Department of the Interior
US Geological Survey

Pacific Islands Climate Science Center
5-year Summary Report
2012-2017

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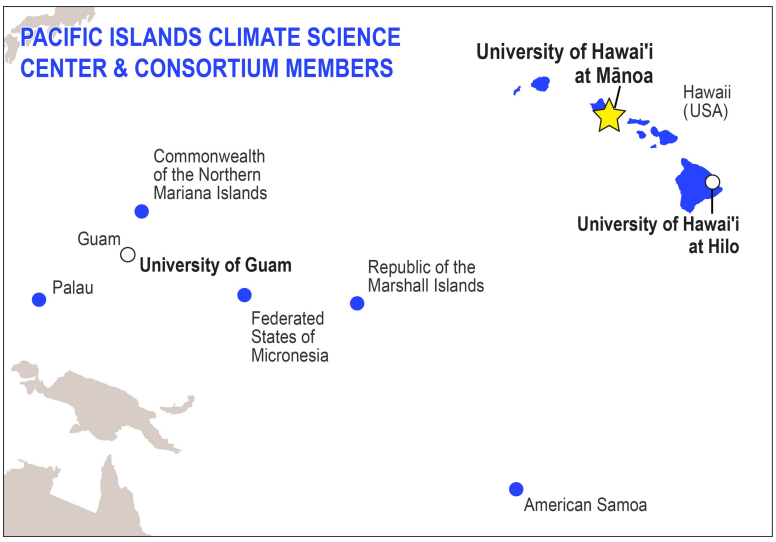
List of Acronyms

CCVD	Climate change, climate variability, and drought
CNMI	Commonwealth of the Northern Mariana Islands
CWI	cloud-water interception
DEM	Digital elevation map
DLNR	Department of Land and Natural Resources
DOD	Department of Defense
DOI	Department of the Interior
EEZ	Exclusive Economic zones
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
EROS	Earth Resources Observation and Science Center (USGS)
FEMA	Federal Emergency Management Agency
GCC	global climate change
GCM	Global Change Model
GIS	Geographic Information Systems
HAVO	Hawai‘i Volcanoes National Park
HETF	Hawai‘i Experimental Tropical Forest
HIMB	Hawai‘i Institute of Marine Biology
ICAC	Interagency Climate Adaptation Committee
IPRC	International Pacific Research Center
JIMAR	Joint Institutes for Marine and Atmospheric Science
LCC	Landscape Conservation Cooperative
MCC	Manager Climate Corps
MCT	Micronesia Conservation Trust
MRSA	Methicillin-resistant *Staphylococcus aureus*
NAS	National Academy of Sciences
NCCWSC	National Climate Change Cooperative and Wildlife Science Center
NCEI	National Centers of Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
OIA	Office of International Affairs
PacIOOS	Pacific Islands Ocean Observing System
PacRISA	Pacific Regional Integrated Sciences and Assessments
PDO	Pacific Decadal Oscillation
PICCC	Pacific Islands Climate Change Cooperative
PIRCA	Pacific Islands Regional Climate Assessment
RCP 4.5, RCP 8.5	Representative Concentration Pathways: 4.5 or 8.5 W/m^2 by 2100
RCSD	Regional Climate Services Directors
RFP	Request for proposal
RMI	Republic of the Marshall Islands
SAC	Stakeholder Advisory Committee
SDM	Species distribution modeling
SEAs	Special Ecological Areas
SLR	Sea level rise
SOEST	School of Ocean and Earth Sciences and Technology
SPREP	Secretariat of the Pacific Regional Environment Programme
TNC	The Nature Conservancy
UHH	University of Hawai‘i at Hilo

UHM	University of Hawai‘i at Mānoa
UoG	University of Guam
USACE	US Army Corps of Engineers
USAPI	US-Affiliated Pacific Islands
USDA	US Department of Agriculture
USFWS	US Fish and Wildlife Service
USGS	US Geologic Survey
WERI	Water & Environmental Research Institute
WRRC	Water Resources Research Center

Executive Summary

The Pacific Islands Climate Science Center was established by the Department of the Interior (DOI) on October 7, 2011, as part of a network of eight regional centers managed by the National Climate Change and Wildlife Science Center (NCCWSC). Each center is a collaborative partnership between the US Geological Survey and a consortium of universities. The PI-CSC consortium is hosted by the University of Hawai‘i at Mānoa (UHM) with the University of Hawai‘i at Hilo (UHH) and the University of Guam (UoG) as consortium partners. Each consortium partner brings a unique perspective to the PI-CSC and develops regionally specific projects and products. The Pacific Islands region is unique with its diversity of cultures, stakeholders, resources, and ecosystems, and the PI-CSC works within this context “to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate” with the vision of informing and supporting sustainability and climate adaptation of human and ecological communities across the Pacific Islands.



Over the past 5 years the PI-CSC, both the federal and university consortium components, have worked together to support research focused on four science themes defined by the stakeholder-driven Five-Year Science Agenda 2014-2018. The themes identify areas where climate and climate variability will create significant challenges for resource managers, cultural stewards, and decision makers, requiring new plans and approaches in anticipation of predicted changes. Those topical areas decided on as ripe for actionable science were:

- Guidance for anticipated intermediate-term climate changes;
- Potential effects of changing climate on freshwater resources;
- Anticipating and mitigating change in coastal and low-lying areas; and
- Forecasting sustainability for resource management and planning.

The guiding principle of projects and work from the PI-CSC Science Agenda 2014-2018 was an emphasis on actionable science—science with a clear path for integration with resource stewards and organized around themes that guide progress of the PI-CSC. The below summary report highlights the PI-CSC’s story, operations, leveraging and partnerships, science themes with specific representative case studies, education and capacity-building. Also included in the appendices are short summaries of all PI-CSC-supported research projects from March 1, 2012 thru February 28, 2017. Lastly, we provide a brief narrative on challenges and a way forward to capitalize on lessons learned to better serve Pacific Island communities, stakeholders, and local managers in coming years.

Introduction

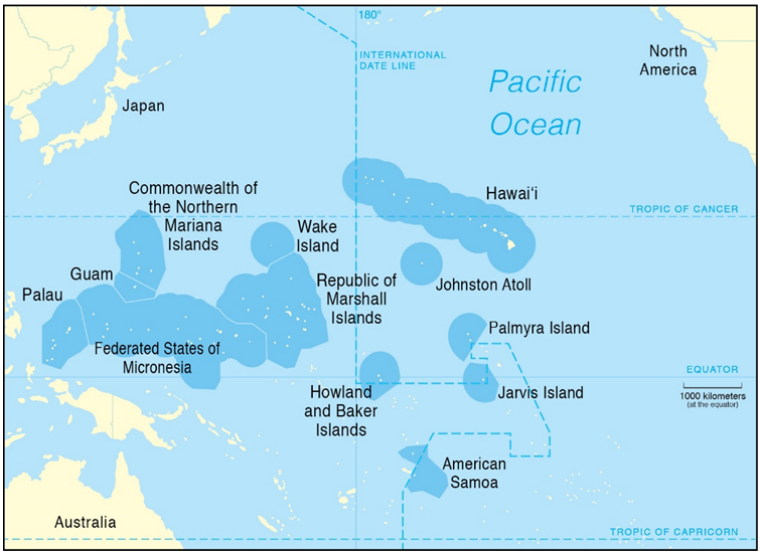
The Pacific Islands Climate Science Center was established by the Department of the Interior (DOI) on October 7, 2011, as part of a network of eight regional centers managed by the National Climate Change and Wildlife Science Center (NCCWSC). Each center is a collaborative partnership between the US Geological Survey and a consortium of universities. The PI-CSC consortium is hosted by the University of Hawai‘i at Mānoa (UHM) with the University of Hawai‘i at Hilo (UHH) and the University of Guam (UoG) as consortium partners. Each consortium partner brings a unique perspective to the PI-CSC and develops regionally specific projects and products: UHM is a large and active research institution with a R1 Carnegie Classification within the heart of urban Honolulu; UHH is a comprehensive, regional university set amid richly diverse rural communities with strong ties to local community programs and a substantial representation of Pacific Island nations; and UoG provides a vital higher education opportunity for underserved populations throughout Micronesia. Through this partnership, the PI-CSC works to accomplish the mission, vision, and goals of the NCCWSC-CSC network.

The Mission of the NCCWSC enterprise is to “deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.” To accomplish this Mission, the vision of the PI-CSC is: ***to develop science and other knowledge products and capabilities designed to support policy and management directed toward the sustainability of interconnected human and ecological communities and the conservation of species of concern in Hawai‘i and the Pacific Islands.*** Striving for sustainability means to respect, conserve, support, restore and build resources and communities now and for the future by identifying priorities of resource managers and community leaders and creating “actionable science.” Co-developed actionable science produces information, tools, and techniques that natural and cultural resource managers can smoothly integrate into effective resource management with the goal of strengthening adaptation capacities in anticipation of likely future conditions.

The Story of the PI-CSC

A Unique Climate Science Center

The PI-CSC spans the Pacific Basin from the Hawaiian Island archipelago to the US-Affiliated Pacific Islands (USAPI) across the western Pacific, encompassing a diverse range of ecosystems, landscapes, and cultures. Island landscapes comprise more than just tropical beaches, from low-lying atolls a few feet above sea level to high islands with coastal plains encircling mountainous volcanic terrains, surrounded in substantial oceanic Exclusive Economic Zones. Pacific Islands may have dry alpine summits, arid leeward plains, lush tropical forests, and diverse coastlines; the Hawaiian Islands alone span 10 of the



The PI-CSC region, illustrating the US and US Affiliated jurisdictions using Exclusive Economic Zones (EEZ).

world's 14 climatic zones from polar tundra to tropical. Because of the vast ocean expanses between small, isolated emergent islands and atolls, Pacific island ecosystems display unique characteristics, with high levels of species endemism and often-endangered species interacting within rare and threatened remnant native landscapes and seascapes. The Hawaiian chain contains over 500 species of flora and fauna listed by the Endangered Species Act.

The ecological diversity of the Pacific region is rivalled only by its cultural diversity. Thriving indigenous cultures interact with other introduced cultures from across the Pacific and beyond. This diversity, woven into the fabric of every island in the Pacific, creates patchwork communities with significant potential adaptive capacity. In such an atmosphere, we aim to encourage and strengthen networks and collaborations between researchers, cultural practitioners, local managers, and stewards of natural and cultural resources, in an effort to discover the best methods to adapt to climate change impacts. The importance and type of natural and cultural resources varies greatly among the islands, creating the need for diverse approaches to studying and managing these resources. For example, the Marshallese rely heavily on agroforestry on the more rural islands getting much needed nutrition from food-producing trees, such as coconuts, breadfruits, and pandanus, which are threatened by changing conditions. These resources provide both diverse and resilient crop production. For many Micronesian cultures, coral reefs and reef fisheries play an important role, with many cultural traditions associated with artisanal fisheries and fish providing the primary source of protein for communities. Cultural resources, such as recreation opportunities, heritage services, and aesthetic appreciation are also very important to the Pacific Region.

The threat of climate change

The tropical and subtropical islands of the Pacific have been among the first areas to experience climate shifts and to witness their socio-ecological effects. Observed climatic trends across the Pacific Basin--rising sea levels, increasing sea surface temperatures, shifts in ocean chemistry with increased ocean acidification, increasingly variable precipitation and wind patterns, rising air temperatures (particularly at higher elevation), increasing storm and cyclone intensity, and more prominent droughts--all promise growing stresses on terrestrial, coastal, and marine ecosystems, as well as on human communities. The ongoing changes in climate factors have already begun to produce noticeable ecological effects, from deteriorating coral reefs to salinization of wetlands and mangrove areas, and upward migration of climate zones. Seasonal changes in precipitation patterns, coupled with increased temperature and evapotranspiration, have the potential for widespread and significant effects on water resources, which will create both societal and ecological problems. Based on historical and projected patterns of land-cover change in this region, impacts from invasive species and human development are likely to amplify the adverse effects of climate change on habitats and species, particularly intensifying the effects of wildfire. With their fragile, distinctive landscapes, ecosystems, and cultures, the Pacific Islands require management and care based on the best available science combined with indigenous knowledge and traditions.

A biocultural perspective

Understanding the impacts of climate change and identifying effective climate adaptation strategies is particularly important to the Pacific Islands region. While vulnerability of native biodiversity in the past has been quantified in terms of endangered species, it can also be understood in the context of its richness and uniqueness as a whole, and it is a natural heritage

requiring wise and forward-looking management and stewardship goals and strategies. 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, which all may experience the impacts of climate change in some capacity.

The PI-CSC has served a vital role interpreting climate adaptation from a "biocultural" context, which it shares with its sibling US Fish and Wildlife Service Landscape Conservation Cooperative, the Pacific Islands Climate Change Cooperative (PICCC). 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. 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.

Operations

History of the PI-CSC

The first five years of the PI-CSC have been somewhat irregular, with numerous changes in personnel (Table 1). The overall organizational structure of the original Host Cooperative Agreement has been maintained throughout, with UHM as the lead of the consortium and UHH and UoG as partners. The large geographic expanse represented by the PI-CSC (Fig. 1) presents unique logistical challenges (e.g., variety of time zones, long distances between consortium partners, etc.) to maintaining a well-connected center. The position of USGS director of the Center turned over three times in the first year, with the current director, David Helweg, beginning in April 2013. Meanwhile, the university consortium director changed three times before the current director, Darren Lerner was appointed in August 2016. Similarly, the university lead at UoG saw numerous changes resulting in John Peterson becoming co-investigator in April 2013. While UHH has also recently had a change in leadership as Donald Straney moved to a UH System role, UHH PI-CSC Program Coordinator Sharon Ziegler-Chong will continue to work with UHH Dean Bruce Matthews to lead that campus' efforts. (More details on current staff and center budgets are listed in Appendix tables).

The Original Host Cooperative Agreement defined the five primary functions of the center:

(1) to work with downscaled Global Change Model (GCM) to create derivative models and tools that link physical forcing factors with biological, physical, ecological and cultural resource response variables; (2) to develop regional response models and projections for priority ecosystems, species, habitats, and other natural and cultural resources within the region;

(3) to work with Advisory Councils to set priorities for development of response models and forecasts, to support adaptation and adaptive management strategies;

(4) to help partners define natural, physical, and cultural resource outcomes and endpoints for their adaptation activities in a way that can be measured and used to refine the next iteration of models and outputs;

(5) to facilitate and fund research that supplies regional-level information on the effects of climate change on land, water, fish and wildlife, and cultural heritage resources, and on related model and tool development.

Table 1. PI-CSC Leadership timeline

	Guiding Documents	Center Director	Host Leadership			
				UH Manoa	UH Hilo	U o G
February 2010	• CSC/LCC implementation guidance • "fundamental climate impact science"					
			Proposal signatories	Chip Fletcher	Don Price	Sam Walker
March 1, 2012		Loyal Mehrhoff	Host Award start	Kevin Hamilton	Don Price (Don Straney)	John Jenson (Sam Walker)
August 2012		Deanna Spooner & Jeff Burgett				
February 2013					Sharon Ziegler-Chong (Don Straney)	
January 2013		Cindy Kolar				
April 2013		Dave Helweg				John Peterson
January 2014	Science Agenda 2014 – 2018					
September 2014				Kelvin Richards (on sabbatical Jan 2–Jun 30, 2015)		
March 2015	ACCNRS Report "actionable science"			Jim Potemra (acting lead)		
July 2015				Kelvin Richards		
August 2016				Darren Lerner		
February 28, 2017			Host Award End (original)			
August 2017					Don Straney depart UHH	
January 2018	5-Year Review					

In 2013 the Science Agenda was developed with stakeholder input to construct a science priorities framework for choosing projects, and was released in January 2014. Projects funded in FY2012 and FY 2013, therefore, did not necessarily have the optimal connection to the later priorities of the PI-CSC. Similarly, there was a shift in focus for all the CSCs following the release of the ACCCNRS report in 2015, which emphasized a move from fundamental or applied science to truly actionable science, developed in active cooperation with stakeholders and partners.

Partners and Leveraging

Collaboration and partnership provides the avenue and opportunities for leveraging. By definition, partners working together leverage their resources and expertise toward finding synergistic outcomes that could not otherwise be realized by individual sources. The university consortium connects the federal program and stakeholders in the region to the scholarly excellence of the university enterprise. Importantly this includes connectivity and engagement of undergraduate, graduate and post-graduate students. In addition, the partnership between the USGS and the university consortium provides flexibility and a broadening of resources. Leveraging of both financial and facility resources has multiplied the impact of the PI-CSC throughout its lifetime. Establishing formal and informal partnerships with already well-established local institutions and networks has also proven an effective method of extending the resources and influence of the Center and was invaluable to the start-up of the PI-CSC.

