Tracking Climate Change in Hawai'i: Status and Prospects

Final Report

Summary and Recommendations from a Workshop sponsored by the Hawai'i Cooperative Studies Unit and the USGS Pacific Islands Ecosystem Research Center, in collaboration with the Pacific Islands Climate Change Cooperative, held in Honolulu, HI, June 8-9, 2015

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August 31, 2015

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Acknowledgments

This project is conducted for the Hawai'i Cooperative Studies Unit and the USGS Pacific Islands Ecosystem Research Center, in collaboration with the USFWS Pacific Islands Climate Change Cooperative, per Agreement with RCUH (P.O. #Z10082822). We especially thank Dr. Jeff Burgett, PICCC Science Coordinator, for his assistance and guidance. Elizabeth Kent ably served as Facilitator for the workshop. Dr. Ryan Longman provided valuable assistance. In addition, we thank the staff at PICCC and the USGS Pacific Islands Climate Science Center, all workshop participants, and Dr. Tom Giambelluca for helpful discussions.

Executive Summary

The goal of the project, *Tracking Climate Change in Hawai'i: Status and Prospects*, is to help initiate the development and implementation of a Climate Change Monitoring Network (CCMN) for Hawai'i. There is a recognized need for information and improved understanding of the effects of climate change on terrestrial ecosystems of Hawai'i—yet no such network is in place that addresses that need. Point Blue Conservation Science (Point Blue) has led this project, guided by the Pacific Climate Change Cooperative (PICCC) with funding and assistance by the US Geological Survey (USGS) and the Hawai'i Cooperative Studies Unit (HCSU). A two-day expert workshop was held in Honolulu on June 8th and 9th, 2015 to identify the important features of a CCMN for Hawai'i and to make recommendations regarding steps necessary to implement such a network.

In preparation for the workshop, Point Blue created and distributed two documents. The Phase 1 Report summarized existing monitoring programs in Hawai'i that would be potentially useful for a CCMN and characterized important features of existing monitoring data sets. As part of their evaluation, the authors identified promising monitoring elements that could form the core of a CCMN. The Phase 2 Report evaluated the current monitoring efforts with respect to the attributes of a successful CCMN.

In the workshop the following seven principles were identified as critical to a successful CCMN:

1. **Comparability and compatibility of data** collected at different locations and by various investigators, including the need for standardization of protocols and data processing.
2. **Integration** of monitoring efforts. This includes co-location of monitoring stations in a way that increases understanding of patterns.
3. Emphasis on the **value and accessibility of information**, including specific products resulting from the integration and analysis of data.
4. **Strategic spatial expansion** of existing monitoring to improve coverage, geographically, and with respect to human-influenced habitats.
5. **Increased temporal coverage** of biological monitoring to detect changes in trends and the influence of extreme events.
6. **Development of a strategic plan** that targets specific audiences and uses for CCMN products.
7. Developing a funding strategy that provides a compelling case for establishing and maintaining the network, resulting in **stable, long-term funding.**

Workshop participants identified twelve monitoring elements to form the framework for the envisioned CCMN; each element consists of a monitored variable or group of variables. Six elements (Tier 1) were identified as critical: air temperature, rainfall, wind, stream flow, landbird abundance, and vegetation. These elements were considered to have the highest priority in the strategic implementation of the CCMN. The second group of six elements (Tier 2) were considered desirable and next in priority. These included: relative humidity, solar radiation, soil moisture, ground water levels, water quality, and stream biota. We stress that both Tier 1 and Tier 2 monitoring elements play important roles in the envisioned CCMN, but in establishing new monitoring stations, priority would be placed on Tier 1 elements.

Air temperature and rainfall monitoring stations currently exhibit the most spatially extensive coverage and temporally intensive coverage on the main islands. Thus these two climate monitoring elements form the "backbone" of the entire CCMN, and the other ten elements build on this backbone.

