, evaluate, and refine climate models and predictions feeding into specific management decisions.
- Focus: Assessing Risk across Multiple Time Frames – What Must Happen Now? Managers and decision-makers face multiple challenges to sustainable stewardship of natural resources, and seek to prioritize their investments of time and effort based on the likelihood of demonstrable success. Although projections of climate impact frequently play out across longer time scales, at the order of 30–100 years, resource managers generally focus on actions that can be implemented and justified within much shorter time spans of 1–10 years. The PI-CSC will work with managers to identify time scales relevant to the resources they manage and to projections of climate-related impacts to biocultural resources across both shorter-term and longer-term time scales.

- **THEME: Adaptation and Survival in Low Islands and Atolls.** For human communities and living resources in low islands or atolls, climate impacts are so immediate and extensive that adaptation is essentially equal to survival. Climate impacts are as much about coastal adaptation as freshwater security and food security. Supporting adaptation in these types of landforms are challenged by (1) technical limitations (e.g., ineffectiveness of downscaling; limited environmental time series or geospatial data layers; logistic challenges for boots-on-ground fieldwork), (2) the proximate interaction of coastal, freshwater, and terrestrial systems impacts (e.g., wave inundation of shallow aquifers), and (3) limited potential options for adaptation. Therefore, a separate Theme was created for this complex adaptation challenge. Government officials seek to better understand and anticipate potential or actual human population displacement as a result of climate-related ocean inundation that will affect food security, freshwater security, and livelihood, to develop programs to transition the displaced and develop means to preserve cultural identity.

  Importantly, this Theme is strongly associated with programs of the DOI Office of Insular Affairs (OIA). In the PI-CSC service region, the majority of low islands and

atolls are in the Freely Associated States (FAS), part of the USAPI and the responsibility of OIA. Implementation of the focal areas would follow the lead of, or substantial investment by, offices of local jurisdictional governments, as well as federal agencies such as OIA, Army Corps of Engineers, Federal Emergency Management Agency, EPA, and the State Department for the FAS. CSC products have tremendous value to many sectors. The PI-CSC will ensure that products developed for natural resource management are promulgated to agencies working in atoll jurisdictions, and can provide some degree of technical assistance.

- Focus: Coastal Flooding / Infiltration, Freshwater, and Food Security. Climate-related ocean inundation (including storm surge) and shoreline change are likely to affect community systems, practices and infrastructure (energy, aquaculture/agriculture, transportation / shipping, healthcare, housing, water). The PI-CSC will work with resource managers and community planners to develop biocultural, predictive modeling/simulation, and economic tools to support the transformation and adaptation of atoll communities to multi-sectoral impacts.
- Focus: Timelines for Critical Habitability Decisions. Shoreline erosion and flooding associated with sea level rise and wave overwash are predicted to cause flooding within major population centers in coming years. Preparation for and management of impacts may best be approached across multiple timeframes, from "now" (the next few years) to the next 25-50 years. PI-CSC will work with community planners to understand how many people, and from what specific communities, will be vulnerable to displacement due to the loss of community systems and infrastructure caused by climate-related coastal impacts.
- Focus: Adapting Agroforestry to Projected Future Conditions. Agricultural production on atolls frequently involves a mixture of both native species and indigenously transported cultivars that are grown in traditionally managed, intercropped systems. PI-CSC will work with agronomists, agroforesters and community nutrition experts to identify the components of such systems that are likely to be more heavily affected by climate change impacts, and potential options for shifting agroforestry systems to new crop varieties that may provide an adaptive buffer to projected future changes.

The framework described here portrays a wide and complex spread of issues, not surprising given the communities, infrastructure, and natural and cultural heritage of this vast region. The region is known for the ability of federal, state, and local agencies and organizations to collaborate, and thus this framework also represents substantial opportunity for partnering. The challenges to implementation are chronic – limited funds and the logistics of working with partners across millions of square miles of ocean. Thus, a detailed multi-year work plan is infeasible and impractical. Instead, we provide a Plan of Action that describes how to select and implement focus in the next few years.

Plan of Action

Implementation will consider (1) existing, active work, (2) issues in the existing Science Agenda that remain priorities, (3) opportunities for new lines of work, and (4) other efforts important to the success of adaptation efforts. The PI CSC will continue collaborating or leveraging existing and new contacts and networks, as appropriate. Some aspects of CSC contribution may be through technical assistance and convening of expert groups and resource managers in partnership with agency leads. Extent of implementation will depend on levels of funding and partnerships available.

Drought in the Pacific Islands

- Continue existing, active work
    - *Ecohydrology and Watershed Function*. The PI-CSC has three active, linked projects on the relationship between freshwater resources and watershed plant communities. This work is scheduled to be completed in 2019. Before any new ecohydrology investigations are started, PI-CSC will work with scientists and freshwater managers to evaluate the results of the existing work.
    - *Drought, Fire, and Landscape Change.* The PI-CSC has an active Ecological Drought project that also is linked to a national effort coordinated by the NCCWSC. With active drought and fire management across multiple sectors and agencies in Hawai‘i and the USAPI, the *Drought in the Pacific Islands* theme is highly relevant and will continue in the next few years.