LCC: The Pacific Islands Climate Change Cooperative

The PI-CSC service region is identical to that of our single Landscape Conservation Cooperative, the Pacific Islands Climate Change Cooperative (PICCC). The PICCC was formed in 2010, under the leadership of Deanna Spooner, and their many contributions can be viewed online at http://piccc.net/. The PICCC has a Science Coordinator (Jeff Burgett), and had federal agency representatives working on PICCC efforts (Stanton Enomoto, NPS, Cultural Coordinator; Lucas Fortini, USGS, Scientist), along with an administrative and communication staff. The PICCC and the PI-CSC share a Data Manager (Patrick Grady), hired through the same office that coordinates the UHH PI-CSC efforts. The PI-CSC sits in an ex officio capacity on the PICCC Executive Committee, and has participated on its Steering Committee.

The identical service regions of the PI-CSC and the PICCC has created chronic optics of redundancy, not helped by NAS (http://dels.nas.edu/Report/Review-Landscape-Conservation/21829) and subsequent reports that have mis-reported various projects. In reality, the PI-CSC and the PICCC have been in close communication, both to identify and prevent redundancy and to maximize investment through leveraging and shared planning (Table 2). The PI-CSC and the PICCC also coordinate with the NOAA NCEI, NOAA Pacific RISA, the USDA Climate Hub, and other climate programs in the region.

Project Partnering by the PI-CSC and the PICCC: Since the inception of the PI-CSC in 2012, the PI-CSC and the PICCC have partnered in science development and delivery. Following is an informal summary of five project-specific aspects of these partnerships.

Statistical Climate Downscaling. In 2010, PICCC funded Oliver Elison Timm to use the IPCC A1B scenario to perform *statistical* climate downscaling in the Main Hawaiian Islands. In 2012, the PI-CSC funded him for a follow-on project with the newer IPCC RCP 4.5 and RCP 8.5 scenarios, which provided an advancement of modeling and a bracketing of projected future condition (with and without greenhouse gas reduction). The 2012 project was selected in a joint solicitation by the PI-CSC and the PICCC, in which project selection and funding was coordinated to maximize complementarity.

Dynamical Climate Downscaling. In 2010, the PICCC funded Kevin Hamilton and Yuqing Wang to use the IPCC A1B scenario to perform *dynamical* climate downscaling at 3 km

resolution in the Main Hawaiian Islands. Pacific RISA funded him at the same time to develop finer-scaled (1 km) projections for Maui. In 2012 and 2013, PI-CSC funded Wang for follow-on projects with the newer IPCC RCP 4.5 and RCP 8.5 scenarios, which provided an advancement of modeling and a bracketing of projected future condition (with and without greenhouse gas reduction). By funding Elison Timm and Wang, we created the ability to have contrasting future climate projections using the two major downscaling methods. The 2012 project was selected in a joint solicitation by the PI-CSC and the PICCC, in which project selection and funding was coordinated to maximize complementarity. The PICCC participated in the 2013 solicitation proposal review, which increased the coordination of our investments and ensured we were driving towards the same broad goals.

Plant Vulnerability Assessments. In 2011, the PICCC began supporting Lucas Fortini (USGS scientist stationed at the PICCC) to use climate modeling projections and biological data to create a vulnerability assessment for over 1000 native plant species in Hawai‘i. In 2013, the PI-CSC funded Fortini to advance the modeling effort, taking what had been developed with the PICCC support, incorporating new climate data and expert opinion, and making the software ready for sharing. The PICCC participated in the 2013 solicitation proposal review, which increased the coordination of our investments and ensured we were driving towards the same broad goals.

Table 2: Project partnering between the PICCC and the PI-CSC.

Project	**PICCC**	**PI-CSC**
Statistical downscaling of Hawai‘i climate (Timm)	2010 initial A1B scenarios http://piccc.net/project/future-rainfall-projections-for-hawaii/	2012 next-step RCP 4.5 and 8.5 scenarios https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/50118bd1e4b0d78fd4e59ba1
Dynamical downscaling of Hawai‘i climate (Wang)	2010 initial A1B scenarios http://piccc.net/project/projections-of-future-temperature-rainfall-and-wind-patterns-for-the-islands-of-hawaii-and-maui/	2013 next-step RCP 4.5 and 8.5 scenarios https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/52165f17e4b0b45d6ba394fb
Hawaiian plant species vulnerability (Fortini)	2011 initial vulnerability assessments http://piccc.net/project/vulnerability-assessment-for-native-hawaiian-plants/	2013 next-step model advancement https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/52165f2ce4b0b45d6ba395e9
Coral reef vulnerability (Maynard)	2012 develop global projections http://piccc.net/project/predicting-the-degradation-of-coral-reefs-due-to-climate-change/	2013 next-step add Mariana Islands https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/52165ec0e4b0b45d6ba39122
Haleakalā silverswords (Krushelnycky)	2012 joint selection and funding http://piccc.net/project/understanding-how-climate-change-is-affecting-hawaiis-high-elevation-ecosystems/	2012 joint selection and funding https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/5011925fe4b0d78fd4e59baa

Coral Reef Vulnerability. In 2012, the PICCC funded Jeff Maynard and Ruben van Hooidonk to develop a global projection of coral reef vulnerability to warming and ocean acidification using new climate models. This project was selected in a joint solicitation by the PI-CSC and the PICCC, in which project selection and funding was coordinated to maximize complementarity.

In 2013, the PI-CSC funded Maynard and Laurie Raymundo to conduct the detailed measurements and modeling needed to estimate coral vulnerability and resilience in the Marianas (Guam, Saipan, Rota, Tinian), and in 2015 the PI-CSC funded an additional effort for Maynard and Raymundo to conduct the community engagement needed to flow the results of their science into community-based coral reef management planning. The PICCC participated in the 2013 and 2015 solicitation proposal reviews, which increased the coordination of our investments and ensured we were driving towards the same broad goals.

Haleakalā Silverswords. In 2012, the PI-CSC and the PICCC conducted a joint solicitation for proposals, in which project selection and funding was coordinated to maximize complementarity. Paul Krushelnycky's Haleakalā Silverswords project was selected for funding, and the PI-CSC and the PICCC decided to share the funding (50:50).

University Consortium Leveraging

University of Hawai'i at Mānoa: UHM is recognized as a land-, sea-, space- and sun-grant institution, with a strong and active research program that brings in over $300 million in extramural research grant funds. Over 20 of the researchers (and 26 students) who have been funded through the PI-CSC were associated with UHM.

Recently, the university consortium leadership has come under the University of Hawai'i's Sea Grant College Program (Hawai'i Sea Grant), which also administers the Water Resources Research Center (WRRC). Both programs have a more than 50-year presence and history of activities in Hawai'i and the Pacific region. Both have a degree of commonality among their missions and with that of the PI-CSC, which makes them natural partners and collaborators. In addition to the grant making capacity of Hawai'i Sea Grant and WRRC in support of excellence in research, Hawai'i Sea Grant has a well-established and robust workforce of professional faculty and staff steeped in extension and outreach. With the evolution of the PI-CSC toward co-production of knowledge gained through research and driven by stakeholder participation, these new partnerships, added to the existing university efforts at UoG and UHH are ripe for leveraging assets toward a high output of synergistic outcomes.

Other important partners at UHM that the PI-CSC has and continues to collaborate with are: the University of Hawai'i's Sea Level Rise Center, Joint Institutes for Marine and Atmospheric Science (JIMAR), the Pacific Islands Ocean Observing System (PacIOOS), the International Pacific Research Center (IPRC), Hawai'i Institute of Marine Biology (HIMB), and the Coastal Geology Group, all within the School of Ocean and Earth Sciences and Technology (SOEST); the Department of Natural Resources and Environmental Management in the College of Tropical Agriculture and Human Resources; the Ecohydrology Lab, the Department of Geography, and others in the College of Social Sciences, and the William S. Richardson School of Law.

University of Hawai'i at Hilo: With a focus on excellence in undergraduate and graduate education, UHH offers programs that take advantage of the unique breadth and diversity of ecological and cultural characteristics of Hawai'i Island, with active faculty research enhancing student engagement. Selected graduate degree programs in conservation (the Tropical Conservation Biology and Environmental Science Master degree program) and cultural resources management (the Heritage Management Program) are offered in areas where the university has strong expertise and partnerships.

The PI-CSC university consortium staff have built on UHH's strong ties and partnerships by identifying and engaging local stakeholders with faculty and students in collaborative adaptation-

focused research, resource management, and outreach efforts. The key program of the PI-CSC UHH efforts is the Manager Climate Corps (MCC) program (see below for more detail). MCC brings those partners and networks together to build the adaptive capacity of island communities by expanding existing professional networks and rooting collaborative research efforts within these local, in-person networks of natural and cultural resource managers. Local stakeholder organizations involved in MCC programs and projects include managers from watershed, native ecosystem (terrestrial and marine), traditional Native Hawaiian biocultural resources, invasive species, food production and fire sectors, as well as community leaders and policy professionals, university, federal, state, and county resource managers and researchers in biological, ecological, physical, and social sciences. By identifying and enlisting existing stakeholder networks, the MCC fosters communication and mutual understanding across diverse professional networks which helps build capacity for local communities to adapt to socio-ecological change.

University of Guam: UoG is a land-grant institution which serves as the primary center for higher education and research in Micronesia, maintaining strong ties with the regional community colleges that provide associates' degrees and professional training. The majority of the 3912 students (graduate and undergraduate) enrolled at UoG are from under-represented communities throughout Micronesia, and the PI-CSC at UoG works with federal and local partners to expand the opportunities for the whole region. UoG serves as a key member of the Climate Change Task Force, working with the Office of the Governor, and conducting a climate change vulnerability assessment of Guam.

A key program developed by the PI-CSC at UoG is the GIS@CIS center for climate science GIS investigations (see below for more detail), designed to promote outreach to GIS users throughout the USAPI, bringing GIS training and supporting data to the western Pacific. Partnering with EPSCoR, both by a grant through NASA EPSCoR Research Infrastructure and Development and via connections with UoG's NSF-EPSCoR award, the GIS@CIS program has been able to expand its capabilities substantially. The connection made available NASA-supported imagery and technology for highly sophisticated analyses, as well as methodologies to advance and support climate change research and data monitoring in the region. Cyberinfrastructure improvements through the NSF EPSCoR program have directly benefitted the GIS@CIS program by expanding bandwidth and connectivity, and data transfer capacity to connect UoG with USAPI and mainland US research communities. Locally, it has also improved real-time data monitoring efforts of Guam's coral reefs to evaluate climate change impacts and communicate these data to island stakeholders for their management needs.

Regionally, UoG PI-CSC partners with agencies in Guam, the CNMI, Pohnpei, Palau, and the Marshall Islands to share resources such as GIS software, access to UAV support for projects, and data resources. Government agencies include the Department of Environmental Quality (CNMI), Historical Preservation Offices (throughout USAPI), and NGO's such as the Micronesian Conservation Trust in Pohnpei. GIS@CIS personnel conduct trainings and coordinate with other agencies such as USGS EROS to conduct research toward long-term monitoring of sea level change by establishing ground controls and shoreline data clouds. Within the consortium, UoG and the UH system coordinate and collaborate through proposals on science agendas, alignment, and support of UoG cyberinfrastructure and data management programs by UH System consultation and joint effort.

Federal Partnering

Retrospectively, over the past five years the PI-CSC has coordinated and collaborated with regional organizations and programs to address priority issues identified in the Science Agenda and NCCWSC-CSC network enterprise. The PI-CSC was instituted in a region already characterized by a substantial number of climate programs. In addition to the PICCC, there is the NOAA Pacific Regional Integrated Sciences Assessments (PacRISA), NOAA National Centers of Environmental Information (NCEI), Environmental Protection Agency (EPA), US Department of Agriculture (USDA), and State Department programs. The islands are included in descriptions of the Southwest USDA Climate Hub.

In addition to US Federal agencies, the state of Hawai‘i has an active climate adaptation program, including the Interagency Climate Adaptation Committee (ICAC) later renamed the Hawai‘i Climate Change Mitigation and Adaptation Commission (Climate Commission) and co-chaired by the Department of Land and Natural Resources (DLNR) and the State Office of Planning. Major non-governmental programs include The Nature Conservancy (TNC), the Micronesia Conservation Trust (MCT), Pacific Birds Joint Venture, and the Secretariat of the Pacific Regional Environment Programme (SPREP). More generally, programs related to capital improvement, adaptation and sustainability in the islands are led by the Office of International Affairs (OIA), State, EPA, the Federal Emergency Management Agency (FEMA), NOAA, and USDA. Also networked with these programs are the National Park Service (NPS), US Fish and Wildlife Service (USFWS), US Army Corps of Engineers (USACE), and the Department of Defense (DOD). In the CSC service region, a substantial portion of science for living resource management occurs under the umbrella of conservation and state, federal and non-governmental organizations are highly networked in those efforts.

Mission commonality is the Sweet Spot for Collaboration: Given how crowded the field is (especially when one considers climate impact in relation to broader issues of conservation, sustainability, human health and safety, cultural resources, and national security), there is fairly regular discussion about the potential for redundant investments. The reality is that the CSC and regional partners maintain close communication and plan the directionality and implementation of their investments to avoid duplication and leverage collaborative efforts. This was a topic of discussion at Stakeholder Advisory Committee (SAC) meetings in early years. Through dialogue, the SAC concluded that the overlapping missions among several programs do not represent redundancy. Instead, the SAC concluded that these commonalities represent shared goals, and in fact represent the sweet spots for partnership and collaboration because the overlaps identify where the programs align and provide a path for defining where the gaps and capacity needs exist.

The Pacific region has a long cultural and political history of collaborative effort typical of insular regions and hence is known for the tendency toward interagency collaboration, rather than competition. CSC collaboration started with a strong base of networked federal, state, and federally-funded programs and expanded that to include additional collaborators. However, unlike other CSCs, the PI-CSC is also challenged with coordination with the multitude of international programs in the region, such as those funded by Australasian, EU, or university programs. A sample of these programs and projects is provided in the *PICSC Background Documents\Strategic Documents* folder. We look to these challenges as opportunity for future activities and collaboration across the region.

COLLABORATION CASE STUDY

"Vegetative Guide & Dashboard": Relating atoll agroforestry recommendations to predicted climate and sea level conditions in the Marshall Islands

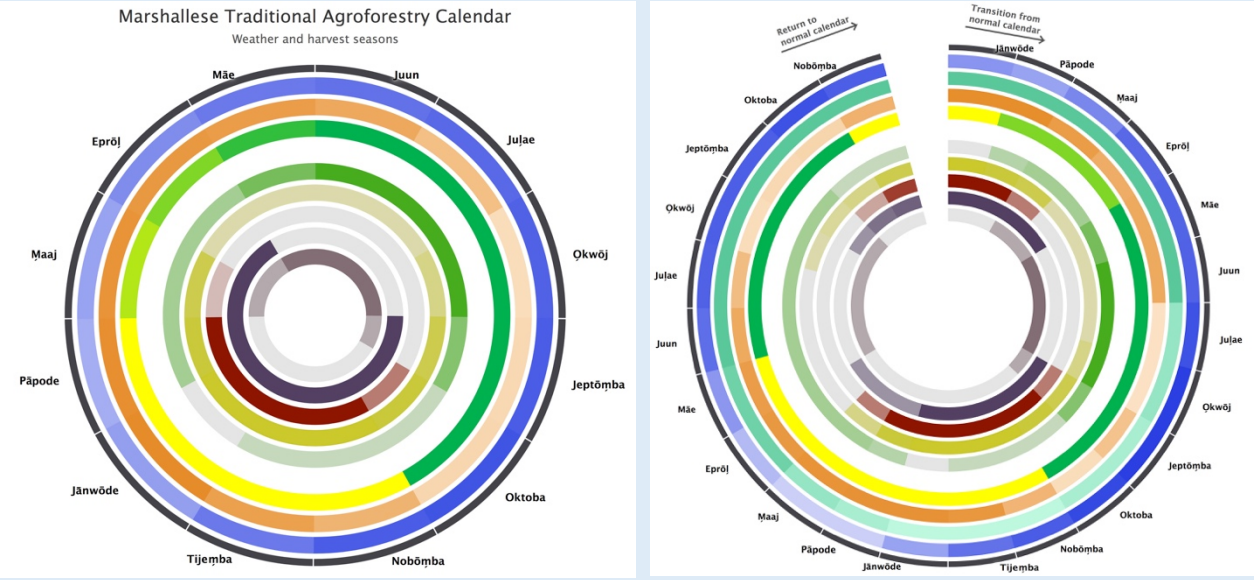
PI: Maria Haws and Kathleen Friday

Summary: The "Vegetative Guide and Dashboard" project is a prime example of a successful partnership and collaboration among a diverse group of scientists and stakeholders. Diverse expertise combined to generate actionable information which could then be communicated to community members, increasing resilience and adaptive management capacity. With partners, Haws and Friday developed an Online Dashboard, with printable versions in Marshallese, that provides clear farming information and recommendations to agricultural communities and growers on the Marshall Islands for both normal and El Niño years. The broad partnership evolved from the needs of multiple stakeholders and the community and involved the PI-CSC, College of the Marshall Islands, Republic of the Marshall Islands Ministry of Research and Development, SOEST at UHM, NOAA, USDA, and UH Sea Grant College Program.