An important organizing feature of the proposed CCMN is the grouping of established and new monitoring stations into monitoring transects that will span important gradients of climate, elevation, human land-use, and non-native species influence. By focusing on key gradients, the monitoring transect allows for better efficiency and interpretability. The workshop identified a goal of at least one transect on the leeward and windward sides of each main island. Monitoring transects with Tiers 1 and 2 monitoring elements will enhance the interpretability of current monitoring stations, enabling a robust framework for the CCMN.

Workshop participants identified key next steps: 1) Establishment of a Steering Committee with members from multiple agencies and organizations. One of its important functions is strategic planning for the CCMN, including communication of short-term outcomes and longer-term benefits of the network to potential funders. 2) Assembly of a Technical Assistance Team. Important functions include identifying and prioritizing optimal sites for the CCMN and developing standardized protocols for each of the monitoring elements. 3) Hiring a systems analyst/data manager. Workshop participants agreed that "a functional network will require resources to support centralized data management." 4) Completion of a funding proposal jointly developed by the Steering Committee and the Technical Assistance Team to support medium- and long-term activities. The proposal will be structured so the smaller pieces of the network could be funded individually and then combined at a later date with other CCMN elements as funding becomes available. The proposal will emphasize short-term and long-term benefits, which include tracking impacts to people (health, fire, flooding, agricultural impacts, etc.) as well as to native ecosystems.

At the close of the workshop participants were excited and motivated to move forward on creating a climate change monitoring network in Hawai'i, recognizing the challenges that lie ahead, but also with a clear picture of the value and feasibility of such an undertaking.

Introduction and Background

The goal of the project, *Tracking Climate Change in Hawai'i: Status and Prospects*, is to help initiate the development and, ultimately, the implementation of a Climate Change Monitoring Network (CCMN) for Hawai'i. Since October 2014, Point Blue Conservation Science (Point Blue, henceforth) has led this project, guided by the Pacific Climate Change Cooperative (PICCC) with funding and assistance by the USGS and the Hawai'i Cooperative Studies Unit (HCSU).

As part of this project, a group of experts were assembled with expertise and interest regarding the development, implementation, and utility of a CCMN for Hawai'i. A 2-day workshop was conducted in Honolulu, HI, June 8th and 9th, 2015 (Appendix 1).

The project is motivated by the recognized need for information and improved understanding of the effects of climate change on terrestrial ecosystems of Hawai'i—yet, at present, there is no climate change monitoring network in place that addresses that need. The objectives of the workshop were multiple. Participants addressed the following questions:

- What would an effective climate change monitoring network (CCMN) look like? What variables would be monitored, how would they be distributed over space and time, and how would they be integrated?
- What is the vision and the compelling motivation to implement a CCMN? How can the value of a CCMN be maximized, both for the scientific and management communities, as well as the general public?
- What are the necessary steps to be undertaken in order to successfully implement a CCMN?

This document summarizes the findings and recommendations of the workshop and suggests next steps. This report will also facilitate discussion among participants and potential partners as a CCMN takes shape.

In preparation for the workshop, Point Blue completed two preliminary phases. In Phase 1, Dr. Greg Kudray led the Point Blue effort to summarize ongoing and historic monitoring programs for the main islands of Hawai'i that are most relevant to a CCMN and could provide the basis for implementation of such a network. The scope included only terrestrial and aquatic (freshwater) ecosystems. Attention was focused on specific monitoring variables, i.e., what was monitored, where, over what time period, how likely was the monitoring to be continued, and how relevant was the monitoring to climate change? The review and evaluation were summarized in a report, which we refer to as Point Blue Phase 1 Report (Kudray et al. 2014).