Coastal Adaptation and Planning

- PI-CSC funded several projects in recent years designed to better understand exposure, vulnerability, and impacts of coastal flooding. These projects have been completed and the results have been incorporated into development of priorities for this Theme.
- Start new lines of work, as funding becomes available.
    - *Coastal cultural heritage sites.* Coastal environmental impacts of changing sea levels and wave regimes include inundation, erosion, flooding, storm surge, wave impacts, and loss of coral and other habitat. The PI-CSC will work with stewards of coastal cultural sites, landscapes, and seascapes in Hawai‘i and the U.S. affiliated Pacific Islands to understand vulnerability or thresholds of change to help them prioritize sites, practices, or knowledge for co-production of adaptation and resiliency strategies.
    - *Effective Community Adaptation Planning.* Planners and regulatory managers of coastal communities seek to develop strategies that consider multiple risks, including the implications of changing climate. PI-CSC will work with community managers to provide knowledge or tools for their adaptation decisions, which may seek to balance benefits from successfully managed ecosystem goods and services with potential for regulatory and non-regulatory approaches

Forest Conservation in a Changing Environment

- PI-CSC funded several projects in recent years designed to better understand impacts of climate on native forest communities and species of concern. These projects have been completed and the results have been incorporated into development of priorities for this Theme.
- Start new lines of work, as funding becomes available.
    - *Managing Wildlife in Forest Habitats.* Changing climate will affect populations of native and introduced wildlife and their ability to provide essential ecosystem services. PI-CSC will work with wildlife managers to understand how climate change will alter non-game and game wildlife populations and the ecosystem services provided, especially in non-native areas for services such as grazing to defend native-dominated areas from forest stand-replacement events (e.g., fire) and to reduce invasive grasses, while also providing opportunities for recreational and subsistence hunting.

Core Questions for Resource Managers

- Identify new opportunities for continuing priorities
    - *Evaluating Model Predictions.* In recent years, PI-CSC has worked with scientists to collect environmental data that will be used to verify, evaluate, and refine climate models and predictions feeding into management decisions. PI-CSC will seek opportunities to develop new proposals and partnerships to collect environmental data to evaluate model predictions.
- Start new lines of work, as funding becomes available.
    - *Adaptation Decisions for High Risk Future Scenarios.* Modeling of future environmental conditions includes prediction of average conditions but also produces predictions of conditions that would be considered extreme. An example might be the “once-in-a-century flood” or sudden spread of an invasive weed or disease in response to a change in environmental conditions. They are by definition low in likelihood, but risks to natural resources or human communities are high. PI-CSC will work with resource managers to understand whether predicted environmental change is affecting likelihoods and intensities of high-risk conditions, as well as to identify potential management options.

Adaptation and Survival in Low Islands and Atolls

- Complete and Evaluate existing, active work in the Marshall Islands
    - *Coastal Adaptation.* The PI-CSC has an active Coastal Vulnerability project focused on estimating vulnerability to sea level rise on Majuro Atoll, the center of population and commerce of the Republic of the Marshall Islands. This work is scheduled to be completed in 2019.
    - *Adapting Agroforestry to Projected Future Conditions.* PI-CSC recently co-produced a live online dashboard providing climate-related planting and

harvest information for agroforestry extension agents in the Marshall Islands (http://oos.soest.hawaii.edu/pacific-rcc/Marshalls%20Agroforestry/site/).
    - The body of work developed for the Republic of the Marshall Islands should be evaluated in partnership with RMI leadership before any further work in the RMI is initiated.

- Importantly, this Theme is strongly associated with the DOI Office of Insular Affairs (OIA). Implementation of the focal areas would require the lead of, or substantial investment by, offices of local jurisdictional governments, along with federal agencies and NGOs. The PI-CSC will ensure that products developed for natural resource management are promulgated and can provide some degree of technical assistance. New lines of work will be started, as regional partnerships and funding become available.

Support Adaptation Success

- *Using Existing Knowledge.* The PI-CSC has partnered with other regional climate programs to convene two workshops aimed at understanding how to incorporate climate modeling results in resource management. Supporting application of climate science is a core element of the PI-CSC mission. Examples might include incorporation of climate information in agricultural vulnerability analyses in collaboration with the USDA, or workshops on development of scenarios for high-risk future conditions with resource management and cultural stewardship partners.
- *Action-Ready Knowledge and Tools.* Environmental change already is impacting the PI-CSC service region. Jurisdictional managers are faced with immediate decisions, especially in coastal communities. In other words, knowledge is needed now, without time to wait for new science to deliver results. PI-CSC will seek to find ways to support the immediacy of decisions with projects focused on informing decisions, and to balance this with the need for new knowledge or tools.
- *Put Boots on Ground.* Adaptation is about identifying critical or protected resources and ecosystem services that are at risk, and understanding how information and uncertainty influences decisions of resource managers and community members. PI-CSC will seek to continue to support cycles of learning and implementation by scientists and resource managers, and the mutual learning by scientists, resource managers, indigenous stewards, and indigenous practitioners of how to work together to combine study and boots-on-the-ground practice to deliver actionable science and maximize adaptation success.