Results: This highly collaborative effort resulted in a user-friendly dashboard that provides invaluable environmental information, in English and Marshallese, to Marshall Islands agricultural communities for informing farming practice in a changing climate.

Application: The website provides easy access to well-researched, localized information at a variety of timescales to assist with both short and long term agroforestry planning so that traditional agriculture practices can be integrated with new information on plant varieties and planting/harvest schedules. The website is currently found at http://oos.soest.hawaii.edu/pacific-rcc/Marshalls Agroforestry/site/.

The Take-away: The collaboration allowed for a scientifically rigorous, user-friendly product that will help local communities and has been disseminated in various forms to reach relevant stakeholders. This living website creates an opportunity for Marshallese partners to add or refine in order to provide a clearinghouse of information and increase interest in traditional foods and agricultural practices. The website has been translated to Marshallese and translated pages can be downloaded, printed and distributed by local agricultural extension services.



Agroforestry calendars for normal (left) and El Niño (right) conditions, illustrating the months (in Marshallese) for weather (rain, sea level, wind, seasons) and harvesting seasons (Breadfruit, Pandanus, Arrowroot, Giant land taro, true taro), outer rings inward.

The PI-CSC Stakeholder Advisory Committee (SAC): The PI-CSC has operated a SAC since 2013, using the Terms of Reference developed for the NCCWSC-CSC network. The PICCC sits on the SAC, and their input has also been solicited informally. Not surprisingly, the CSC SAC and the PICCC Steering Committee have had substantial overlap in participating agencies. An important challenge for the PI-CSC has been turnover on the SAC, especially from representatives of the USAPI, along with lack of engagement of some Hawai‘i state offices despite repeated efforts to bring them aboard at the strategic level of the SAC. Turnover also means there is lack of corporate memory – only about 25% of the people sitting on the current CSC SAC were participating when the Science Agenda was developed in 2013. An additional challenge is the costs, logistics, and technical limitations of convening and interacting across such a large service region typified by relatively undeveloped and sporadic IT and communication networks.

Table 3: 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	

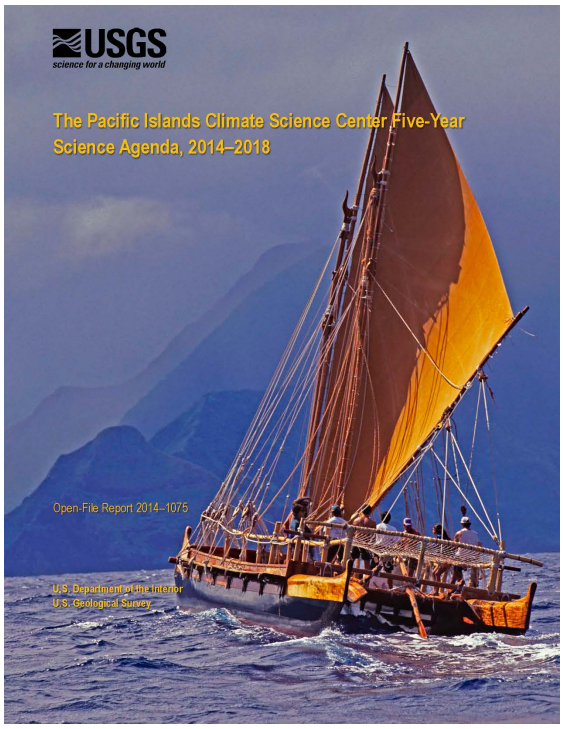
The PI-CSC Science Advisory Panel (SAP): Per the SAC Terms of Reference, the SAC provides counsel to the Center Director in identifying priority needs related to ways in which climate change may be affecting resource management and environmental planning. In other words, the SAC perspective is that of resource management, and the Center Director works with the SAC to capture their perceived priorities and combine them with national and agency priorities in the 5-yr Science Agenda. To make this process robust, the PI-CSC created a Science Advisory Panel (SAP), an *ad hoc* working group consisting of directors of scientific institutions in the PI-CSC service region. The SAP was the science interface with the SAC, at the strategic level, and participated in SAC meetings. Their role was to help transform resource management

priorities elicited from the SAC into tractable science questions by working with subject matter experts in their home institutions and then synthesizing the expert input at the SAP level. By working with institution directors rather than practicing scientists, this created a firewall between the purpose of the Science Agenda as guide to future funds investment and the practicing scientists who may seek CSC funds in future proposals.

The 2014-2018 Science Agenda

Agenda Development

Development of the science agenda began in early 2013, soon after the permanent Director was aboard. An extensive review of climate-related biophysical literature helped identify and sort major issues, separating those already well-served by other programs and those that presented opportunities for the PI-CSC to help advance knowledge and potentially fill gaps. The Stakeholder Advisory Committee (with representatives from the Federal, state and local government; see Table 3 above) gave input in identifying both high-priority issues as well as possible future directions. Throughout the summer, input was also collected from nongovernmental stakeholders and managers of relevant programs, as well as cultural and scientific professionals from the university consortium and partner government agencies and local institutions. During this process, several major science needs repeatedly emerged and, thus, were integrated into four Science Themes for this agenda, which was then approved by stakeholders and the Secretary of the Department of the Interior before the end of the year. This deliberate development process resulted in the creation of a regionally relevant and effective science agenda. The four themes with example projects are described below.



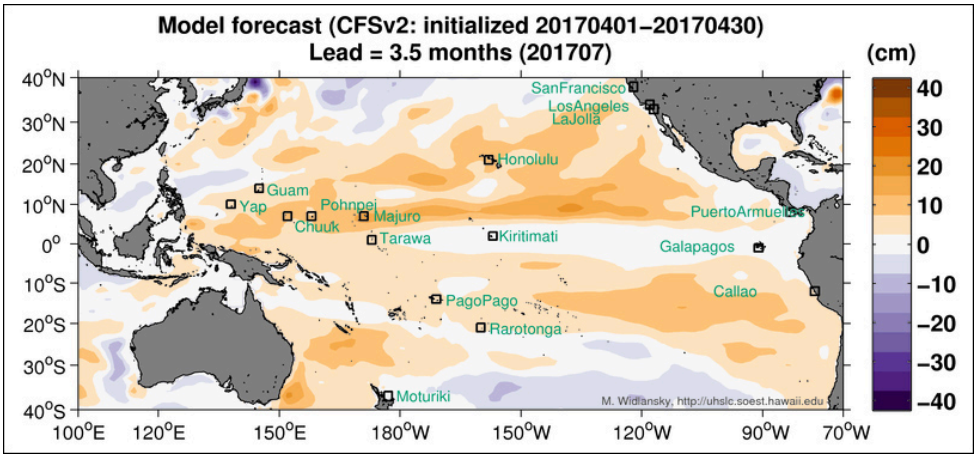
Science Projects

The Agenda focuses on topics where climate and climate variability pose great challenges to resource managers, cultural stewards, and decision makers. It therefore emphasizes "actionable science" designed to be integrated into strategic planning and decision-making, with the outcomes motivating further investigation and application.

Over the five years so far of the PI-CSC, 54 projects that span the four science themes have been funded, 27 directly through USGS RFP solicitations and 27 through university consortium allocations. The projects have spawned over 47 peer-reviewed publications and generated products for Pacific Basin resource managers, decision-makers, teachers, and the general public, in many different formats:

- Online tools (e.g. a "**Vegetation Guide and Dashboard**" for the Marshall Islands; a "**Sea Level Anomaly Forecasts**" tool for the Pacific Basin);
- Databases (e.g. Hawaiian native plant vulnerability; Hawaiian plant species abundance database; **Coral Traits Database**; Predicted future erosion hazard zones for Kauaʻi)
- Models/spatial tools (e.g. Statistical downscaling seasonal rainfall anomalies; Dynamical downscaled and projected climate for the Pacific Islands)
- Maps (e.g. high-resolution digital elevation maps of Majuro Atoll; predicted shifts in vegetation distribution in the Hawaiʻi Volcanoes National Park; coral resiliency and annual bleaching likelihood in CNMI; high-resolution predictions of rainfall distribution)

- Informative brochures and posters (e.g. Observations of Water Level Extremes and Inundation Events in American Sāmoa; Marshallese Agroforestry Calendar, Normal years vs. El Niño)
- Teaching lesson plans (Culturally Relevant Lesson Plans on Climate Science in Guam)



Theme 1: Guidance for anticipated intermediate-term climate changes

Much of the effort in developing climate projections, using complex numerical atmospheric and oceanographic models, has been to determine how predicted changes in the atmosphere may cause changes to terrestrial and marine climate and weather over the next century. However, much of the experienced climate in the Pacific depends on the inter-decadal variability of the atmosphere-ocean system through such multi-year cycles as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Since local decision making and planning must happen on even shorter seasonal or multi-annual timeframes, it is important to develop climate outlooks for the shorter term windows (multi-annual to decadal), as well as the longer-term (century) timeframe.

The modeling and projection efforts that fall under this science theme addressed primarily two Science Agenda-defined objectives: assessing and improving downscaling projections, and collecting environmental data to help verify and improve climate models.

Assessing and improving downscaling projections

The scale and complexity of global climate models usually necessitate that the resolution of those models is fairly large, with a pixel size easily larger than any Pacific Island. These models are then of limited use for predicting the future conditions of islands like those of Hawai‘i, which have numerous diverse topographies and microclimates bundled into small areas. **Elison Timm** and **Wang** took two different approaches to downscaling global models to pull out details of future rainfall and temperature distributions for the various Pacific Islands. Elison Timm used statistical methods to produce high-resolution maps for the Hawaiian Island chain, while **Wang** used a dynamical downscaling technique to produce his high-resolution projections of O‘ahu, Kaua‘i, Guam, and American Sāmoa.

CASE STUDY

Very Fine Resolution Dynamical Downscaling of Past and Future Climates for Assessment of Climate Change Impacts on the Islands of O`ahu and Kaua`i

and

21st Century High-Resolution Climate Projections for Guam and American Samoa

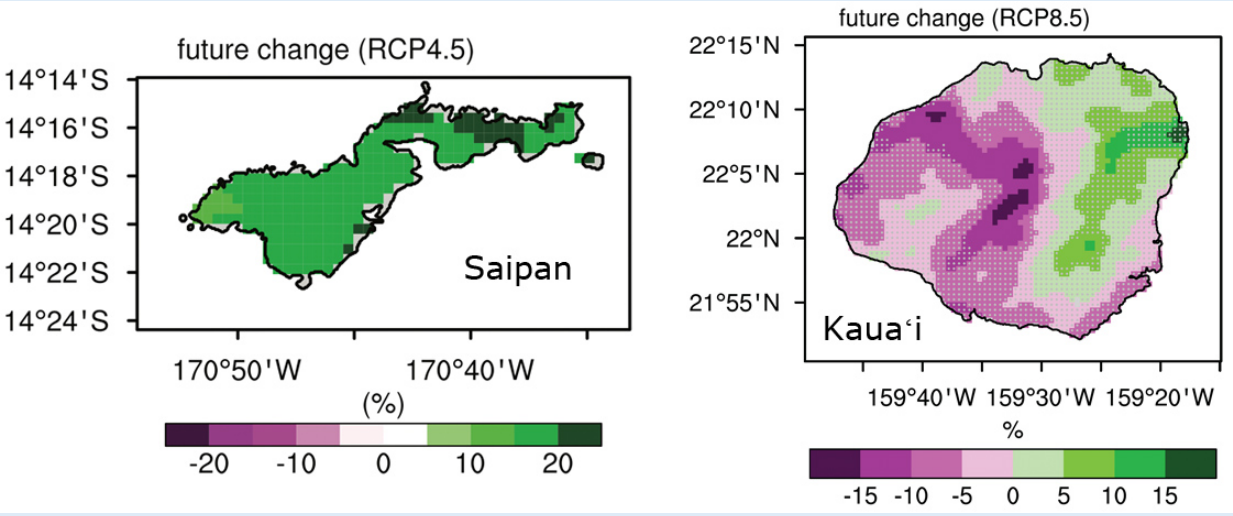
PI: Yuqing Wang, IPRC, University of Hawai‘i at Mānoa

Summary: For both of these projects, Wang applied dynamical downscaling to generate very fine-resolution regional climate models from global models. The goal was to provide the best possible projections of the climate at the end of the century, focusing particularly on the details of future precipitation, surface temperatures, and wind, but also including a variety of other variables important for land management decision-making.

Results: Results for both high and medium emission scenarios were developed for Guam, American Sāmoa, O‘ahu, and Kaua‘i. Surface air temperatures show predicted increases of 1.5-3.5°C for Guam, O‘ahu, and Kaua‘i, with similar but smaller increases for American Sāmoa. The high-resolution output illustrated greater temperature increases for leeward areas than windward. Rainfall changes for Hawai‘i imply 15% increases in windward regions, but 15% *decreases* in leeward sections. American Sāmoa will likely have substantial rainfall increases, up to 20-25%, while Guam will see no significant changes. However, the frequency of strong tropical cyclone activity around Guam will increase.

Application: Information from these downscaling models has been presented at application workshops run in partnership with PacRISA and the PICCC, delivering the results to “intermediate modelers” from federal agencies (USGS Pacific Islands Water Science Center, USFS Institute of Pacific Islands Forestry, etc.) who then introduce the data into smaller-scale, targeted models for ecological, wildfire, or water concerns. Downscaled models were used in a Strategic Environmental Research and Development Program (SERDP) project looking at water resources on Guam.

The Take-away: These unique high-resolution downscaled models have made significant strides in modeling basin-wide processes, but also providing the island-scale details necessary for addressing future climate conditions across the Pacific Islands.



Example maps illustrating projected rainfall for Saipan and Kaua‘i under different future emission scenarios. Note the strong contrast on the small island of Kauai, necessitating the high-resolution modelling to visualize.

Collecting environmental data for model improvement

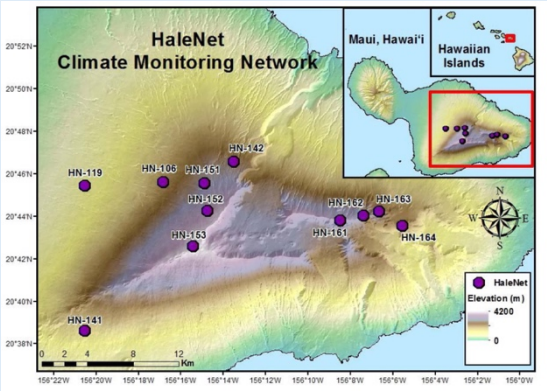
Several projects involved measuring climatic conditions with an ultimate goal of improving inputs for climate models of the Hawaiian area. A couple early consortium projects used dendrology to clarify historical climatic trends across the state (**Hart**, **Alegado**), and Alegado also searched a unique cultural resource of knowledge, 150 years' worth of Hawaiian language newspapers, to ferret out climatic information recorded by the Hawaiians of old. More recent efforts by **Longman** involved active measurements using a network of climate stations across Hawai'i (HaleNet) to examine conditions during El Niño and the ecosystem responses to those shifts in environmental conditions.

CASE STUDY

Monitoring and analysis of climate variability and change in Hawai'i

PI: Thomas Giambelluca, Professor of Geography, University of Hawai'i at Mānoa
Student Co-I: Ryan Longman, Dept of Geography, University of Hawai'i at Mānoa

Summary: The primary focus of this project was to examine historical climate data obtained from several locations across the State of Hawai'i in an effort to detect changes in climate at a variety of spatial and temporal scales. Part of this work included an in-depth analysis of data obtained from the HaleNet climate network located on the flanks of Haleakalā on the island of Maui. Understanding how climate has changed in Hawai'i over the past few decades will serve to further stimulate ecological research and help to develop successful management strategies for preserving native Hawaiian ecosystems and properly managing freshwater resources.