The Phase 1 Report was disseminated to workshop participants along with a second report, which we refer to as Point Blue Phase 2 Report (Nur et al. 2015). That Report explored the needs for a climate change monitoring network and evaluated current monitoring efforts, with regard to their adequacy from a statistical and ecological perspective. That is, emphasis was on the necessary characteristics of a network, as opposed to characteristics of individual monitoring programs. Point Blue Phase 2 Report provided specific recommendations, to provide a basis for discussion by workshop participants.

The Need for a Climate Change Monitoring Network for Hawai'i

The objective of this Final Report is to summarize workshop recommendations, and to suggest a path for CCMN implementation. But before reviewing the workshop, it is helpful to address the question: Why does Hawai'i need a climate change monitoring network? Here we highlight a few of the needs and potential benefits of such a network.

Climate change is now evident in Hawai'i (Giambelluca et al. 2008) and model projections demonstrate that large changes can be expected (Elison Timm et al. 2015), but these projections are characterized by high uncertainty and, in many cases, divergence of predictions depending on assumptions or modeling approach used. These climate changes are expected to have strong impacts on biota (e.g., Fortini et al. 2013, Liao et al. 2015). Climate change impacts on ecosystems will be pervasive, but are also expected to differ spatially, among and within islands (Elison Timm et al. 2015). However, there is no extensive network in place to track changes that occur in key climate variables, their effects on ecosystems, or on the services ecosystems provide to the people of Hawai'i. Current monitoring programs were designed for other purposes, are often tailored to local conditions, and can be limited in scope. As a result it is difficult to understand changes that occur or to draw conclusions across large spatial scales and over time.

As stated by Parmesan and Yohe (2003),

> "Existing research programs are well suited to the analysis of short-term, place-based, and high-intensity effects, but many changes forecast for this century are long term, geographically widespread, and low intensity. Precisely because their impact will continue for a long time and will be felt across broad areas, however, such changes may have an enormous cumulative impact."

A successful CCMN does more than simply chronicle change over time - it provides insight into causes of change and enables forecasting of future changes. For example, are observed changes in ecosystems due to climate change or other drivers, such as human land-use, or to a combination of factors? Climate change effects cannot be studied in isolation, rather there will be an interaction between climate change and other stressors (land-use change, disease, non-native species, etc.). A network that can provide insight into ecosystem effects of climate change and their causes will provide a robust basis for informed management and policy. But achieving this goal will require the integrated study of climate, hydrology, and biological populations in a consistent manner across large spatial scales and multiple time scales, important features of a CCMN.

The establishment of a CCMN in Hawai'i would directly benefit educators, the research community, and managers of the State's critical natural resources. The compiled and real-time outputs of a CCMN would be available online, providing an important educational resource by linking students to processes that impact their lives and communities. Researchers would benefit by having centralized, reliable data to calibrate, validate, and improve modeling of climate and ecosystem responses. Future studies of natural systems on the landscape could be referenced to the measured context of changes in key variables. Natural resource managers are now challenged to make decisions within a new paradigm of ongoing, and accelerating, change in environmental conditions. A CCMN would provide the ability to detect change while there is still time to react and modify management strategies. This increase in reaction time would allow adaptive management, and adaptive monitoring, which is critical to efficient and effective management of resources in an era of global change. Finally, management actions intended to reduce climate impacts on sensitive species can only be tested for effectiveness when both the species, and the climate, are adequately monitored.

The need for improved understanding of climate change effects in Hawai'i was highlighted by Keener et al. (2012) in *Climate Change and Pacific Islands: Indicators and Impacts*. The authors point out both the needs and a key constraint by stating,

> "Further research is needed to strengthen scientific understanding of climate change and its impacts and to inform adaption strategies…The current lack of funding for maintaining existing monitoring networks and for developing more comprehensive and integrated observation networks across the vast region needs to be addressed urgently."

Brief Summary of Findings from Phase 1 and Phase 2 Reports

Details on Point Blue's work leading up to the workshop are described in the Point Blue Phase 1 and Phase 2 Reports. Here we briefly summarize the findings from the two reports.