The above Science Agenda provides a framework for science to support climate adaptation for the Pacific Islands region over the next five years. The Agenda was developed in collaboration with resource managers, community planners, and cultural practitioners. Extent of implementation will depend on levels of funding and partnerships available.

References

Helweg, D., Nash, S., & Polhemus, D. (2014). The Pacific Islands Climate Science Center five-year science agenda, 2014–2018: U.S. Geological Survey Open-File Report 2014–1075. http://dx.doi.org/10.3133/ofr20141075.

Keener, V.W., Marra, J.J., Finucane M.L., Spooner, D., & Smith, M.H. (Eds.). (2012). *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA).* Washington, D.C.: Island Press. http://www.cakex.org/sites/default/files/documents/NCA-PIRCA-FINAL-int-print-1.13-web.form_.pdf

Keener, V.W., Hamilton, K., Izuka, S.K., Kunkel, K.E., Stevens, L.E., & 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. https://www.nesdis.noaa.gov/sites/default/files/asset/document/NOAA_NESDIS_Tech_Report_142-8-Climate_of_the_Pacific_Islands.pdf

Marra, J.J. et al. (2017). State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands under a Changing Climate: 2017. Coordinating Authors: J.J. Marra and M.C. Kruk. Contributing Authors: M. Abecassis; H. Diamond; A. Genz; S.F. Heron; M. Lander; G. Liu; J. T. Potemra; W.V. Sweet; P. Thompson; M.W. Widlansky; and P. Woodworth-Jefcoats. September, 2017. NOAA NCEI

Appendices

Appendix 1. Resource Management Statements of Need (SONs) developed by the Stakeholder Advisory Committee. These are the foundation for which the science framework is developed.

Statement of Need: Agriculture. To ensure long term food security, managers of agricultural lands seek to better understand vulnerability of current crops and agricultural practices to: sea level rise; rainfall amount and distribution; and tropical cyclone intensity and frequency, in order to develop adaptation and resiliency strategies for the next 5 to 20 years that will be economically and environmentally sustainable in future climate scenarios.

Statement of Need: Coastal Cultural Heritage Shifts. Stewards of coastal cultural sites, landscapes, and seascapes (e.g. sacred sites and burials, communal sites, archeological sites, littoral indigenous harvest zones), associated cultural practices, and traditional/indigenous knowledge systems in Hawai'i and the U.S. affiliated Pacific Islands seek to understand vulnerability or thresholds of severe change due to climate change impacts (i.e. inundation, erosion, flooding, storm surge, wave impacts, and coral loss) to help them prioritize sites, practices, or knowledge for co-production of adaptation and resiliency strategies.

Effective Community Adaptation Planning. Planners and regulatory managers of coastal communities seek to develop strategies that consider multiple risks, including the implications of changing climate. Strategic thinking can include consideration of natural infrastructure (e.g., coral reefs, vegetation to counter erosion) and built infrastructure, as well as the implications of climate-driven coastal flooding and infiltration on ecosystem goods and services. Managers could immediately benefit from analyses that seek to understand how exposure to climate change is predicted to affect essential services. Strategic options may include spatially-explicit economic impacts arising from extreme climate events, annual and decadal variability, and long-term shifts. In this context, decisions for adaptation may seek to balance benefits from successfully managed ecosystem goods and services with potential for regulatory changes to policies, statutes, or rules, and non-regulatory approaches such as modified insurance rates, coastal lands acquisition, and incentives for managed retreat in particularly vulnerable areas.

Statement of Need: Fresh Water Resources. In order to identify and prioritize appropriate climate change adaptation measures, resource managers and policy makers responsible for water and land use decisions seek usable projections of freshwater input (e.g., precipitation and cloudwater intercept), and to understand the implications of uncertainty associated with projections to inform management decisions related to water supply, water quality, and extreme drought and flood events.

Statement of Need: Terrestrial Habitat Shifts. To manage terrestrial protected areas, cultural resources and practices, ecosystems, and sensitive/important species over the next fifty years, managers seek to understand how resource abundance, distribution, and ecological interactions could be affected by changes in environmental drivers. Managers also seek to explore and identify adaptation and mitigation strategies appropriate for individual sites and/or suitable for larger-scale applications.