Locations of HaleNet climate monitoring network stations across the flanks of Halakalā volcano, Maui.

Results: The annual, diurnal, and elevational characteristics of eleven climate variables through space and time were documented using HaleNet. This network (originally installed in 1988) includes eight climate stations along the windward and leeward slopes of Haleakalā, covering elevations from 960 m to 2990 m. Important findings were that precipitation decreased, as did relative humidity and cloud attenuation of sunlight. Concurrently, there were increases in evapotranspiration, solar radiation, and days with no rain. All this points to changes in the elevation of cloud formation (the Trade Wind Inversion or TWI) and thus, precipitation distribution during wet and dry seasons.

Application: The dataset established and analyzed for this project has been applied further to such diverse projects as examining a decline in Haleakalā silverswords, and mapping solar radiation and relative humidity state-wide. In the future, it will be used as a baseline for comparison with forthcoming climate measurements to evaluate atmospheric evolution in the central Pacific.

The Take-away: Examination of long-term climate data proved useful in identifying fundamental shifts in cloud formation and the accompanying trends in such important factors as precipitation, solar radiation, and evapotranspiration, which will help with future resource management decisions.

Outcomes

The results and conclusions from the projects of this theme produced a number of informative lessons learned and outcomes for guiding future research on this topic. Researchers found a lack of available environmental data from which to develop climate projections or to use for evaluating climate projections in the region. Managers indicated that, for their purposes, the more relevant projections of climate variability and change are on the seasonal and multi-annual (e.g. ENSO) timeframes. In fact, for resource management decision-making, we found that climate variability is as important as long-term climate changes. Another important realization was that resource managers want error estimates included with integrated climate, ecological impact, and management effectiveness models. although often the resulting errors are so large the models become useless for decision-making. Another hurdle was the lack of agreement among climate projections, confusing the issue for managers of which outcomes to predicate decisions on. However, applications workshops were a useful tool in developing narratives to describe the best environmental information to use. Lastly, a lower limit on downscaling was discovered for ecological modeling where local environmental conditions (e.g. temperature, soil moisture) became the dominant control on impact variation, rather than climate.

Theme 2: Potential effects of changing climate on freshwater resources

Adequate clean freshwater is essential to sustaining life in terrestrial and nearshore ecosystems, but changing climate is predicted to bring shifts across the Pacific Basin in total precipitation as well as timing of precipitation events. Whether a given location is expected to experience an increase or decrease in annual rainfall, any change in amount or frequency will certainly cause repercussions. Informed decision making is critical to managing this precious resource.

Funded projects in this theme have fallen under three objectives defined in the Science Agenda: freshwater resource assessments, drought and drying projections, and enhancing models by including broader freshwater sources and inputs.

Freshwater assessment

In assessing freshwater resources, there are several avenues that have been applied. **Bassiouni** examined streams on Maui during low-flow conditions and varying rainfalls, as a method for estimating flow and habitat of the streams under predicted dryer future conditions. **Ostertag** is investigating the impacts of future drying on the native ecosystems, by measuring water use of the forest trees on Hawai‘i Island in contrasting rainfall regimes. **DeMaagd** is employing an economics bent to predicting human water demand on O‘ahu with the increasing temperatures expected from a shifting climate. And **Oleson** uses socio-economic data to evaluate adaptation outcomes across several climate scenarios.

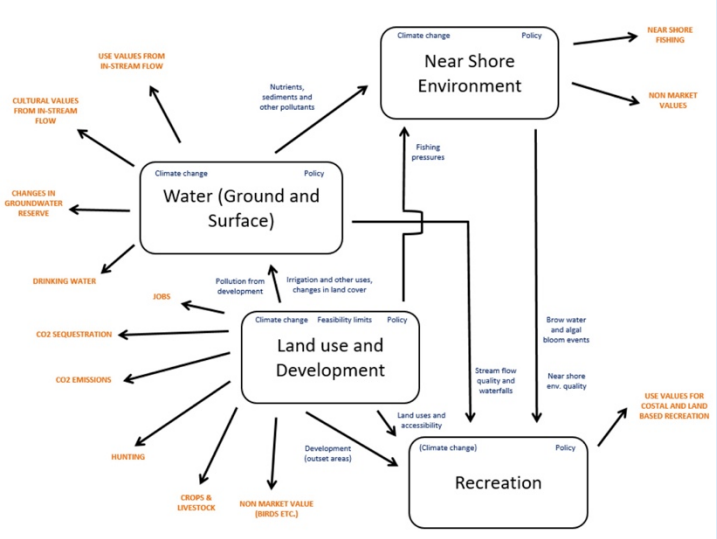
CASE STUDY

Evaluating the economic impacts of climate variability and change on Maui's freshwater resources and ecosystem services

PI: Kirsten Oleson, Natural Resources and Environmental Management, University of Hawai'i at Mānoa

Summary: Decision makers need to prepare for long-term impacts of climate change, and want to choose adaptation options based on technical and socio-economic considerations. This project is focusing on the socio-economics of Maui's natural resources and ecosystem services, since they will be altered by shifting ecological dynamics. Analyzing and quantifying the trade-offs between such ecosystem services arising from climate change impacts provides a way to compare the costs and benefits of different adaptation strategies.

Results: This work attaches value to different adaptation outcomes and business-as-usual trajectories, to produce a novel, ecological-economic model that will suggest which adaptation options will deliver the most benefit under alternative climate futures. Our aim is to provide a tool that decision makers can use to assess on trade-offs and opportunities. After one year, the project has engaged with community members and decision-makers to identify priority ecosystem services and their main drivers and has created a conceptual framework to begin constructing a model of interrelated modules, which are being gradually populated with data.



Integrated modelling approach using models which assess the trade-offs and opportunities arising with climate change to explore alternative policy scenarios.

Application: Partner organizations already involved in the project and ready to apply the results include the West Maui Ridge to Reef Initiative, PacRISA, and local government entities via Maui County, the Division of Aquatic Resources, and the Department of Health.

The Take-away: Application of novel ecological-economic modelling and environmental valuation methods, built with community engagement, will provide a decision-making tool for choosing between different adaptation plans for the future of Maui's freshwater resources.

Drought and drying projections

Statewide trends since 1920 show drying across every Hawaiian island, particularly at the highest elevations and on the leeward sides. **Frazier** targeted these high elevation ecosystems, which are critically important for supporting downslope water resources, to establish these trends through time and the connection between rainfall and periodic El Niño events. **Mair** aimed his Hawai'i Island studies at impacts from drought conditions on soil moisture, evapotranspiration rates, and groundwater recharge, particularly with decreases in input from fog drip. Like Mair, **Giardina** examined drought conditions on Hawai'i Island, but with particular emphasis on its impact on future fire behavior.

CASE STUDY

Influences of climate change, climate variability, and drought on human communities and ecosystems in Hawai‘i

PI: Christian Giardina, Research Ecologist, US Forest Service

Summary: Several climate-related factors are influencing Hawai‘i’s landscapes and contributing to declines in precipitation and stream flow, and to an increasing number of droughts. Climate change, climate variability, and drought (referred to collectively as CCVD) will exert a growing influence on Hawai‘i’s ecosystems and communities, but there is currently little information on its historic impacts in the region. This project aims to improve understanding of past conditions in order to help Hawai‘i’s natural resource managers better prepare for the future impacts of CCVD on ecosystems and communities, with a particular emphasis on fire hazards.

Results: By synthesizing recently developed products, including Hawai‘i wildfire history, downscaled climate models, fire weather modeling, and biome change projections, high-resolution maps are being produced of fire behavior and associated fire danger indices.

Application: Several partners are already intimately involved in the project, including UHM Cooperative Extension, the Pacific Fire Exchange, and individuals at the USDA Forest Service, USGS, and US Fish and Wildlife.

The Take-away: CCVD will exert a growing impact on Hawai‘i’s watersheds, and understanding the role of wildfire is critical for fire mitigation and better management of threatened ecosystems and communities.

Enhancing models by including broader freshwater sources and inputs

One of the key inputs of freshwater to groundwater and ecosystems in Hawai‘i is the accumulation of cloudwater droplets on plants. **Giambelluca** is studying the impact of this fog on plant growth and other environmental variables to establish its role in the water cycle and plant survival, and Wang is using these measured data to update dynamical models. Another important project Giambelluca conducted studied the relative responses of native (‘ōhi‘a lehua-dominated) and non-native forests (strawberry guava-dominated) to climate variability, particularly reduced water flow. Results showed the invasive plants suffer more decreased growth rates under dryer conditions, weakening non-native forests. **Fortini** is looking at this issue reversed: he is investigating the changes to water flow (runoff and groundwater) in forests with expanding invasive plant populations. Groundwater health is also of great concern in Guam where **Bautista** did a detailed study of groundwater percolation mechanisms into the single aquifer system on Guam, determining the rates of recharge during wet and dry seasons.

Outcomes

Not unexpectedly, many stakeholders are interested in future effects of a changing climate on freshwater resources, especially where the freshwater sector is related to municipal water and wastewater management. Several projects found that, often, freshwater managers operate on the assumption that engineering can solve projected changes in freshwater systems. The various projects highlighted some areas where there was still more research that could be done to benefit local managers, including watershed function research, Ridge-to-Reef surface flow erosion and coastal impacts research, and ecological drought. Additionally, work with managers revealed that they need climate modelers to move beyond "percent change" precipitation projections to real-valued precipitation projections. Results from a cloudwater intercept project suggests that consideration of this water source in freshwater hydrology, plant distribution, and plant vulnerability assessments could be necessary to understanding fully the potential effects of changing climate on freshwater resources.

Theme 3: Anticipating and addressing change in coastal and low-lying areas

With most of the land in the PI-CSC on small islands, coastal issues associated with climate change are high priority to the region. Climate change is predicted to deliver multiple impacts to coastal and low-lying areas, including threats from inundation and erosion from increased wave action, impacts to fisheries and coastal habitats, weakening of coastlines and coastal infrastructure, as well as the associated hazards from increased runoff including inland flooding, pollution, and excess coastal sedimentation. Developing products and capabilities for coastal and wetland management, bio-cultural and community planning, and risk and crisis management becomes essential, particularly in collaboration with partners and stakeholders.

Funded projects have focused on three objectives defined in the Science Agenda: development of regional baselines of oceanic incursion, development of regional baselines of land cover and use, implications of climate variability on coastal and low-lying habitats.

Development of regional baselines of oceanic incursion

Islands in the Pacific, especially low-lying atolls, are particularly vulnerable to ocean incursions whether from storm surge, king tides, or sea level rise. **Thompson** tied together multiple factors that affect sea level (seasonal swells, storms, ENSO, PDO, sea level rise) to model extreme sea level events (both rising and falling), and developed seasonal inundation outlooks for Pacific islands of interest: Hawai‘i, Guam, American Sāmoa, and Kwajalein and Majuro in the Republic of the Marshall Islands. Similarly, **Timmermann** used seasonal prediction models to generate real-time monthly forecasts across the Pacific Basin of relative sea level anomalies out to six months. Ongoing work is looking to explore decadal forecasting approaches. **Fletcher**, meanwhile, produced projections of future shorelines around Kaua‘i, O‘ahu, and Maui to the year 2100, which have proved important to Hawai‘i state efforts to evaluate sea level rise vulnerability. Fletcher is also applying the same shoreline projection techniques to Majuro in the Marshall Islands, as a follow-up to **Danielson**'s efforts there to generate a high-resolution digital elevation/bathymetric map of the coastline. The DEM was produced as a collaboration between the CSC, USGS Earth Resources Observation and Science Center (EROS), NOAA, UH, and UoG, and will provide the basis for Fletcher to begin his modelling projections. The pair of projects illustrates a fundamental challenge for our region: a lack of baseline data and extremely limited monitoring, which in turn limit any ability to understand and predict climate change at landscape levels.

CASE STUDY

Empirical projection of future shoreline position and inundation due to sea level rise

PI: Chip Fletcher, Professor of Geology and Geophysics, University of Hawai‘i at Mānoa

Summary: Recent maps of historical shoreline change and vulnerability to flooding due to Sea Level Rise (SLR) are improving understanding of shoreline variability and climate change. The purpose of this research was to model shoreline response to rising sea level over the 21st century, detailing erosion hazard zones. An easily transferable methodology and planning tool were developed that can form the basis of a climate-ready strategy of beach management. Using data and maps of erosion exposure produced by the project, decision-makers will be able to prioritize beach conservation efforts, screen permit applications, identify potential future impacts, and increase the resiliency of the current management network of decision-making.

Results: The new model was applied to produce erosion hazard maps for the years 2030, 2050, 2075, and 2100 for ten shorelines around Kaua‘i, O‘ahu, and Maui (assuming a “business as usual” SLR scenario). Results suggest most areas of the Hawaiian Islands will experience coastal retreat, with increasing rates of retreat as the century progresses. The model projects for Kaua‘i over 80% erosion by 2050 and 90% by 2100.

Application: Once finalized, the GIS map products will be easily accessible online (at the PacIOOS website) to identify critically vulnerable natural and cultural resources that fall within the erosion hazard zones. Meanwhile, results have been shared broadly with the Interagency Climate Adaptation Committee, the Department of Land and Natural Resources, Hawai‘i Sea Grant College Program, and various state legislators and agencies.

The Take-away: By planning for future beach response to SLR, this project allows for the existing decision-making system to evolve new strategies focused on adaptation to future SLR.

Map illustrating future erosion hazard zones on Kauai coast due to future sea level rise, as projected by Fletcher.

Development of regional baselines of land cover and use

Hart, on Hawai‘i Island, is attempting to quantify shoreline change rates along three geomorphologically diverse coastal stretches, by comparing historic aerial photography with newly acquired unmanned aerial system imagery. In the Marshalls, the baselines are being drawn now, as Danielson completes a detailed Digital Elevation Map (DEM) of the Majuro coastline and near shore. (This project will be the jumping off point for Fletcher's Majuro work mentioned above.)

Implications of climate variability on coastal and low-lying habitats

Many projects delved into the near-shore environments around the Hawaiian Islands and the western Pacific Islands, looking especially at the effects of changing ocean conditions on coral reef ecosystems. Oleson has focused several endeavors on the coastal systems of Maui, using economic valuation techniques to examine the impacts from climate changes on coastal **ecosystem services**, including the coral reefs, as well as determining the results of greater **sediment transport** into coastal waters as agricultural priorities shift on Maui. **Colbert** measured carbon dioxide dynamics in Hawai‘i Island coastal waters, studying the processes that affect calcification of benthic organisms with an eye to recommendation for better groundwater management. **Toonen** and **Matsuda** each examined aspects of coral resilience in Kaneohe Bay, O‘ahu, with the idea of helping craft hardier corals of the future, while **Raymundo** focused on the current coral resilience in Guam and the Commonwealth of the Northern Marianas Islands (CNMI) and projections of future conditions.

Coral health is a concern across the Pacific Basin, as ocean temperature and chemistry shifts with climate change. (Top) Laurie Raymundo assesses coral resilience potential in Guam. (Right) Startling juxtaposition of healthy and bleached branches of rice coral, taken by graduate student Shayle Matsuda as part of his master's research.