A large number of monitoring programs of potential relevance are conducted throughout the islands of Hawai'i by different organizations and investigators. However, the vast majority of these programs were not designed to address climate change and its effects. The Phase 1 Report considered each monitoring "element" separately. Note, in this Report, we follow the usage in Reports 1 and 2 and refer to landbird monitoring, for example, as one monitoring element. Within a monitoring element there will likely be multiple variables that are monitored (e.g., bird abundance and bird species richness).

The Phase 1 Report drew attention to a subset of monitoring elements that appeared to be promising for a CCMN. Of these elements, "weather" provided an especially strong basis for a CCMN because it measures basic physical data on climate factors, even though spatial coverage was in some cases patchy (but often intensive in time). Other priority monitoring elements identified were birds, vegetation, and "hydrology" (which included stream flow and stream biota). The workshop subsequently refined the list of priority monitoring elements for a Hawai'i CCMN (see below).

The Point Blue Phase 2 Report focused on how to design a robust climate change monitoring network. The authors summarized the features of two extant monitoring networks, which are designed in part to address effects of climate change: The United Kingdom's Environmental Change Network (ECN) and the National Ecological Observatory Network (NEON). Using these two networks as a basis, the Point Blue Phase 2 Report identified ten characteristics of an idealized climate change monitoring network:

1. Adequately samples major climate and environmental gradients across the area of interest.
2. Co-locates monitoring of physical and biological phenomenon to allow integration.
3. Ensures data comparability and ease of integration across monitoring locations.
4. Includes monitoring for a representative suite of physical and biological variables that are meaningful to stakeholders.
5. Has monitoring frequent enough to be able to detect change in physical and biological components at multiple time scales.
6. Monitoring is conducted at multiple spatial scales, allowing temporal trends to be assessed across spatial gradients of interest.
7. Sustains an intensity and frequency of monitoring that is not cost prohibitive.
8. Has a long-term funding commitment or a process for ensuring the stability of funding.
9. Manages data curation, discovery and delivery for open data access to facilitate cross-disciplinary studies.
10. Clearly links the data collected, and the analyses they facilitate to management or policy decisions.

The importance of integrating monitoring data was emphasized in both reports. This refers, first of all, to integration among different disciplines with respect to data collection and analysis. In addition, there is a need for the coordination of data collection across multiple spatial and temporal scales. For example, different extant monitoring programs for the same element must be able to integrate their data so that the whole is greater than the sum of the parts. Integration among disciplines (i.e., elements) is especially important so that a CCMN can provide insight into linkages between climate drivers and the ecosystem responses. The result will be a CCMN that can track both climatic changes and ecosystem responses to inform management actions.

Temporal resolution was another important consideration in the Phase 2 Report. A number of current monitoring programs were designed to measure constant trends over time, whereas a CCMN needs higher sampling frequency to identify changes in trends, threshold responses, and the effects of extreme events.

Findings, Recommendations, and Conclusions of the Workshop

The objectives of the Workshop were:
To bring together experts to discuss development of a climate change monitoring network (CCMN) for Hawai'i, outline the desired attributes of a CCMN, develop a strategy to pursue for implementing a CCMN, and identify next steps to achieve that goal.

We identify seven key principles that characterize a CCMN for Hawai'i, as contrasted with a collection of individual monitoring programs. These principles were initially articulated in the Point Blue Phase 2 Report and discussed at the workshop. Further details are provided below in this document.