Statement of Need: Nearshore Habitat Shifts. Nearshore habitats, including littoral ecosystems, lagoons, and brackish systems such as mangroves (where they are native), fish ponds, and coastal wetlands, will experience climate impacts related to coastal flooding or changes in rainfall patterns. Managers of nearshore resources seek to understand how predicted changes in climate and land cover stressors may affect structure and function of nearshore and coastal ecosystems, and how changing climate will affect ecosystems services provided by nearshore habitats.

Statement of Need: Societal Shifts. Government officials seek to better understand and anticipate potential or actual human population displacement as a result of climate-related ocean inundation that will affect food security, freshwater security, and livelihood, in order to develop programs to transition the displaced and develop means to preserve cultural and societal identity.

Appendix 2. Reducing Duplication and Maximizing Alignment

		Department of Interior Stakeholder Agencies			Other Federal Stakeholder Agencies				
SAC Statement of Need	PI-CSC MISSION	USFWS	NPS	OIA	DOD	EPA	USACOE	NOAA	USDA
Agriculture									
Commercial Production	N					XXX			XXX
Traditional Agroforestry and Harvest	Y	XXX	XXX	XXX					XXX
Coastal Cultural Shifts									
Coastal Heritage Sites	Y	XXX	XXX				XXX	XXX	
Effective Community Adaptation Planning									
Sociopolitical (Policy/Legislation)	N			XXX	XXX				
Construction and Engineering	maybe	x		XXX	XXX	XXX	XXX		
Hazards Planning	maybe	x		XXX	XXX	XXX	XXX	x	
Natural Infrastructure	Y	XXX	XXX	XXX		XXX	XXX	XXX	
Ecosystems Goods & Services	Y	XXX	XXX	?			XXX	XXX	XXX
Fresh Water Resources									
Municipal Water and Wastewater	N			XXX	XXX	XXX	XXX		
Watersheds and Streams (Ecohydrology)	Y	XXX	XXX		XXX	XXX	XXX	XXX	XXX
Nearshore Habitat Shifts									
Pollutants and Waterborne Disease	N	x				XXX		XXX	
Commercial Fisheries	N							XXX	
Indigenous Aquaculture and Subsistence Harvest	Y	XXX	XXX					XXX	
Coral Reef Ecosystems	N	US Coral Reef Task Force							
R2R and Brackish Systems	Y	XXX	XXX			XXX		XXX	
Protected Species	Y	XXX	XXX					XXX	
Terrestrial Habitat Shifts									
Forests and Woodlands	Y	XXX	XXX		XXX				
Recreation and Subsistence Harvest	Y	XXX	XXX						
Indigenous Stewardship	Y	XXX	XXX	XXX	XXX				
Protected Species	Y	XXX	XXX	x	x				x
Societal Shifts [Survival in Atolls]									
Ecosystems Goods & Services	Y	XXX	XXX	?			XXX	XXX	XXX
Hazards Planning	maybe	x		XXX	XXX	XXX	XXX	x	

Filters and Exclusions. The PI-CSC has limited funds and must invest them carefully. To help focus and for the PI-CSC to be transparent, we make it clear that PI-CSC will not work on or fund activities in the following areas and/or domains, excepting direction from the DOI or USGS:

- Other Agencies or Programs
  - Commercial fisheries (NOAA)
  - Commercial crops (USDA)
  - Climate variability (in the main Hawaiian islands, NOAA Pacific RISA; note this remains an important need for the USAPI)
  - Municipal water (USGS Water programs, and NOAA Pacific RISA)
  - Pollutants and contaminants (EPA)
- Geographic Areas:
  - The PI-CSC is tasked with focusing on climate impacts at various spatial and temporal scales, so it follows that places or sectors with little predicted climate change will not be addressed.
  - Blue water research (deep ocean, pelagic or offshore systems)
  - Highly localized habitats that are not representative of a sub/region's primary landscapes, seascapes, ecosystems, or biomes. However, these places may benefit from regional products and services of the PI-CSC and its partners.
  - For the period covered by this Science Agenda, work in Hawai'i will focus on the main Hawaiian Islands.
  - Because funding is predicted to be extremely limited, the PI-CSC will not be able to consider work in remote locations, such as the USFWS Pacific Remote Islands[7].
- Conservation Domains:
  - Resource Management tools that will remain effective under changing conditions
  - Coral reef conservation. Along with the US Coral Reef Task Force[8], reef ecosystems have and will continue to receive massive international investment, thus the relatively small PI-CSC dollars will make very little additional contribution.
  - Genomic, genetic, molecular, or physiological investigation into vulnerability, tolerance, or resilience, unless the results will be directly actionable by and co-produced with DOI resource managers.
  - Federally listed species with highly restricted distributions will not be a focus of efforts by the PI-CSC. These species are likely to benefit from the habitat-centric regional products and services of the PI-CSC and its partners.

[7] https://www.fws.gov/refuge/pacific_remote_islands_marine_national_monument/
[8] http://www.coralreef.gov/

Appendix 3. Progress and lessons learned from Agenda Cycle 1.