CASE STUDY

Coral reef resilience to climate change in the Commonwealth of the Northern Mariana Islands

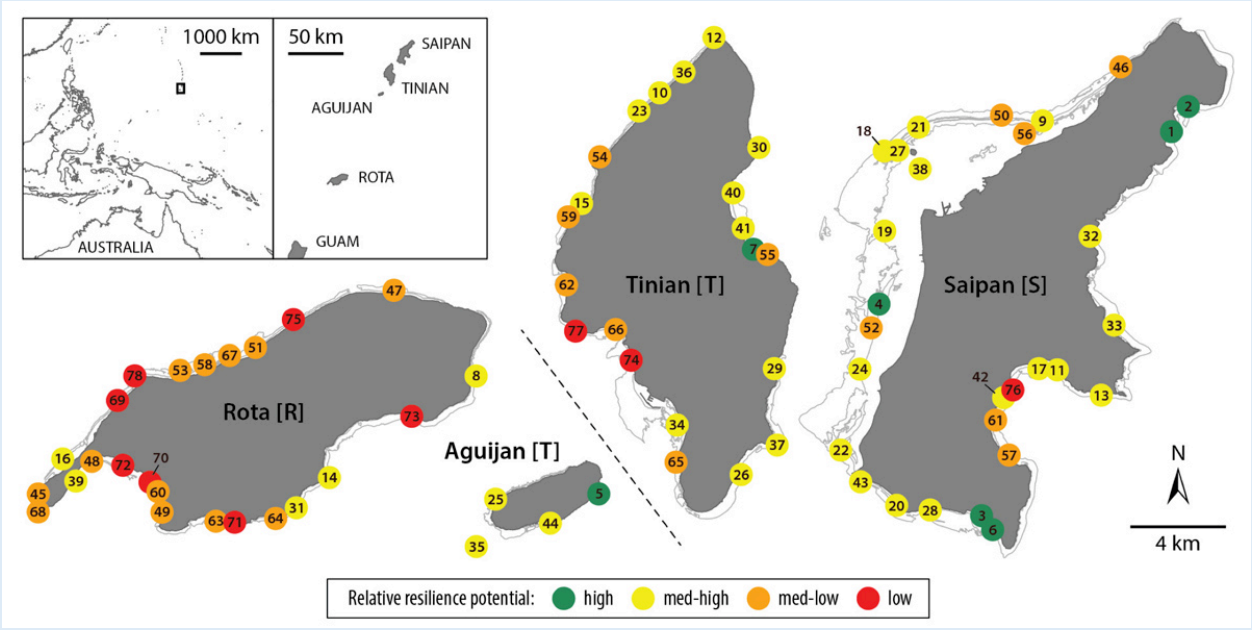
PI: Lauri Raymundo, Professor of Marine Biology, University of Guam

Summary: Reducing coral reef vulnerability to climate change requires that managers understand and support the natural resilience of coral reefs. Coral reef resilience is defined as: the capacity of a reef to resist and/or recover from disturbance given its probable exposure regime, and maintain provision of ecosystem goods and services. For this project, Raymundo conducted ecological resilience assessments in CNMI and collaboratively developed a decision-support framework with local manager partners for resilience-based management.

Results: At 78 sites along reefs surrounding several CNMI islands, Raymundo's team performed surveys of that measured and assessed variables considered "indicators" of the processes that underlie reef resilience. These produced scores for relative resilience potential, which varied greatly within and among islands. Raymundo defined seven custom criteria for a decision-support framework that identifies sites that warrant management attention. Of the 78 sites, only 7 ranked with high resilience potential, with 34 ranking either med-low or low resilience potential, suggesting they are good targets for management.

Application: Results of the assessments were compiled into tables and 25 custom map graphics which, with the custom criteria, are being used by managers in education and outreach programs. Partners utilizing these products locally include NOAA Fisheries and the Bureau of Environmental and Coastal Quality's Marine Monitoring Team. Results have also been shared with managers in Hawai'i and helped update sections of The Nature Conservancy's Reef Resilience Toolkit online.

The Take-away: The decision-support framework developed from the reef resilience assessment, with extensive collaboration with local managers, provides an important tool for others to use in resilience-based management efforts.



Maps showing relative resilience potential for coral reefs in the Northern Mariana Islands, based on eleven variables, including coral diversity and disease, temperature variability, and anthropogenic factors.

Outcomes

Although coastal vulnerability studies are plentiful, there is a research gap in foundational mapping work, especially in coastal vulnerability of human communities. Many managers expressed a strong need for high-resolution map products, such as the Topo-Bathymetric Digital Elevation Model produced for Majuro. Our projects on coastal issues discovered that like freshwater managers, coastal managers operate on the assumption that engineering can solve many predicted changes in coastal systems. However, many impacts on coastal and low lying areas seem to have stronger connections to regulation and legislative solutions. Addressing some of these conclusions and building on these outcomes will require strong collaboration with agencies, such as NOAA and Office of Insular Affairs.

Theme 4: Forecasting sustainability for resource management and planning

To incorporate climate predictions into decision-making, management, and planning within a community, it becomes essential to understand which local resources are most important to sustain, especially in the eyes of that community itself, whether they be ecosystem habitats, native populations, or even cultural practices. Actively working to sustain these resources requires first understanding how much change can occur to a place or system before it becomes unsustainable, or loses its value or meaning. Beyond that, it is important to evaluate multiple options for maintaining the resources, such as resilience, restoration, adaptation, or mitigation. For forecasting ecosystem sustainability in particular, a broad range of factors need to be understood, including details like productivity and nutrient flow; system-wide implications of the loss of critical system components; the effects of external forces such as invasive species or extreme weather events; and the influence of habitat fragmentation on system vulnerability.

This theme is broad and has encompassed projects targeting several aspects of flora and fauna resource sustainability. Just a few of the studies have ranged from a more general evaluation of the vulnerability of Hawaiian plant species (**Fortini**) and tropical alpine shrubs (**Ainsworth**) to the demographics and climate tolerance of culturally important species (**Barton**: ʻōhiʻa lehua; **Krushelnycky**: silversword), while **Jacobi** has made model projections of plant migration with future changes in temperature and rainfall (see below). **Samuel** has investigated how insect migration with changing temperatures has proven an increasing danger to endemic Hawaiian birds, while **Burkett** is studying how migration of the Marshallese people, between islands and to other countries, in response to changes in ecosystem goods and services (see below).

Pacific Islands are characterized by endangered flora and fauna, so projects focused on sustainability of populations, like the silversword (right) and the Iʻiwi (top) are crucial for decision making to maintain healthy ecosystems.

CASE STUDY

Assessing the potential effects of climate change on vegetation in Hawai'i Volcanoes National Park

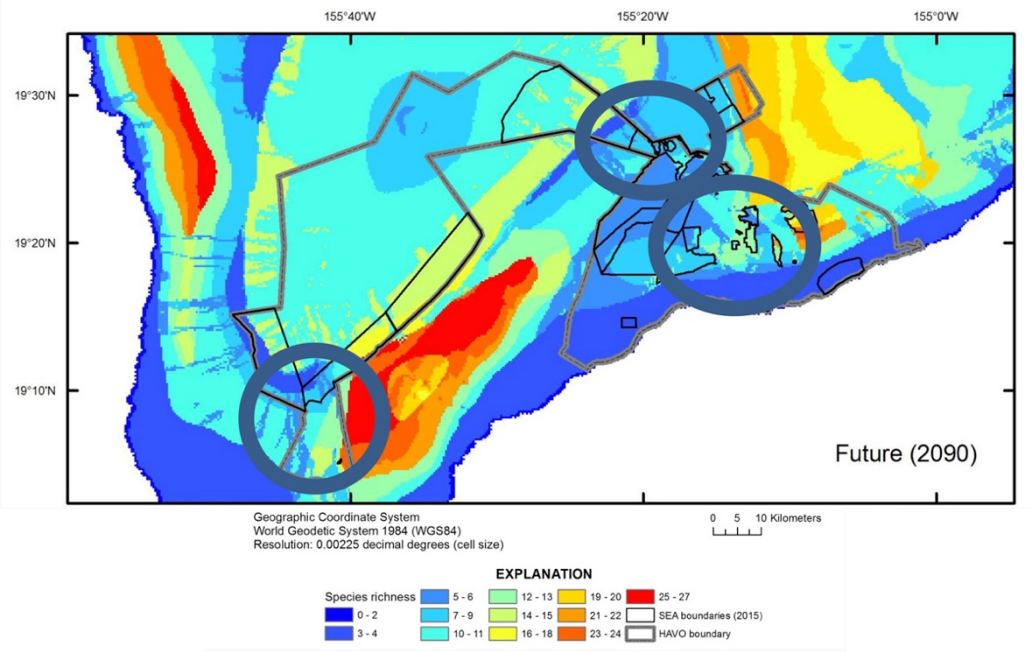
PI: Jim Jacobi, Biologist, USGS Pacific Island Ecosystems Research Center

Summary: Climate change is expected to alter the seasonal and annual patterns of rainfall and temperature in the Hawaiian Islands, changes which are likely to result in an increased frequency and intensity of droughts through the twenty-first century. These climate changes may have potentially large impacts on Hawaiian plants and animals, a major concern for resource managers at Hawai`i Volcanoes National Park (HAVO). They want to know how climate change may shift plant distributions, especially in the highly managed Special Ecological Areas (SEAs), focal sites to nurture rare and endangered plants. Results from this research will inform managers as to how vegetation types will migrate across the Park, and if species can successfully be established in more suitable sites.

Results: By combining recent high-resolution climate modelling for Hawai'i with existing plant distribution models, projected species range maps were generated for 2000, 2040, 2070, and 2090 for three climate change trajectories (slow, moderate, rapid). The maps illustrate suitable habitats for 39 plant species, native and invasive, of interest to HAVO resource managers. Most of the SEAs were projected to lose the majority of native species and all but one invasive species, with species-rich spots occurring outside these protected areas, and even, ultimately, outside HAVO.

Application: Maps produced will assist HAVO managers working with adjoining land owners and partner agencies to prioritize conservation efforts island-wide. Results have been shared with managers in the Cultural Resources and Natural Resources divisions of HAVO.

The Take-away: Tracking shifts in temperature and precipitation makes possible projections of important plant species migration and future distribution, enabling managers to plan future protected ecological areas where needed.



Projection of future distribution of plant species within Hawai'i Volcanoes National Park, compared with current protected Special Ecological Areas.

CASE STUDY

Analyzing correlations and effects of human migration of Marshallese Islanders

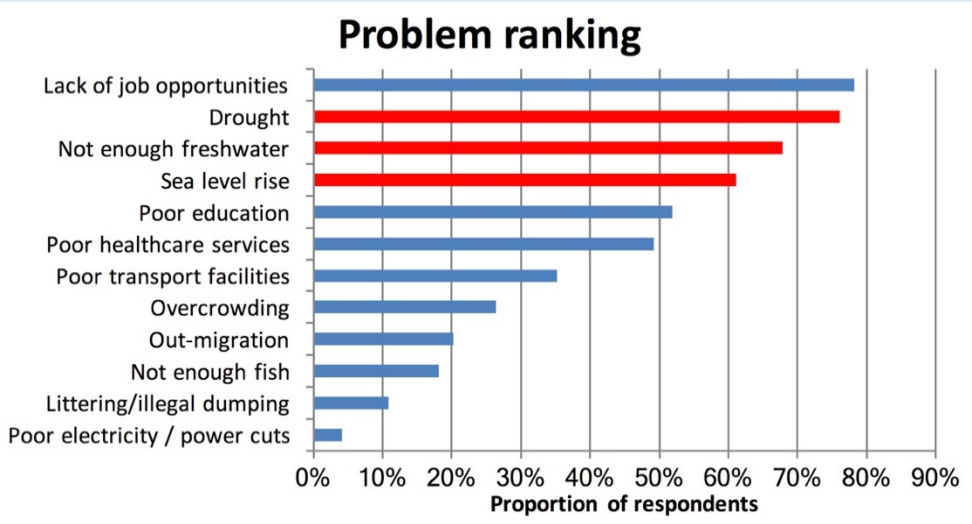
PI: Maxine Burkett, Professor of Law, University of Hawai‘i at Mānoa

Summary: The Republic of the Marshall Islands (RMI) is acutely vulnerable to sea-level rise, the associated intrusion of saltwater into crucial freshwater supplies, and contrarily, to persistent drought. Many Marshallese communities are already experiencing these changes and are migrating to seek alternative means of living. In an effort to aid decision makers at local and state levels considering policies related to migration, this project is examining the linkage between patterns of human migration and climate events. Burkett and her team are determining migration trends and motivations, and characterizing changes that have taken place to local lands and ecosystems in the RMI. Combined with projections of climate change, these data will help decision-makers understand which islands and communities may be at highest risk in the future.

Results: Preliminary findings from questionnaires given to over 200 Marshallese islanders show that the people are concerned about the effects of climate change, particularly threats to freshwater supplies and from sea level rise, and do not feel prepared to deal with these threats. But many strongly resist the idea of leaving their islands and believe solutions will be found. Migration is widespread but is put down to seeking better education, healthcare, and employment opportunities more than fleeing climate change, and many view migration as harmful to the Marshallese culture and development.

Application: Results will be transformed into a map displaying climatic data with social and vulnerability data overlaid. An online mapping platform will be co-produced with managers and stakeholders in RMI and typical migration destinations (Guam, Hawai‘i, and Arkansas) to ensure variables of interest are included, and results are disseminated appropriately.

The Take-away: This research will uniquely contribute to understanding how climate change and variability impacts migration, and will help identify best practices in managing the consequences of potential climate induced migration on both human and natural ecosystems.



Preliminary results from RMI survey ranking the most important problems local Marshallese islanders face. Red bars highlight climate-related stressors.

Outcomes

Projects results under this theme revealed that adaptation is place-based and very granular. Generalizing specific adaptation plans is difficult and potentially irrelevant at larger scales, requiring the incorporation of local conditions into planning. Similarly, shorter periods (i.e., several years) of biological and environmental data may show strong correlations, but problems arise when those results are applied long term: correlations tend to break down over longer timeframes, or with inclusion of other stressors or condition changes, illustrating the difficulties of using the results for long term adaptation planning. several vegetation projects illustrated that habitat change (e.g., changes in 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. Thus, it is challenging to separate the effect of climate change from the other factors to project future vegetation communities, and ultimately to project habitat for listed species. Another important lesson was that managers often felt helpless to combat conditions predicted for RCP 8.5, suggesting it is necessary for modelers to include at least one RCP with reduced emissions to retain manager engagement when discussing resource sustainability and planning.

Education and Capacity Building

Student involvement

An important element of the Climate Science Centers, reflecting the priorities of the DOI and USGS to build capacity for the future, is the support of the next generation of scientists and resource managers focused on climate science and climate adaptation. Because of regional priorities and resource availability in many parts of the Pacific Basin, instructional emphasis and capacity building is focused as much, if not more in some locations, at the undergraduate level as the graduate or early professional level. This is due, in part, to greater numbers of students who leave school to get natural resource jobs immediately after obtaining an undergraduate degree, rather than pursuing a graduate degree, emphasizing the need to train the next generation of managers at all levels.

Over the years, the PI-CSC has supported the pursuit of knowledge in climate sciences of 28 undergraduates, 45 graduate students, and 8 post-doctoral researchers, with 20 Bachelor's degrees, 19 Master's degrees, and 6 PhD's being conferred, and 8 Bachelor's degrees, 14 Master's degrees, and 5 PhD's currently in progress. Of the 81 people supported, 48 were women, and more than 11 from the underrepresented communities of native Hawaiian or native Pacific Islanders. The variety of academic disciplines represented by this group is impressive, with some students engaged with more traditional departments focused in the climate sciences such as biology, marine science, botany, environmental science, geography, geology, and tropical conservation. Other students, however, have been associated with departments not typically thought of as having a climate science focus, such as anthropology, psychology, economics, urban planning, development practice, business administration, and Micronesian studies.

Table 4: Student and early career scientist participation, by the numbers

Supported Students	#
Undergraduates	28
Graduate students	45
Post-doctoral Researchers	8

Degree	**Conferred**	**In Progress**
Bachelor's	20	8
Master's	19	14
PhD	6	5

Student projects over the years have been equally diverse, and ambitious. From climate change effects on high-elevation Maui subalpine shrublands (**Ainsworth**) and freshwater resources (**Frazier**) to coastal concerns of thermal resilience of O'ahu coral reefs (**Matsuda**), the vulnerability of coastal wastewater infrastructure (**Dean**), the hydrology and production of Hawaiian fishponds (**Anthony**, **Kauahi**), quantifying Hawaiian shoreline change rates (**Hart**), and even detecting changes to staphylococcus contamination of Hilo Bay with changes in rainfall (**Economy**). Predictive projects included using epiphyte health as a bioindicator of changing freshwater conditions (**Kettwich/Price**), employing economic data to predict how water demand on O'ahu would shift with increasing temperatures (**DeMaagd**), and looking in depth at how climate change might affect water percolation and chloride contamination in Guam's only aquifer system (**Bautista**, **Miller**). Other students engaged in a variety of other topics, such as

improving agroecosystem functioning by using an invasive tree as fertilizer (**Norton**), studying the level of small business resilience in Guam (**Higgs**), and developing culturally relevant climate science lesson plans for geography teachers on Guam (**Flores-Hughes**).