1. **Comparability and compatibility of data collected** at different locations and by different investigators. In particular, there is a need for standardization of protocols and processing of data. A CCMN would facilitate data input and compilation.
2. **Integration** of monitoring efforts. This includes co-location of monitoring stations in a way that increases understanding of patterns and ultimately of causation (e.g., what are the drivers that are or may influence responses observed as part of the CCMN?).
3. Emphasis on the **value and accessibility of information**, including specific products and other benefits, resulting from the compilation, integration, and analysis of data collected as part of the CCMN.
4. **Strategic spatial expansion** of existing monitoring to improve coverage, geographically and with respect to human-influenced habitats. Such expansion involves building off of existing stations, thus filling in gaps to build a comprehensive CCMN.
5. **Increased temporal coverage** of biological monitoring in order to detect changes in trends and the influence of extreme events.
6. **Development of a strategic plan** that targets specific audiences and uses for CCMN products.
7. Developing a **stable, long-term funding** strategy that provides a compelling case for establishing and maintain the network.

Above all, a CCMN must be strategic, maximizing the benefits with respect to investment in resources. Not all possible metrics can be monitored, and certainly not in all locations. Of additional concern were current monitoring gaps, especially in regard to the above principles.

Workshop participants identified twelve key monitoring elements that could form the framework for a CCMN, using the Point Blue Reports 1 and 2 as a starting point for discussion. Six of these monitoring elements were considered **critical**. Four of the six elements were physical: Air temperature, rainfall, wind, and stream flow. Two of the six critical elements were biological: vegetation and landbirds (primarily forest birds, but not exclusively so).

In addition, six elements were identified as **desirable**. These six would still be an important part of a proposed CCMN, as described below, but their inclusion might be more opportunistic. The six desirable elements included five physical elements: relative humidity, solar radiation, soil moisture, ground water levels, and water quality. The sixth element was biological: stream biota.

For six of the elements, standardized protocols have been developed by various organizations or investigators, but not always implemented (e.g., vegetation). For three of the critical elements and three of the desirable elements a need for standardized protocols was identified (rainfall, air temperature, wind, soil moisture, solar radiation, and stream biota). For most of the elements, there was a need to extend monitoring spatially to cover more habitats, areas that are human-influenced, or to increase efforts to allow the co-location of the diverse monitoring elements. For several elements, especially the biological elements, there was need to intensify the frequency of monitoring so that responses can be linked to shorter term environmental fluctuations.

Monitoring datasets specifically relevant to the CCMN are listed in Appendix 2 for the twelve key monitoring elements.

A Tiered Approach

Recognizing that not all monitoring can be conducted everywhere, and where it is conducted, the benefit should be maximized, leads to the concept of tiers of monitoring as an important feature of the CCMN. At minimum two tiers of monitoring are envisioned, with the exact details still to be developed. Given that the workshop identified two sets of key monitoring elements, critical and desirable, and endorsed a tiered approach, we propose the following tiers: **Tier 1**, composed of the six critical elements and **Tier 2** which is composed of the six elements deemed desirable components of the CCMN (Table 1).

Table 1. Priority Monitoring Elements for the CCMN, Categorized in the Two Tiers.

Tier	Element	Status of Standardized Protocol
Tier 1 (Critical elements)		
	Rainfall	Needs standardized protocol
	Temperature	Needs standardized protocol
	Wind	Needs standardized protocol
	Stream flow	Has standardized protocol
	Vegetation	Has standardized protocol
	Landbirds	Has standardized protocol
Tier 2 (Desired elements)		
	Relative humidity	Has standardized protocol
	Soil Moisture	Needs standardized protocol
	Solar Radiation	Needs standardized protocol
	Ground water level	Has standardized protocol, for salinity
	Water quality	Has standardized protocol
	Stream biota	Needs standardized protocol

In general, Tier 1 elements, have the greatest and most comprehensive spatial distribution. Tier 2 allows for the addition of monitoring elements, as much as possible co-located with elements from the tier below, thus resulting in a selective but strategic distribution of intensive monitoring efforts.

The workshop also recognized that within a tier, there will be important differences among the monitoring elements with regard to spatial and temporal coverage, and the CCMN must take this into account. In particular, air temperature and rainfall monitoring stations currently exhibit the most spatially extensive coverage with the widest footprint. In addition, these monitoring stations display temporally intensive coverage. Thus these two climate monitoring elements form the "backbone" of the entire CCMN, and the other elements, both critical and desirable, build on this backbone.