The first cycle of the PI-CSC Science Agenda emphasized four themes: Terrestrial Climate Modeling and Application; Fresh Water Resources; Coastal Adaptation; and Forecasting Sustainability. Good progress was made addressing objectives within these themes, and as a result we also were able to learn some lessons about putting climate science to work through collaboration with resource managers and decision makers.

Project ID numbers in the text below refer to the table at the end of this Appendix.

Theme 1. Climate Modeling

- Progress (Project ID 5, 4, 9, 14, 21, 22, 29, 30)
- Lessons Learned
    - There is a paucity of environmental data with which to develop climate projections or to evaluate climate projections
    - For many sectors, seasonal and multi-annual (e.g., ENSO) timeframes are more relevant to managers than are multi-decadal timeframes. In other words, climate variability is at least as important as long-term climate change.
    - Resource managers request inclusion of error estimates (likelihoods), but confidence intervals (error terms) blow up when combining climate model + ecological impact model + resource managers effectiveness estimates, resulting error terms so large that decisionmaking is paralyzed
    - Lack of agreement between climate projections (almost a certainty given the complexity of modeling using different methods and conditions) froze inclusion of climate projections in decisionmaking. Resource managers want to know which projection is correct, but this issue is unanswerable. This log jam was broken in application workshops through development of narratives in which all available environmental information was included.
    - Resource management timeframes are a few months to perhaps a decade or so out. End-of-century climate projections are too abstract for resource managers to commit to adaptation planning unless accompanied by several waypoints to create a management trajectory. Can interpolate with statistic projections, cannot with dynamical projections.
    - Despite requests from ecological impact modelers, modelers should not downscale at granularity so fine that local environmental conditions (e.g., temp, soil moisture) are likely to be forced by environmental parameters (e.g., vegetation), rather than climate.
- Opportunities for Further Study
    - Complete downscaling of high-enough islands in the USAPI
    - Resource management timeframes are a few months to perhaps a decade or so out. Climate modeling emphasis on predicting near-term, management-relevant seasonal and multi-annual variability is needed.
    - Systematic study on limits of downscaling skill as a function of island size and topography.
    - Dynamical downscaling must move on from atmospheric pseudo-global warming (projections for a warming world with fixed boundary conditions)

to coupled models that interact with their boundary conditions (projections in which the entire system changes through dynamic feedback). In an ideal world, the modeling system also would couple atmospheric and oceanic conditions.

Theme 2. Freshwater

- Progress (Project ID 6, 16, 23, 24, 26, 31)
- Lessons Learned
    - Freshwater managers operate on the assumption that engineering can solve projected changes in freshwater systems
    - Very crowded field, especially where freshwater sector is related to municipal water and wastewater management. In the water-for-people domain, some room for contribution in watershed function. Also, water for commercial agriculture is well-covered, at least from weather and seasonality timeframes.
    - Some room for contribution on Ridge-to-Reef surface flow-erosion-coastal impacts.
    - Almost no other program work on ecological drought, good niche.
- Opportunities for Further Study
    - Freshwater managers need climate modelers to move beyond "percent change" precipitation projections to real-valued precipitation projections
    - Continued investment in ecological drought work
    - Incorporate cloudwater intercept project results into freshwater hydrology, plant distribution, and plant vulnerability assessments.

Theme 3. Coasts

- Progress (Project ID 7, 8, 10, 13, 18, 19, 20, 25, 28)
- Lessons Learned
    - Coastal managers operate on the assumption that engineering can solve predicted changes in coastal systems
    - Incredible demand – paucity of foundational high-resolution map products (seamless Topo-Bathymetric Digital Elevation Model) for region
    - Strong application linkages to regulation and legislative solutions
    - Very crowded field for analytic coastal vulnerability work, but not foundational mapping work, especially in coastal vulnerability of human communities.
    - Disparity between opinions of waterbird managers versus wetlands managers on potential for climate change impacts on systems. Waterbird experts believe birds will adapt; wetlands managers want to assess, but even they are not unified and some believe changing climate will not affect low-lying wetlands.

- Opportunities for Further Study
    - CSC cannot afford to do high-resolution maps alone, need partnership with USGS, NOAA, and jurisdictional agencies and/or OIA
    - Sea level baseline measurements require partnership with NOAA
    - To avoid overlap with bulk of human community (hazards) work, work in DOI and state natural area locations where hi-resolution map products already exist

Theme 4. Sustainability

- Progress (Project ID 1, 2, 3, 11, 12, 15, 17, 27)
- Lessons Learned
    - Adaptation is place-based and very granular. It is not easy, and perhaps not valid, to attempt to generalize adaptation plans to larger landscapes. In contrast, it may be valuable to develop adaptation planning best practices than can be applied in various settings.
    - Short periods (several years) of biological + environmental data may show correlations, almost to the point of suggesting climate causality, but correlations typically break down over longer time series and/or with inclusion of other measurements of change or stressors.
    - Habitat change (vegetation community species composition and stand structure) is driven by many factors, including succession, land use change, land use history, wildfire-and-recovery, storm-and-recovery, and invasion by introduced plant species and plant predators. Plus there are almost no biophysical data on plant species environmental tolerances. It is almost implausible to separate the effect of climate change from these other factors to project future vegetation communities, and thus to project habitat for listed species.
    - RCP 8.5 futures are so dire that managers of biological systems cannot envision functioning native ecosystems or continuity of listed populations in the wild. To keep managers engaged, at least one RCP that includes GHG reductions (e.g., RCP 4.5) should be included during engagement.