An additional effort to enhance student support was the creation by the university consortium in spring 2017, in conjunction with the Hawai‘i Sea Grant College Program, the new Pacific Islands Climate Science Center Summer Research Fellowship. The fellowship provides an undergraduate or graduate student with the opportunity to gain research experience and skills in climate science and to expand their knowledge of environmental issues in Hawai‘i through active research with a university scientist. The first recipient was an undergraduate student from Hawai‘i studying Geographical Biogeosciences who spent 12 weeks at UHM working with Abby Frazier and Tom Giambelluca examining historical trends, in space and time, of consecutive dry days across the Hawaiian Islands. Her work was so promising she is continuing the work as an independent study project while she finishing up her last undergraduate year. Future programs hope to include additional resources for undergraduates to work with graduate student mentors and researchers, opening doors to future graduate study.

Capacity Building Programs

Manager Climate Corps

Hawai‘i Island is home to a great diversity of cultures and strong community bonds, which are well represented within local professional organizations working to respond to the challenges of climate change. These networks are driven largely by in-person communication and collectively represent a significant capacity for adaptation to socioecological change. Beginning in 2015, the PI-CSC Manager Climate Corps (**MCC**) was developed at the University of Hawai‘i at Hilo (UHH) to support these local networks and their adaptive capacities by connecting local natural resource managers, researchers, cultural practitioners, policy professionals, community leaders, and graduate students on Hawai‘i Island through in-person networking events and collaborative research products. The MCC builds adaptive capacity locally by identifying existing professional networks and expanding them through manager-based research projects and collaborative forums that align with the Science Agenda themes. The four foundational elements of the MCC are: 1) supporting and developing long-term trust; 2) building upon existing in-person professional networks; 3) knowledge coproduction, which is collaboration between researchers and decision-makers in all aspects of a project; and 4) multiple ways of knowing, such as rational analytical capacities, experience, group norms and values, individual perceptions, instincts, emotions, and intuitions

> ***“For me, the take-home message from the camp was the importance of collaboration of people from different professional and cultural perspectives…building trust among this community of people who all want to protect Hawai‘i in the face of climate change…I gained a view into the world of collaboration, a world we need to welcome if we are going to find solutions.”***
> ***Anonymous Boot Camp attendee***

To initiate the iterative process of knowledge co-production, five graduate projects were developed between UHH faculty and resource managers in spring 2016, and a Climate Boot Camp was conducted in the fall (see below). Workshops and seminars on climate-related issues and management are also being developed for graduate students and early career professionals.

GIS@CIS

The University of Guam (UoG) is aiming to be the geospatial hub for Micronesia, supporting the use of Geographic Information Systems (GIS) in research and application development, with a special focus on building resilience to climate change. In partnership with the Center for Island Sustainability (CIS) at UoG, the PI-CSC has developed the GIS@CIS program to increase regional technical capacity at the university, the Guam Community College, and other interested community colleges in Micronesia by providing regular trainings, hosting geospatial data, and providing technical assistance through a geospatial coordinator (Ms. Maria Kottermair) and a climate science coordinator (Dr. Romina King). To work towards increased local technical capacity, GIS@CIS has partnered with the Geography Program and the Water & Environmental Research Institute (WERI) at UoG to develop a robust GIS program at the university with a strong, Micronesia-focused curriculum. The first undergraduate GIS course was offered in summer 2016, and the program hopes soon to offer both an undergraduate minor degree (expected 2020) and a major degree (expected 2024). For the graduate level, the existing GIS courses have been restructured, and a GIS Bootcamp was offered for graduate students during the spring of 2016.

To address local needs more directly, GIS@CIS conducted a regional survey of GIS users, producing an important geospatial framework for the US-Affiliated Pacific Islands, which was released as a technical report in January, 2017. With graduate and undergraduate student efforts, GIS@CIS has assembled several databases and inventories as usable resources for the region, and has worked to reach out to the regional community via pre-conference workshops, training sessions on a mobile GIS laboratory, technical support, and a GIS equipment "library" from which GPS receivers and a Trimble unit can be borrowed for on-site work.

Two recent projects have highlighted partnerships with federal agencies. With NOAA, DOI, and NASA Ames Laboratory, GIS@CIS helped create 3D maps of critical coral reef habitats. And the program partnered with Dr. James Randall, the UNESCO Co-chair in the Island Studies and Sustainability at the University of Prince Edward, for a proposed project to the Social Sciences and Humanities Research Council in Canada to conduct a global study comparing sustainable island futures of small island states and subnational island jurisdictions.

Symposia, Conference Forums, and Workshops

Over the past 5 years, the PI-CSC has hosted 4 symposia, 17 webinars, 4 conference forums (i.e., conference sessions organized by the PI-CSC), and approximately 3 workshops located across the Pacific Islands region. Below, we provide an overview of selected symposia, conference forums, and workshops that highlight the outcomes and impacts of these PI-CSC coordinated events.

2015 Climate Science Symposium

In February 2015, the PI-CSC, along with the PICCC, sponsored a Second Annual Climate Science Symposium, providing an opportunity for program scientists to share their progress and discuss future directions and opportunities for their research. Keynote speaker Dr. Virginia Burkett (Associate Director for Climate and Land Use Change, USGS, and IPCC Report Co-author) set the tone with her address focusing on climate change threats to vulnerable low-lying coasts and small islands. Oral and poster presentations followed for two days, describing Pacific cyclone activity, the climate of Guam over millennia, changes to low-flow streams in the

Hawaiian Islands, the movement of marine life on coral reefs, how managers might lessen impacts on endangered plants and animals, and the integration of local knowledge with scientific study. Highlights of the second day were two special panel sessions, one that discussed steps the state government is taking to lessen its dependence on fossil fuels and discussed the very real challenge of projected "climate refugees" to the global community, the other emphasizing the value of knowledge co-production by sharing how local communities guided research and produced valuable tools using the knowledge, experience, and collaboration of community members.

2017 Student Research Symposium

In April 2017, our PI-CSC Student Research Symposium in Guam illustrated the high caliber of students we are funding to do climate science as they work toward their bachelor's, master's, or PhD degrees. Fourteen students from UHM, UHH, and UoG represented nine distinct departments or schools and demonstrated multi-disciplinary perspectives on tackling climate issues. PI-CSC Director Dave Helweg launched the event with a summary of the goals of the Center, emphasizing its role to "link measurement with management" and deliver practical, objective science to resource managers. The students then showed how well they are putting that plan into practice. The presentations fell into three topical clusters: evaluation of groundwater resources, wastewater and the effects of rising seas, and a potpourri of other climate change concerns, all exploring different issues associated with climate change adaptation. The rest of the afternoon focused on soliciting useful advice for the students from a panel of climate professionals—from researchers to governmental managers--to help them in their eventual transitions to employment in "the real world." Advice ranged from coping with the slower pace of governmental work to coping with conflict, finding the right mentor, the benefits of multi-disciplinary studies, and the importance of following their own interests. From the poise of the students and the quality of their presentations, it is clear these future climate professionals are already headed down some amazing paths and are sure to shine as they advance in their careers.

Interactive Conference Forums

UHH members of the MCC have led several workshops and collaborative forums over the last three years. Their first event, in March 2015, brought people from across campus and east Hawai‘i together in an interactive workshop on climate communication, led by a trainer from the American Association for the Advancement of Science (AAAS) Communicating Science Program. The 36 attendees to the half-day workshop resulted in future conversations that helped form the MCC. After conducting extensive interviews with resource managers, UHH led a workshop in early 2016 in Hilo that brought together natural resource managers with the technical expertise of a wide range of interdisciplinary faculty at UHH. The needs assessment acted as a focus for round-table discussions to generate ideas for new research directions to support climate adaptation and resilience, locally. These discussions led to the development of five graduate student projects.

Throughout the rest of 2016 and into 2017, the MCC team led interactive forums at several events: the National Climate Science Centers' Early Career Training Symposium in Amherst, MA (sponsored by NE CSC in 11/16), the University of Guam's 2017 Island Sustainability Conference in Tumon (4/17), the National Adaptation Forum in St. Paul, MN (5/17), and the 2017 Hawai‘i Conservation Conference in Honolulu, HI (7/17). These forums employed a variety of formats (panel presentations, small-group breakouts, etc.) and organizational scales

(local, regional, national) but were all prime opportunities for managers, policy professionals, community leaders, graduate students, and researchers to participate together in the collaborative process of knowledge coproduction, uniting multiple knowledge forms and distinct worldviews to create broad professional networks. Beyond that, in-person forums such as these allow researchers and stakeholders to develop relationships, deepen understanding, and develop actionable products, enhancing the processes of adaptation and resilience development. And ultimately, the events provided the chance to display the MCC process as a successful example of development of a networking program.

Climate Boot Camp

UHH and the PI-CSC developed and hosted the first Climate Change Boot Camp at the picturesque Kioloka‘a Ranger Station in Ka‘ū, August 9-12, 2016. This event showcased collaborative research efforts driven by local natural resource managers across Hawai‘i Island in a new program entitled the UHH Manager Climate Corps (see above). The boot camp was an exploratory forum for the 57 cultural practitioners, managers, scientists, graduate students, and community leaders to come together in person and collectively address important issues they face. Three core themes explored during the boot camp were knowledge co-production, multiple ways of knowing (e.g., experience, culture, intellect, etc.), and place-based management. The boot camp took place outdoors amid native forests to stress experiential knowledge and a sense of place ecologically and culturally, while showcasing the five newly developed manager-led graduate projects with UHH's Tropical Conservation Biology and Environmental Science graduate program. Open forums such as this, uniting distinct worldviews in growing collaboration, offer a major step toward building long-term and diverse local professional networks, networks that can be an effective means for communities to adapt to significant socio-ecological change. A short film was produced of the boot camp and has been screened at several stakeholder-driven events, from Guam to Minnesota, as a field-based example of networking across professional disciplines, cultures, and worldviews.

Lessons learned and paths forward

In Hawai‘i and on other Pacific Islands, as is typical of insular settings, we work and interact with the same people in many different roles. The bonds of social capital play a role in professional work, resulting in a high level of interconnectedness of personal networks. The discussions and interactions between researchers, managers, decision makers, and other community members focused on adaptation to climate change, are heavily influenced by this highly interconnected dynamic. Focus on climate and adaptation has come to a head in the last 5 years across almost all economic, social, and research sectors in the country, as political and environmental changes have impacted lives and livelihoods. The PI-CSC was created in the midst of that change and has also been a part of the resultant discussions looking for strategies to move forward.

Early efforts at actionable science in the PI-CSC took place in the smaller partners of the consortium, UoG and UHH, where research was integrated into existing networks, and projects were better able to engage those groups to focus on adaptation with new partnerships and initiatives. Once Dave Helweg began as USGS Director, he made substantial efforts to focus the entire center on bringing stakeholder and science groups together. When joined by Darren Lerner, Sharon Ziegler-Chong, and John Peterson, all with strong backgrounds in research and stakeholder engagement, the actionable science efforts of the PI-CSC accelerated across the whole center. The early actionable science projects can serve as models for future endeavors that the current consortium can grow across its enterprise, pulling in the strong networks of Hawai‘i Sea Grant, Land Grant and Extension, Social Science Research Institute, as well as the Stakeholder Advisory Group and the recently activated Hawai‘i Climate Change Mitigation and Adaptation Committee. We are now well-positioned to grow our partnerships and be a key part of the dialogue in the region focused on strategies of adaptation and action.

The advantages of this emphasis on stakeholder engagement have been clear. One researcher described PI-CSC support of projects focused on stakeholder needs as a “rare kind of funding.” He noted that unlike other research funding through agencies such as the National Science Foundation, this support focuses on developing actionable science with an active expectation that stakeholders will play a key role in the work. This gives PI-CSC the potential to kick-start actionable research efforts by connecting managers with researchers, providing both groups the opportunity to work together and benefit from the partnerships. While research may take longer when co-production teams are involved, analysis of results can be richer and the results themselves can be more immediately and directly applied. With the future of the LCC network uncertain, the PI-CSC may have an expanding role in facilitating communication and engagement between research and management networks and across diverse professional cohorts to collectively integrate a wide range of viewpoints. This is particularly important in the Pacific region where so many players of different local, state, national, and international organizations are relevant to our communities’ response and adaptation to climate change.

Looking forward for the PI-CSC, the new 2018-2022 Science Agenda, which has just received SAC and NCCWSC approval, is based on extensive stakeholder meetings that identified the biggest needs in the region that the PI-CSC should tackle in its next phase. A companion Strategic Plan is being developed that will build on lessons learned from the first five years of the center and will identify an optimal path moving forward to implement the new Science Agenda and fulfill the mission and vision of the PI-CSC as well as the larger goals of the NCCWSC. Incorporated into this plan will be ways to take advantage of potential collaborations and leveraging opportunities with the numerous organizations in the Pacific Region mentioned

previously. In carrying out any plan, the center leadership will face important decisions of how best to balance investment of the center in scientific research, science transformation, capacity building, education at all levels, and other roles expected of an enterprise whose mission is to provide useful, useable science to support climate adaptation in our region.

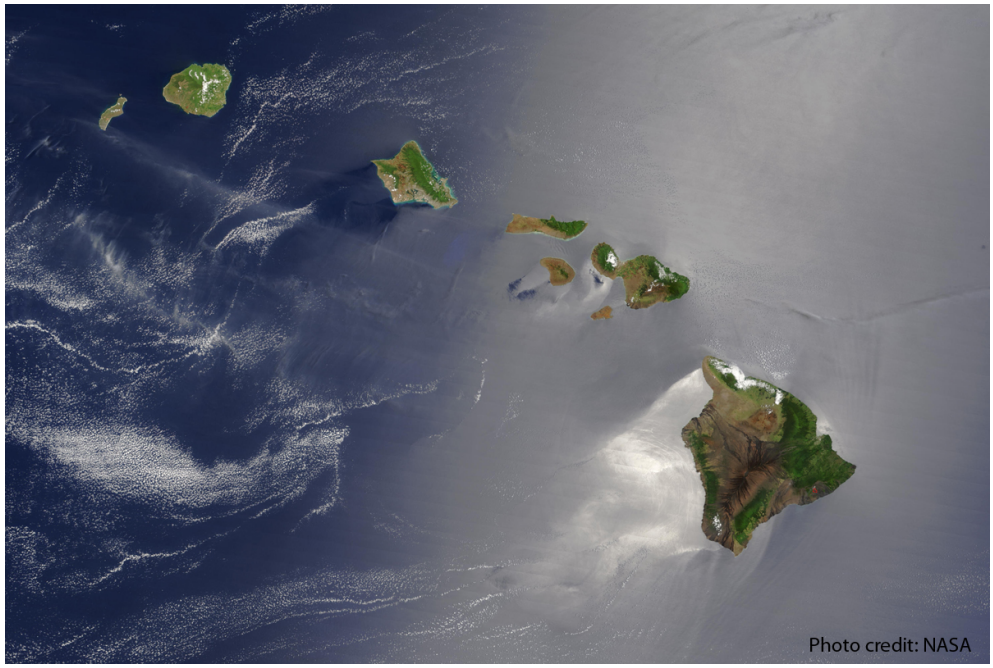


Photo credit: NASA

Appendices

Appendix 1. Center Operations Details

The table below highlights the current personnel working on PI-CSC activities. Personnel perform a variety of duties, including research project management, data management, communication efforts, education and capacity building, and other administrative and coordination duties. The only fully funded PI-CSC employee is the USGS Director. All other personnel are partially funded, with 0-65% FTE contributed by either PI-CSC federal or consortium funds, and they do not spend 100% of their time on PI-CSC-associated work. For example, the Communications Manager allocates anywhere from 25%-65% of her time working on PI-CSC communications efforts, and the Acting Science Manager provides 50% of her time on PI-CSC-related work. The Data Manager is also partially funded by the PI-CSC and the PICCC and performs duties for both centers.

Table A1: Current PI-CSC Personnel

Name	**Role**	**Affiliation**	**Start Date**
David Helweg	Director	USGS	Apr 2013
Darren Lerner	University Consortium Director	UHM	Aug 2016
John Peterson	University Consortium Lead	UoG	Apr 2013
Bruce Matthew	University Consortium Lead	UHH	Oct 2017
Sharon Ziegler-Chong	Program Coordinator	UHH	Feb 2013
Romina King	Climate Science Coordinator	UoG	**2013**
Rachel Lentz	Communications Specialist	UHM	Sept 2015
Bonnie Myers	Acting Science Manager	NCCWSC	July 2016
Patrick Grady	Data Manager	UHH/PICCC	2013
Maria Kottermair	GIS Coordinator	UoG	**2013**
Scott Laursen	Technical Project Specialist	UHH	2015

Table A2: PI-CSC budget for FY2012 through FY2016

Fiscal Year (FY)	**FY12**	**FY13**	**FY14**	**FY15**	**FY16**
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Federal Director	1,549,591	1,075,000	1,545,000	1,545,000	1,545,000
University Consortium					
UH Manoa	345,052	345,052	348,639	346,956	346,956
UH Hilo	300,349	300,349	265,285	283,283	283,283
University of Guam	83,008	83,008	83,000	83,008	83,008
TOTAL	2,278,000	1,803,409	2,241,924	2,258,247	2,258,247

Appendix 2: Other Project Summaries

Science Theme 1: Guidance for anticipated intermediate-term climate changes

Reconstructing historical climate patterns in Hawai'i using traditional knowledge and dendrology **Rosie Alegado**

In order to better complete the historical record of Hawai'i's climate variability especially due to El Niño/Southern Oscillation events, this project integrates human observation (Hawaiian language newspaper accounts), biological records (evidence of climate events through tree ring analysis), and weather data in the islands. The long-term goal is to use indigenous-based historical records to reconstruct Hawaiian regional climate beyond the instrumental records.