Project cluster for the Republic of the Marshall Islands (Project ID 15, 25, 27, 28). The CSC invested substantially in climate adaptation research and tools for Majuro, Republic of the Marshall Islands. After these projects have completed and learning has been shared with Marshallese stakeholders, new investment will be focused on other USAPI jurisdictions who participated in Science Agenda planning (CNMI, Guam, Palau) or those prioritized in Departmental guidance.

Proj. ID	Year	Award Number	ScienceBase URL	Project Name	Principal Investigator	Institution
1	2012	G12AC20399	https://www.sciencebase.gov/catalog/item/50118f9fe4b0d78fd4e59ba6	Vulnerability of Hawaiian forest birds to climate change - using models to link landscape, climate, disease, and potential adaptation	Samuel, Michael	USGS Madison CRU
2	2012	G12AC20499	https://www.sciencebase.gov/catalog/item/501190e1e4b0d78fd4e59ba8	Modeling climate-driven changes to dominant vegetation in the Hawaiian Islands	Price, Jon	U Hawaii Hilo
3	2012	G12AC20500	https://www.sciencebase.gov/catalog/item/54cc4172e4b01fabb3001df4	Understanding how climate change is affecting Hawaii's high-elevation ecosystems: an assessment of the long-term viability of Haleakala silverswords and associated biological communities	Krushelnycky, Paul	U Hawaii Manoa
4	2012	G12AC20501	https://www.sciencebase.gov/catalog/item/50118ddce4b0d78fd4e59ba3	21st century high-resolution climate projections for Guam and American Samoa	Wang, Yuqing	U Hawaii Manoa
5	2012	G12AC20502	https://www.sciencebase.gov/catalog/item/5591d136e4b0b6d21dd6755a	Climate Change Research in Support of Hawaiian Ecosystem Management: An Integrated Approach	Elison Timm, Oliver	U Hawaii Manoa
6	2013	G13AC00314	https://www.sciencebase.gov/catalog/item/52165eede4b0b45d6ba39312	Understanding the response of native and non-native forests to climate variability and change to support resource management in Hawaii	Giambelluca, Thomas	U Hawaii Manoa
7	2013	G13AC00361	https://www.sciencebase.gov/catalog/item/52165effe4b0b45d6ba393e8	Valuing climate change impacts on coral reef ecosystem services	Oleson, Kirsten	U Hawaii Manoa
8	2013	G13AC00362	https://www.sciencebase.gov/catalog/item/52165ec0e4b0b45d6ba39122	Coral reef resilience to climate change in CNMI; field-based assessments and implications for vulnerability and futue management	Raymundo, Laurie	U Guam
9	2013	G13AC00363	https://www.sciencebase.gov/catalog/item/52165f17e4b0b45d6ba394fb	Very fine resolution dynamical downscaling of past and future climates for assessment of climate change impacts on the islands of Oahu and Kauai	Wang, Yuqing	U Hawaii Manoa
10	2013	G13AC00395	https://www.sciencebase.gov/catalog/item/52165e8ee4b0b45d6ba38f05	Future coral reef community projections of DOI-managed coastal assets in the Hawaiian Islands	Franklin, Erik	U Hawaii Manoa
11	2013	COA	https://www.sciencebase.gov/catalog/item/52165f2ce4b0b45d6ba395e9	Expanding a dynamic model of species vulnerability to climate change for Hawaii and other Pacific Islands ecosystems	Fortini, Lucas	USGS PIERC
12	2014	G14AP00176	https://www.sciencebase.gov/catalog/item/53b1bf0be4b0c9da2f809d29	Hawaiian seascapes and their management implications	Puniwai, Noe	U Hawaii Hilo
13	2014	G14AP00179	https://www.sciencebase.gov/catalog/item/537cc9f6e4b00e1e1a484ab4	Empirical projection of future shoreline position and inundation due to sea level rise	Fletcher, Chip	U Hawaii Manoa
14	2014	G14AP00183	https://www.sciencebase.gov/catalog/item/54637033e4b0ba83040c6b21	Measurement of ENSO-related climate variables and ecosystem responses in Hawaii	Giambelluca, Thomas	U Hawaii Manoa
15	2014	G14AP00184	https://www.sciencebase.gov/catalog/item/537bafe0e4b0929ba498b965	Vegetative guide dashboard relating atoll agroforestry recommendations to predicted climate and sea level conditions in the Marshall Islands	Haws, Maria	U Hawaii Hilo
16	2014	COA	https://www.sciencebase.gov/catalog/item/5362ad89e4b0c409c6289ba8	Development of statistical methods to estimate baseline and future low-flow characteristics of ungaged streams n Hawaii	Bassiouni, Maoya	USGS PIWSC
17	2014	COA	https://www.sciencebase.gov/catalog/item/5362af3ee4b0c409c6289bc7	Assess the potential impacts of projected climate change on vegetation management strategies within Hawaii Volcanoes National Park	Jacobi, James	USGS PIERC
18	2015	G15AP00059	https://www.sciencebase.gov/catalog/item/551eda81e4b027f0aee3ba05	Assessing the sustainability of culturally important marine sites in Guam and CNMI	Raymundo, Laurie	U Guam
19	2015	G15AP00103	https://www.sciencebase.gov/catalog/item/559eb2e7e4b0b94a64018fd9	Mapping and environmental science to support clean reefs of West Maui, Hawaii	Oleson, Kirsten	U Hawaii Manoa
20	2015	G15AP00140	https://www.sciencebase.gov/catalog/item/550311eae4b02e76d7565196	Diagnosing and communicating the effect of climate variability on frequency of coastal inundation	Thompson, Philip	U Hawaii Manoa
21	2015	G15AP00159	https://www.sciencebase.gov/catalog/item/559afca9e4b0b94a64016ff9	Cloud Water Interception in Hawai'i: Developing Capacity to Characterize the Spatial Patterns and Effects on Water and Ecological Processes	Giambelluca, Thomas	U Hawaii Manoa
22	2015	G15AP00166	https://www.sciencebase.gov/catalog/item/559afce2e4b0b94a64016ffe	Cloud Water Interception in Hawai'i: Building Spatial Pattern Maps for the Present-day Climate and Projected Changes by the Later 21st Century using the Hawai'i Regional Climate Model	Wang, Yuqing	U Hawaii Manoa
23	2015	G16PG00037	https://www.sciencebase.gov/catalog/item/56ccba71e4b0b1892d9e06cd	Climate change, variability and drought - dynamics and influences on ecosystems and society in Hawaii	Giardina, Christian	USDA IPIF
24	2016	COA	https://www.sciencebase.gov/catalog/item/580eb5cee4b0f497e794df52	Changes in infiltration in Hawaiian forests caused by invasive species and climate change	Fortini, Lucas	USGS PIERC
25	2016	COA	https://www.sciencebase.gov/catalog/item/59557881e4b04e08be532c9a	Majuro topographic/bathymetric mapping	Danielson, Jeffery	USGS EROS
26	2016	COA	https://www.sciencebase.gov/catalog/item/580f8424e4b0f497e795ffe1	Estimating soil moisture, actual evapotranspiration, climatic water deficit, and groundwater recharge during periods of drought and persistent rainfall for current and future climate conditions in Hawaii	Mair, Alan	USGS PIWSC
27	2016	G16AC00386	https://www.sciencebase.gov/catalog/item/575af95be4b04f417c275287	Analyzing correlations and effects of human migration of Marshallese Islanders	Burkett, Maxine	U Hawaii Manoa
28	2016	G17AP00032	https://www.sciencebase.gov/catalog/item/58a32f8ae4b0c82512869b33	Simulating the impacts of sea level rise on Majuro Atoll using a digital elevation model and delivery to the Marshall Islands government	Fletcher, Chip	U Hawaii Manoa
29	2015	internal	https://www.sciencebase.gov/catalog/item/598db6b2e4b09fa1cb13ef7c	Report from the Workshop on Climate Downscaling and its Application in High Hawaiian Islands, September 16–17, 2015	internal	Pacific RISA, PICCC
30	2017	internal	https://www.sciencebase.gov/catalog/item/59a84436e4b0421949a84200	Applications of Climate Downscaling in the Main Hawaiian Islands: Balancing Climate Modelers' Products and Impact Modelers' Expectations	internal	Pacific RISA
31	2015	internal	https://www.sciencebase.gov/catalog/item/5980c6bee4b0a38ca278a8d4	The Effects of Climate Change on Wetlands in the Main Hawaiian Islands: An Initial Assessment	Polhemus, Dan	US Fish & Wildlife Service

Appendix 4. Connections between the SONs, new Science Agenda framework, old Science Agenda, and NCCWSC strategic planning science objectives.