Developing high-resolution rainfall change scenarios for the Hawaiian Islands **Oliver Elison Timm**

The key goals of this study are 1) to understand how changes in the Earth's future climate system will affect the frequency and severity of extreme weather events in Hawai`i, 2) to support studies of the ecological impacts of climate change on native Hawaiian plants and animals and 3) to provide information needed by natural resource managers charged with preserving native biodiversity. To achieve these goals, this project will build on a previous project work to update climate change projections (using a technique called statistical downscaling) for Hawai`i. With collaboration from partners at the US Geological Survey (USGS) and the University of Hawai`i at Hilo, researchers will also assess species and ecosystem responses to potential climate variations, such as the recurrence and intensity of heat waves, droughts, and storms.

Future coral reef community projections of DOI-managed coastal assets in the Hawaiian Islands **Erik Franklin**

The conditions of coral reefs in the Hawaiian Islands are predicted to decline significantly from climate change over the next 100 years. To better prepare for the impacts of climate change on Hawaiian reefs, the research team uses a system of models to simulate ocean waves and circulation, rainfall and storm run-off, and coral reef community dynamics through the year 2100. These models will identify reef areas that are either vulnerable or resilient to the many stressors that the future may hold for reefs. The team's hope is that this work can identify areas that might benefit from management actions to minimize local stressors such as land-based pollution. Through a collaborative partnership with state and federal resource managers as part of the project, this research will directly provide scientific knowledge to support planning for climate disturbances and the interpretation of climate change science for the general public.

Measurement of ENSO-related climate variables and ecosystem responses in Hawai'i **Tom Giambelluca**

The objectives of this project are to 1) observe microclimate and ecosystem processes at sites near and above the forest line ecotone during the period from Fall 2014 through Summer 2015, 2) determine the response of ecosystem processes to climate variability within the study period, and 3) determine whether plant responses to climate variability and water stress vary along the cross-slope rainfall gradient. This study will provide crucial data, measured for the first time, on how ecophysiological characteristics of M. polymorpha vary in response to climate variability and how the response differs along the cross-slope gradient.

Traces in tree rings of climate variability in Hawai‘i and the tropical Pacific **Patrick Hart**

The main goal of this study is to build a tree ring chronology going back in time that represents the best annually resolved record of how climate has varied in Hawai‘i and across the Eastern Pacific. This information is of great importance to ongoing restoration projects and focuses on ecosystem elements in sub-alpine habitat that are of high biocultural significance but are greatly imperiled by climate change.

Epiphytes as an indicator of climate change **Scarlett Kettwich/Jon Price**

Epiphyte communities (the plants living on trees), as climate-sensitive plants, respond to changes in moisture and physical surroundings. This study aimed to determine whether the health of these plants can be used as an indicator of likely forest changes. Results suggest that moisture is key to epiphyte survival and that smaller species are more sensitive to a drying climate than larger species.

Projecting the frequency and impact of future coastal flooding and inundation events in the Pacific Islands **Phillip Thompson**

This project aims to quantify the effect of local factors and Pacific climate variability on the frequency of inundation events in centers of population and infrastructure in Pacific island communities. It will produce seasonal outlooks that project the number of incursions above a given level at a particular site in 3-6 month windows using seasonal outlooks, because inundation events tend to cluster seasonally based on coastline orientation, storm tracks, dominant swell direction, and tidal amplitude. These same principles will then be applied to quantify how often severe inundation seasons are likely to occur given longer term changes related to natural and anthropogenic climate change.

Cloud water interception in Hawai‘i: Mapping current and future exchange of water between clouds and vegetation in Hawai‘i’s mountains **Yuqing Wang**

Clouds often come in contact with vegetation (often named fogs) within a certain elevation range on Hawai‘i’s mountains. Propelled by strong winds, cloud droplets are driven onto the stems and leaves of plants where they are deposited. Some of the water that accumulates on the plants in this way drips to the ground, adding additional water over and above the water supplied by rainfall. This project aims to create a map for the complex spatial patterns of cloud water interception (CWI) in Hawai‘i. The map will be verified against measurements at five representative observational sites across the Hawaiian Islands. It will also assess the projected changes in the CWI patterns in Hawai‘i by the later 21st century under both weak and strong global warming scenarios.

Science Theme 2: Potential effects of changing climate on freshwater resources

Modelling the response of Hawai‘i streams to future rainfall conditions **Maoya Bassiouni/Steve Anthony**

The objectives of this study are to (1) estimate baseline and future low-flow characteristics of ungaged streams in Hawai`i, and (2) quantify changes in physical habitat for native stream fauna associated with projected changes in low flows. To accomplish these objectives, this study will (1) compute baseline low-flow duration discharges for gaged sites, (2) develop regional regression models to estimate low-flow duration discharges at ungaged sites for baseline conditions, and (3) evaluate the applicability of the regional regression models to estimate low-flow duration discharges for future conditions. The results of this study will provide critical information for managing Hawai`i's limited freshwater resources, and for understanding how climate change may impact ecosystems, agriculture, and communities that are entirely dependent on freshwater.

Groundwater percolation in northern Guam: Insights from Jinapsan Cave **Kaylyn Bautista/John Jenson**

The Northern Guam Lens Aquifer (NGLA), a freshwater lens within the island's limestone bedrock supplies 90% of Guam's fresh water. Rain water that escapes absorption by plants infiltrates the limestone, percolates down to the freshwater lens, and is ultimately pumped by wells to supply water to the island's population. Since the NGLA is Guam's sole source aquifer, understanding the hydrologic processes associated with the aquifer system is vital to protecting and managing this precious resource. The purpose of this project was to understand groundwater percolation through the vadose zone of the NGLA by studying flow in a natural cave system that serves as an underground observatory. Data collected over six years led to a general conceptual model of groundwater flow, distinguishing where flow is dominated by fissure versus matrix storage.

Predicting Hawai‘i water demand under climate change **Nathan DeMaagd/Michael Roberts**

There is great uncertainty about how climate change will affect future rainfall and aquifer recharge in Hawai‘i, but equally important is considering how climate will affect water demand. In most of the world, the largest uses of water (agriculture, landscapes, A/C cooling towers) depend on prevailing climatic conditions. Our project focuses on the effects of temperature on water consumption. We use weather station data to create high-resolution temperature maps that are merged with water-use data at the level of single residences or businesses. Results are then used to estimate detailed, non-linear relationships between water use and weather conditions for various consumer types. Ultimately, this may help inform policy makers about water resource needs under various climate change scenarios.

Investigating climate driven shifts in Staphylococcus aureus and MRSA for water resource and land management solutions **Louise Economy/Tracy Wiegner**

Staphylococcus aureus and methicillin-resistant *S. aureus* (MRSA) abundances are being quantified in association with rainfall and river discharge in Hilo Bay, Hawai‘i, to model how these pathogens vary in response to weather patterns. Bacteria abundance is also being determined in soils, sands, rivers, cesspools, and storm water within the Hilo watershed, to identify sources of the pathogens in recreational waters. Also, MRSA infection rates at the Hilo

Medical Center are being compared with the frequency of rainfall events, to assess if infection risk is greater during the wet season. These data will provide foundational information on how *S. aureus* and MRSA abundance may respond to a changing climate and help guide solutions to manage and mitigate the transport of such pathogens to coastal waters.

Changes in water flow through Hawaiian forests due to invasive species and changing rainfall patterns **Lucas Fortini**

Introduction and spread of invasive plants and animals in Hawaiian forests alters the water-use and soil characteristics of higher elevation upland ecosystems, which can have large impacts on downstream water users. The objective of this project is to understand how expanding invasive plant populations and changing rainfall patterns will impact water resources in the future. Project researchers are exploring the differences in key soil characteristics that control runoff and groundwater recharge in managed and relatively intact native mesic (moderate amounts of water) and wet forests and in similar invasive-dominated forests. Data will also be collected on the canopy and understory composition in the forests and on disturbances by invasive animals, like feral pigs.

The effects of climate change on high elevation ecosystems and freshwater resources in Hawai'i **Abby Frazier/Tom Giambelluca**

This ongoing project aims to assess the sensitivity of the upper limit of the cloud forest (forest line) and adjacent shrubland and grassland to El Niño-induced drought. Statewide trends since 1920 show drying across every Hawaiian island, particularly at the highest elevations during the dry season. High elevation, montane cloud forests ecosystems produce high watershed yields which support water resource needs downstream, making these vulnerable ecosystems extremely hydrologically important. Using remote-sensing satellite data, we can detect the responses of the forest and adjacent shrubland and grassland to climatic extremes, which will ultimately be important for future water resource planning and management as well as preservation of native ecosystems and habitats.

Cloud water interception in Hawai'i: Understanding the impact of fog on groundwater and ecosystems and future changes to these processes **Tom Giambelluca**

Clouds often come in contact with vegetation (often named fogs) within a certain elevation range on Hawai'i's mountains. Propelled by strong winds, cloud droplets are driven onto the stems and leaves of plants where they are deposited. Some of the water that accumulates on the plants in this way drips to the ground, adding additional water over and above the water supplied by rainfall. This project will make measurements of fog, wind, fog interception, soil moisture, and fog effects on plant water use and plant survival and will test a model to estimate CWI as a function of fog---water movement and vegetation characteristics.

Understanding the response of native and non-native forests to climate variability and change to support resource management in Hawai'i **Tom Giambelluca**

In this study, researchers will make use of existing scientific results and datasets on how climate variations affect native and non-native forest species, gather new data of this type, and combine that information with estimates of the expected changes in temperature, rainfall, and other variables to simulate the effects of future climate change on Hawai`i's native and non-native forests.

Aquifer cave data applied to tracking climatic trends in the western Pacific **John Jenson**

The caves and corals of Guam give important clues to past and present trends of the warm waters of the Indo-Pacific including the length and severity of El Niños and other dry and wet cycles. Their findings will help improve forecasting local and global climate as well as the onset, duration, and intensity of wet and dry periods and how these affect Guam's major aquifer, which supplies 80% of Guam's drinking water.

Effects of drought on soil moisture and water resources in Hawai'i **Alan Mair**

Estimates of the changes in water availability during periods of drought are critical to Hawai'i's water, forest, and wildfire managers and planners for developing adaptive management strategies. This study plans to address this information need with these specific objectives: (1) to estimate changes in soil moisture, evapo-transpiration, and groundwater recharge during periods of drought for current and projected climate conditions, and (2) to estimate the combined impact of drought and reduced fog drip on soil moisture, evapotranspiration, and groundwater recharge. The results from this study will be widely applicable to resource managers but will communicate particularly the potential impacts of climate change on water resources and the importance of fog drip in mitigating the impacts of drought.

Tracking climate variability through chloride concentration in municipal production well histories of the Yigo-Tumon basin, Northern Guam Lens Aquifer **Erin Miller/Nathen Habana**

As Guam undergoes increasing development, demand increases on its sole natural aquifer, the Northern Guam Lens Aquifer (NGLA), to support the growth. Excessive pumping, however, can lead to saltwater intrusion of the NGLA. Thus, understanding the balance of recharge rates and well production is critical for future freshwater availability and island progress. This project examines causes and influences on salinity in production wells, with an eye to how the variability of natural climate cycles (wet/dry seasons, ENSO) relate to freshwater recharge of wells. The results of the study will provide critical information for resource managers acting to maximize production while preserving water quality.

Stand level water-use in forests of contrasting rainfall regimes: Assessing the impacts of future drying on native Hawaiian ecosystems **Rebecca Ostertag**

This project will determine the extent, timing, and longevity of moisture effects on water use, water-use efficiency and plant growth in dry and wet forest. We are examining how much water forest trees use and their growth and mortality patterns in an established pair of forest inventory and dynamics research plots located in the Hawai'i Experimental Tropical Forest (HETF).

Science Theme 3: Anticipating and mitigating change in coastal and low-lying areas

Impact of climate change in loko iʻa (traditional Hawaiian fishponds) management I **Kamala Anthony/Steven Colbert**

On the east side of Hawaiʻi Island, there is a valuable coastal ecosystem where upwelling groundwater and marine seawater meet at the shoreline, creating brackish water habitats, which form the basis for loko iʻa or traditional fishponds. These habitats serve as a sustainable food source for coastal communities as well as a location for traditional cultural practices, and thus their environmental health is closely tied to the survival of many Hawaiian traditions. This study assesses the potential impacts of climate change on the loko iʻa along the eastern coastline of Hawaiʻi Island, particularly the potential of salt-water intrusion associated with sea level rise. In addition, this study will examine whether fishpond restoration is advantageous for mitigating environmental changes to brackish water ecosystems.

Observations of benthic ocean chemistry on two coral reefs in West Hawaiʻi **Steven Colbert**

This project investigates the levels of carbonate saturation (which is a measure of ocean acidification) in the ocean around coral reefs of Hawaiʻi Island. Data collected in this research will aid efforts charting present and future ocean acidification.

Developing a high-resolution seamless bathy-topo elevation model for Majuro, RMI **Jeffrey Danielson**

Low-lying atolls in the Pacific Ocean are extremely vulnerable to high tide events, storm surge, tsunamis, and sea-level rise. The Republic of the Marshall Islands (RMI), spread over 29 atolls, has a sizeable population threatened by these climate change-related events. Policy makers and planners, who are faced with decisions about how to prepare for the future, need scientific data and information about the vulnerability of RMI to potential climate change impacts. This study will collect topographic and bathymetric data to map out the overland and underwater formations that comprise the southern half of Majuro Atoll and develop a Digital Elevation Model of the area. These maps will then be used to calculate and visualize potential effects and damage from wave inundation and other coastal hazards.

Assessing the vulnerability of coastal wastewater infrastructure to climate change **Theresa Dean/Daniele Spirandelli**

On-site sewage disposal systems are an efficient and economical means of wastewater disposal in less densely populated communities. However, these systems can fail, due to improper installation, poor maintenance, or siting, and cause water contamination. Coastal inundation contributes to nonpoint-source pollution, by flooding absorption fields and cesspools, which can threaten the long-term health of communities and coastal ecosystems. The goal of this research is to examine the current laws and policies in Hawaiʻi that manage on-site wastewater systems and evaluate how these regulations could be adapted to improve resilience to climate change stressors. It will also explore whether proper management requires better coordination between site assessments and watershed-scale, land-use plans.

Empirical projection of future shoreline position and inundation due to sea level rise **Chip Fletcher**

Recent maps of historical shoreline change and vulnerability to flooding due to Sea Level Rise (SLR) are improving understanding of shoreline variability and climate change. This study will develop an easily transferable methodology and planning tool that can form the basis of a climate-ready strategy of beach management. Using data and maps produced by the project, decision-makers will be able to prioritize beach conservation efforts, screen permit applications, identify potential future impacts, and increase the resiliency of the current management network of decision-making. By planning for future beach response to SLR, this project will allow for the existing decision-making system to evolve new strategies focused on adaptation to future SLR.

Simulating and projecting future impacts of sea level rise on Majuro Atoll **Chip Fletcher**

The Republic of the Marshall Islands (RMI) covers 29 atolls with more than half its population living in the capital on Majuro Atoll. High-end projections of sea level rise (SLR) exceed the average elevation of these low reef islands, threatening RMI's very existence. The past decade has already seen life become increasingly untenable, prompting migration of many to the US. This project will develop and use a digital elevation model (DEM), combined with new topographic and bathymetric information, of Majuro Atoll to model SLR and create flooding simulations to help identify vulnerable areas. Project deliverables, and training on their interpretation and application, will be distributed to Marshallese government agencies to aid in development of appropriate mitigation and adaptation plans and strategies.