SCIENCE THEMES				
Drought in the Pacific Islands	**Coastal Adaptation & Planning**	**Forest Conservation in a Changing Environment**	**Core Questions for Resource Managers**	**Adaptation and Survival in Low Islands and Atolls**
Ecohydrology and Watershed Services SON = 1, 4, 5 OLD = 2 HQO = 1, 2	Coastal Cultural Heritage Sites SON = 2 OLD = X HQO = ALL	Changing Plant Communities in Forests and Woodlands SON = 5 OLD = 4 HQO = 2, 3	Adaptation Decisions for Low Likelihood – High Risk Future Scenarios SON = ALL OLD = X HQO = ALL	Coastal Flooding / Infiltration and Freshwater Security SON = 7, 4 OLD = 3, 4 HQO = ALL
Drought, Fire, and Landscape Change SON = 4, 5 OLD = 2, 4 HQO = ALL	Effective Community Adaptation Planning SON = 3 OLD = 3, 4 HQO = ALL	Managing Wildlife in Forest Habitats SON = 5 OLD = X HQO = 2, 3	Testing and Evaluating Model Predictions SON = ALL OLD = 1, 2 HQO = 1, 2	Timelines for Critical Habitability Decisions SON = 7 OLD = X HQO = 1, 2
Indigenous Agroforestry and Aquaculture Systems SON = 4 OLD = X HQO = 2, 3	Ridge-to-Reef and Brackish Systems SON = 6 OLD = 3, 4 HQO = 1, 2	Indigenous Stewardship of Forests and Woodlands SON = 5 OLD = X HQO = 2, 3	Assessing Risk Across Multiple Time Frames – What Must Happen Now? SON = ALL OLD = X HQO = 2, 3	Adapting Agroforestry to Projected Future Conditions SON = 7 OLD = 2, 3, 4 HQO = ALL

Statement of Needs (SON):
1. Agriculture
2. Coastal Cultural Shifts
3. Effective Community Adaptation Planning
4. Fresh Water Resources
5. Terrestrial Habitat Shifts
6. Nearshore Habitat Shifts
7. Societal Shifts

Old Science Agenda (OLD)
1. Theme 1 Climate Models
2. Theme 2 Fresh Water Resources
3. Theme 3 Coastal Adaptation
4. Theme 4 Forecasting Sustainability

X new, not in the old Science Agenda

NCCWSC Objectives (HQO)
1. Understand Physical Change (Air, Land, and Water)
2. Assess Impacts on Natural and Cultural Resources
3. Inform Adaptation Strategies

Appendix 5. Strategic Implementation Issues

The Science Agenda was developed over the course of more than a year, from April 2016 to September 2017. During this time, substantial input was received from the Stakeholder Advisory Committee (SAC) and the Science Advisory Panel. Some of the concepts that emerged were related more to the structure and content the CSC should seek in future projects, rather than specific scientific questions. These implementation issues are documented here (1) to maintain fidelity to the lengthy stakeholder engagement process and (2) to ensure this Science Agenda provides robust guidance for future work.

- *Visualization*. Some SAC members felt that it would be helpful for them to explore possible futures in visualization systems. We must guard against developing "Decision Support Systems" that are merely visually appealing but fail to help to inform the resource managers. Visualization must go hand-in-hand with Co-Production.

- Understanding Limits of Model Predictions.
    - *Averages and Envelopes.* To date, climate predictions or projections (e.g., rainfall, sea level) have been single-valued averages at particular points in the future. Ecological impacts modeled using these data likewise produce singular portrayals of the future. In the next Science Agenda cycle, work plans should be expected to produce not only averages, but also the envelopes or spread of future conditions, associated with confidence levels. Also, work on climate projections should emphasize developing envelopes from existing projections.
    - *Explicit Likelihoods.* In the next Science Agenda cycle, work plans should be expected to explicitly address uncertainty (likelihoods, confidence).
    - *Realistic and Complete.* Several SAC members expressed desire for models to be as realistic as possible (i.e., multivariate). This, along with *Averages and Envelopes* and *Explicit Likelihoods*, is evidence that impact modelers and resource managers want to use climate change in their planning, but consider current ecological models to be simplistic.

- Core Dependencies
    - *Elevation & Coastal Bathymetry Mapping.* High-resolution maps are essential for climate models, coastal flooding, erosion, surface water flow, and species distribution models. The current status of digital elevation maps for most of the USAPI is uncertain. Hawai'i has fairly good coastal coverage from recent CSMIL LiDAR, but investigations of land-sea connectivity and erosion likely will require additional geospatial data for watersheds. Additionally, if land cover or land use is needed as a change covariate, imagery may be needed. The CSC should strive to find or develop seamless bathymetry/topography (seamless across the shoreline) whenever possible. Seamless bathy-topo allows for modeling of wave run-up and associated impacts that extend beyond simple inundation by rising sea level.

- *Climate Projections.* Vulnerability, resilience, and adaptation analyses require projections of future environmental conditions. Climate projections require high-resolution elevation maps.
- *Sea Level Rise / Flooding Analysis.* Sea Level Rise (and associated wave run-up and underground infiltration) is an environmental state, but in itself has no association with impact. This is a technical step for at least two SONs (Effective Community Adaptation Planning and Coastal Cultural Shift).