Evaluating coastal erosion rates on Hawai'i Island to inform setbacks **Rose Hart/Ryan Perroy**

Despite its vast coastline and unique coastal ecosystems, Hawai'i Island has had no comprehensive shoreline assessment of coastal vulnerabilities, nor any systematic monitoring of long-term shoreline change rates. Consequently, Hawai'i Island is in a weak position for adapting to potential impacts of sea-level rise (SLR). This project seeks to quantify historic and current coastal erosion rates for selected priority areas on Hawai'i Island, using historic photographs and new coastal imagery (via drone). These data will be merged with SLR projections and other geospatial layers to estimate future impacts on Hawai'i, and will ultimately provide a visualization tool for stakeholders to understand local SLR impacts and consider necessary adaptations.

Impact of climate change in loko i'a (traditional Hawaiian fishponds) management II **Cherie Kauahi/Steven Colbert**

Groundwater springs are complex systems, but are also fundamental to providing nutrients to coastal environments. In Hawai'i, groundwater plays a significant role in the functioning and sustainability of coastal loko i'a (fishponds), so understanding the interactions between groundwater and seawater in these environments is important to their persistence. The focus of this project is to identify how groundwater flow changes over different timescales at three fishponds in Keaukaha, Hawai'i. The work will also examine the socio-ecosystems of place by soliciting perspectives from individuals with experience-based relationships to these loko i'a. This research will provide fishponds managers details of groundwater flow changes through time that can be used to enhance loko i'a practices and sustainability.

In the midst of warming oceans, what drives thermal resiliency in Hawai'i's coral reefs? **Shayle Matsuda/Ruth Gates**

Corals are the bedrock of our marine ecosystems and provide critical economic, coastal, cultural, and ecological services to the entire island community. However, corals are particularly susceptible to stressors of a changing climate. Algal bacteria, in symbiosis with coral, provide nutrients (through photosynthesis) to the colony, but are tolerated only under certain conditions. When temperatures rise too high for optimal coral function, the algae are expelled, causing bleaching and potential death. Fortunately, not all corals respond to stress in the same way, with some species less likely to bleach than others. Our project aims to identify the biological characteristics that drive thermal tolerance in several common coral species. This will ultimately help us manage these important resources better for the future.

Valuing climate change impacts on coral reef ecosystem services **Kirsten Oleson**

To better support resilient coral reef ecosystems in Hawai'i, project researchers propose to provide a dynamic, ecosystem-based decision-support tool for decision makers, non-profits, and community alliances. Regional research and management principles have shifted toward an ecosystem-based approach, but the required decision-support tools remain scarce. The team will develop a pilot decision-support tool for coral reef management that can map, assess, value, and simulate changes in ecosystem service flows under alternative GCC scenarios and adaptation strategies. Ecosystem services are the benefit that humans derive from natural systems, such as coral reefs.

Understanding future sediment transport to coastal waters and coral reef ecosystems **Kirsten Oleson**

This project aims to construct a more authoritative sediment budget for West Maui watersheds, and incorporate the information into modeling. Surveying legacy deposits of in fine-grained fill terraces along four representative streams that produced sediment plumes in 2014, instrumenting four sites on these streams to estimate bank-erosion rates of fine sediments and translate findings into Bayesian models to estimate erosion. These activities will produce a sediment budget that allows users to focus mitigation efforts on the sources of sediment they expect be most concerned about.

Coral reef resilience to climate change in the commonwealth of the Northern Mariana Islands **Laurie Raymundo**

Reducing coral reef vulnerability to climate change requires that managers understand and support the natural resilience of coral reefs. We define coral reef resilience as: the capacity of a reef to resist and/or recover from disturbance given its probable exposure regime, and maintain provision of ecosystem goods and services. This project represents globally relevant progress in the novel approach of using resilience assessments to inform management decision-making. Uniquely, the project was undertaken highly collaboratively with local managers in CNMI that are using the results to inform resilience-based management and management planning.

Assessing the sustainability of culturally important marine sites in Guam and CNMI **Laurie Raymundo**

This project will produce climate projections for coastal marine areas in Micronesia and reports that describe the outlook of culturally important marine sites. The climate projections and maps will show what climate science currently suggests the future holds for our sites Micronesia if we continue to use fossil fuels aggressively. The outlook reports will describe pressures in these focus areas as well as current ecosystem state, and will forecast the sustainability of the sites under climate change scenarios and current and alternate management regimes.

Baseline assessment of coral-associated microbial communities **Emilia Sogin/Craig Nelson**

Microbial symbiotic partners facilitate biochemical reactions that contribute to the health of their host, thus improving individual survival and function. These microbial communities are essential components of coral reefs, recycling organic molecules to mobilize nutrients in depleted waters. This project identifies the presence and abundance of bacteria associated with nine common coral species found in the waters off French Polynesia. Results indicate a strong connection between coral species and their bacterial assemblages, suggesting the microbial communities are host specific. Since shifts in climatic and environmental conditions likely alter microbial community function, such future ecological changes may cause different coral hosts to experience varied physiological performance.

Coral adaptation and acclimatization to global change: Resilience to hotter, more acidic oceans **Rob Toonen**

The release of anthropogenic CO_2 to the environment is leading to ocean acidification with potentially severe repercussions for coral reefs and society. Hawai‘i annually derives an estimated $364 million directly from coral reefs, in addition to other benefits, like shoreline protection. Building on our previous research, we seek to understand the basis for coral reef resilience and to provide improved projections of how climate change and ocean acidification are likely to impact Hawaiian coral reefs. We also plan to examine the potential for corals to adapt or acclimatize to future conditions. The project results will inform resource managers about effective and alternate strategies for management in the face of climate change.

Multi-year sea level predictions for the Pacific Ocean **Matthew Widlansky/Axel Timmermann**

This research on sea level rise forecasts will focus on Pacific islands and coastlines, extend time scales to up to a decade, and assess the accuracy of these forecasts. The data made available will become the input for regional-scale assessments to provide a sea level rise prediction system for the Pacific.

Science Theme 4: Forecasting sustainability for resource management and planning

Predicting the effects of climate change: Ecosystem drivers in the tropical subalpine shrubland **Alison Ainsworth/Don Drake**

Tropical mountains are thought to contain many habitat specialist species adapted to harsh environmental conditions. These species may be especially vulnerable to rapidly shifting climates. For this project, we assessed habitat specialization for 170 species on three Hawaiian Islands, and found that many specialists that were identified had small geographical ranges and occurred in climatically-challenging, high-elevation sites. More endemic Hawaiian plant species were found to be specialists than either indigenous or non-native plants.

Archipelago-wide demography of Hawai'i's most abundant, but declining, native tree, Metrosideros polymorpha **Kasey Barton**

As climate change threatens natural ecosystems, much of conservation biology works to minimize effects for the rarest species. Yet common species contribute disproportionately to ecosystem function, so declines in their abundance and distribution have broad ramifications for other species. This study focuses on the health of the dominant tree species across the Hawaiian Islands, *Metrosideros polymorpha* (ʻōhiʻa lehua), which has experienced a dramatic shift in its abundance over the past several decades. ʻŌhiʻa population data have been collected from 37 sites that span five islands and gradients of substrate age, elevation, precipitation, and habitat degradation. Results will shed light on predictions for future species distributions under climate change conditions.

Understanding the effect of climate change on the migration of Marshallese Islanders **Maxine Burkett**

The Republic of the Marshall Islands (RMI) is acutely vulnerable to sea-level rise, the associated intrusion of saltwater into crucial freshwater supplies, and contrarily, to persistent drought. Many Marshallese communities are already experiencing these changes and are migrating to seek alternative means of living. In an effort to aid decision makers at local and state levels considering policies related to migration, this project will examine the linkage between patterns of human migration and climate events. The researchers will examine migration trends and motivations, characterize changes that have taken place to local lands and ecosystems in the RMI, and use projections of climate change to understand which islands and communities may be at highest risk in the future.

Improving Culturally Relevant Educational Resources in Lesson Plans on Climate Science in Guam **CJ Flores-Hughes/ Romina King**

With impacts of climate variability becoming more visible across the Pacific Islands, many teachers want to bring that information into the classroom in an approachable way, but are challenged by lack of time and resources to create appropriate materials. To help students learn about Guam's climate science through a Pacific Islands lens, this project will develop culturally-relevant, age-appropriate climate science lesson plans for use by 9th grade geography teachers in Guam. The plans will be complemented by locally authored resources, aligned with state standards, and ultimately will be accessible online.

Establishing climate change vulnerability rankings for Hawaiian native plants **Lucas Fortini**

In collaboration with research and management partners from federal, state and non-profit organizations, project researchers have devised a flexible species vulnerability approach that can be easily updated with improved data and thus better fits the Pacific reality of often limited and uncertain information. Recently the completion of their first species vulnerability assessment showed that the researchers can use their novel model approach to assess the vulnerability of each individual native Hawaiian plant species to climate change (1086 species). However, given some shortcomings of the original approach the team proposes to make substantial expansion and improvements in their assessment efforts to comprehensively consider the full range of species responses to climate change and thus fill a critical knowledge gap defined by natural resource scientists and managers in the region.

"Vegetative Guide & Dashboard" Relating atoll agroforestry recommendations to predicted climate and sea level conditions in the Marshall Islands **Maria Haws**

A first step towards addressing the vulnerability of agriculture and agroforestry is to provide information in accessible, real time data products. Hence a "dashboard" will be developed that will provide a variety of relevant data sources to users, particularly extension agents, government personnel and educators that support the agriculture and forestry sectors. Additionally, the project will provide web-based access to critical information such as environmental tolerances of various crops, agricultural practices, modern and traditional uses for individual crops, nutritional values and other information that may be useful. The expected outcome is that Pacific Island users will have improved access to information that will enhance their ability to support and engage in agriculture and forestry activities to improve food security and overall community resilience to climate change impacts.

Developing resilience for small businesses affected by climate change **Marcel Higgs/Romina King**

With small island communities seeing impacts of climate change on people's livelihoods, an environmental issue has become a social and economic one. Most of the companies in Guam fit the US Small Business Association's definition of a "small business" (<500 employees). Thus from an economic perspective, it becomes important to understand how climate change impacts are increasing the costs and risks to small business in Guam. This study will determine the readiness of Guam's small businesses to cope with climate change impacts and through workshops bring appropriate help to build community resilience.

Assessing viability of the Haleakalā silversword to uncover the effects of climate change on Hawai'i's high-elevation ecosystems **Paul Krushelnycky**

The Haleakala silversword plant forms the foundation of a diverse alpine community, and its behavior likely reflects wider ecological responses to climate. This species is already exhibiting patterns of mortality related to climate-driven movement towards higher altitudes. This project aims to understand patterns and causes of recent declines in the Haleakala silversword population that are associated with decreasing precipitation, increasing temperature, and related climate changes in Hawai`i's high-elevation ecosystems. Building on extensive research and datasets, this study will collect the demographic and climate data needed to construct a robust population model for the silversword and make future population projections under various climate scenarios. In addition, the project will conduct a range of seedling drought tolerance

experiments to clarify causes of recent widespread mortality in the species, and determine methods most likely to lead to restoration success.

Assessing the potential effects of climate change on vegetation in Hawai'i Volcanoes National Park **Jim Jacobi**

Two major driving forces of climate change are temperature and precipitation. In Hawai`i, temperatures are expected to increase and precipitation decrease, which are likely to result in an increased frequency and intensity of droughts through the twenty-first century. These climate changes have potentially large impacts on Hawaiian plants and animals. Managers at Hawai`i Volcanoes National Park want to know how climate change may shift plant distributions, especially in the highly managed Special Ecological Areas (SEAs), focal sites to manage rare and endangered plants. Results from this research will inform managers as to how vegetation types will migrate across the Park, and if species can successfully establish in more suitable sites.

Forecasting climate change impacts on coastal ecosystem services in Hawai'i through integration of ecological and social participatory models **Christopher Lepczyk/Kirsten Oleson**

Climate and land use/cover changes are expected to have significant impacts on freshwater resources. Thus, we aim to understand how stakeholders perceive and value freshwater, how perceptions differ between stakeholder groups, and how future environmental and policy changes will affect the stakeholder groups. We hypothesize that ecosystem services-based integrated modeling will increase the adaptive capacity of decision-makers. Our approach will enhance managers' understanding of the potential impacts that global climate change, regional land use/cover change, and management/policy response will have on the coupled hydrological-ecological system, as well as the ecosystem goods and services different stakeholders value.

Can albizia mulch be used on agricultural land to replace fertilizer, improve agroecosystem functioning, and provide climate change mitigation and resilience? **Joanna Norton/Rebecca Ostertag**

This project will investigate the potential benefits of composted albizia (*Falcataria moluccana*) mulch applied to agricultural land in East Hawai'i Island. The biomass from this fast-growing, nitrogen-fixing tree contains a large amount of carbon and nitrogen. A management approach that takes unwanted biomass from albizia trees and applies it to cropland could yield a net environmental and/or economic benefit compared with status quo farming practices, while stimulating albizia removal efforts. If this approach is found to be economically viable, climate change mitigation and/or resilience could be a byproduct of agricultural activities.

Modeling climate-driven changes to dominant vegetation in the Hawaiian Islands **Jon Price**

Species distribution modeling (SDM) is an increasingly important tool to address conservation biology and global change issues. SDMs provide critical information on biological refuges and potential future shifts in species ranges. In addition, climate changes could alter not only range, but abundance and capacity to persist. Whereas explicit spatial habitat models typically project occurrence, this project generates species models of abundance projected in response to environmental predictors.

Changing Hawaiian seascapes and their management implications **Noe Puniwai**

In Hawai`i, there is an emphasis on studying both human and ecological systems simultaneously to ensure effective management while recognizing the intercultural differences among the many ocean users. Biophysical values that describe the environment are readily available from insitu data sources such as wave buoys, stream, rainfall and wind gauges. These same values are monitored by ocean communities through their daily interactions along the seashore and in the ocean. Understanding how these resources have changed in the past can assist in forecasting resilience, adaptability and steadystate conditions. By interacting and acknowledging the knowledge that ocean communities have regarding these resources, we are able to not only understand the implications of climate variability on coastal areas but begin a dialogue with the resource users that may lead to a more engaged and resilient community in the future.

Vulnerability of Hawaiian forest birds to climate change **Mike Samuel**

Key objectives of this research will be to 1) predict changes in avian malaria across space and time as a result of anticipated climate change, 2) evaluate the potential for bird species extinctions, 3) research and consider birds' genetic adaptation to malaria, and 4) assess the costs and effectiveness of conservation strategies to mitigate impacts on bird populations. This project will provide the first quantitative assessment of the long-term impact of climate change on bird malaria distribution and on Hawai`i's unique forest birds, and provide a crucial tool to adaptively manage recovery and promote disease resistance among avian populations.

Other

The Pacific Islands Regional Climate Assessment (PIRCA) Sustained Assessment & Research **Victoria Keener**

Natural resource managers in sectors such as freshwater, coastal inundation and hazard response, and marine and terrestrial ecosystems need frequently updated summaries of regional and local climate trends, projections, and impacts to better include future climate in their planning strategies. Managers also desire translation of technical climate variables into sectorally relevant impacts and subsequent action and policy responses. This project will deliver an updated version of the Pacific Islands Regional Climate Assessment (PIRCA) produced for the 2014 US National Climate Assessment (NCA), a collaboration of several regional climate research programs including the Pacific RISA, the PICCC, the NOAA RCSD, and the University of Hawai‘i East-West Center.

Building capacity for coordination of strategic science research in the US-Affliliated Pacific Islands **John Peterson**

Challenges to Pacific Islands in the face of climate change are innumerable, including sea level rise, erosion, saltwater intrusion, flooding, droughts, and coral bleaching. These, in turn, affect food and water security, infrastructure, and the health of humans and ecosystems. With limited resources on hand, island decision makers need current and detailed information to effectively plan and ensure sustainable communities and healthy environments. For this project, the University of Guam Center for Island Sustainability is working with partners in the US-Affiliated Pacific Islands (USAPI) to define potential impacts of climate change on natural, physical, and cultural resources, and provide needed regional geospatial data and products, as well as technical assistance and training, to the USAPI of Micronesia.

Appendix 3: Publications

Publication year: 2017

Elison Timm O. Future warming rates over the Hawaiian Islands based on elevation-dependent scaling factors. Int. J. Climatol. *in review*

Frazier AG, Giambelluca TW. 2017. Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. Int. J. Climatol. **37**(5): 2522-2531. doi: 10.1002/joc.4862.

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Publication year: 2016

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