The objective of **co-location** of monitoring is an important component of the CCMN and is implicit in the tiering concept. Stream biota (a desired element) would be co-located with stream flow gauges, the base meteorology elements discussed above, and additional elements. Co-location would be achieved by a combination of either moving the location of monitoring of one or more elements to coincide with other key elements, or of adding new monitoring effort (e.g., adding rainfall and air temperature if these were not already being monitored) to an existing monitoring station.

Some initial insight into how a monitoring network can be strategically developed, building upon the existing distribution of monitoring elements, can be attained by considering the current distribution of meteorological stations. The Point Blue Phase 1 Report analyzed the distribution of meteorological stations in relation to climate zones and climate variables but did not consider the tiering of stations (i.e., which elements were being monitored where). Ryan Longman has provided a map of 337 weather stations that were still active in 2014, divided into several groupings, indicating whether or not meteorological elements were monitored besides rainfall and temperature (Appendix 3). It can be seen that the total number of stations monitoring rainfall and/or temperature is large, but there are only 95 stations among the seven islands in which at least one of the additional key climate elements of interest (either wind or solar radiation or both) was monitored. Thus, it appears that selectively adding wind (a Tier 1 element) and possibly solar radiation (a Tier 2 element) measurements to stations that only monitor rainfall and temperature would be a priority. We emphasize that this augmentation should be done strategically, considering, for example, where other important elements, including biological monitoring elements, are currently being measured or could be sited.

An important point is that even though elements such as bird and vegetation are "critical", they still build on a "base" of climate monitoring elements, such as rainfall and air temperature; similarly, stream biota builds on the underlying element of stream flow, as well as other important physical elements.

An important future step is to map the distribution of current bird, vegetation, and stream biota monitoring locations in relation to monitoring of important physical elements. Decisions can then be made to determine where augmenting one type of monitoring by adding another monitoring element is most needed. For example, bird monitoring has until now been mostly restricted to mid-level elevations and to areas with less human impact, but the workshop group recognized that extending bird monitoring more broadly is desired.

Monitoring transects

Development of tiers of monitoring is one aspect of the CCMN; these tiers can be extended broadly across the main Hawaiian Islands. A critical and complementary approach developed at the workshop was that of clusters of monitoring stations, i.e., **monitoring transects**. The concept of monitoring transects emerged as a key organizing framework for the future CCMN. Moreover, the set of monitoring transects for the Hawaiian islands defines the "core" of the emerging CCMN.

Each transect consists of a set of monitoring stations that, taken together, could monitor all twelve monitoring elements. Within the transect there would be tiers of monitoring stations as described above. Thus, the six "critical" elements would be prioritized first to be included at the monitoring stations, as appropriate. The other elements would be added at a later stage, or earlier if already in place. The monitoring transect has a number of advantages:

- It can efficiently span several important gradients including climate, vegetation and land use.
- The transect can facilitate the co-location of monitoring elements and thus promotes integration of the diverse monitoring elements.
- The transects are intended to be few in number (see below), but within a transect, monitoring can be intensive, with attendant benefits (which also promote integration). Thus the transects identify priority locations for implementing co-located, integrated monitoring.

Two important features of monitoring transects are:

(1) While each transect spans an elevational gradient, they also span a habitat gradient (subalpine, wet forest, dry forest), and to the extent possible, a gradient of human influence (e.g., degree of domination by non-native species).

(2) The monitoring transect allows for intensive data collection in a strategic manner, by focusing on important gradients.

It is important to develop separate transects for leeward vs. windward sides of the islands. Figures 1 and 2 depict a hypothetical "windward" and "leeward" transect, respectively. The diagrams use a real background but the depiction of monitoring stations is purely hypothetical, to illustrate the principles underlying a monitoring transect.

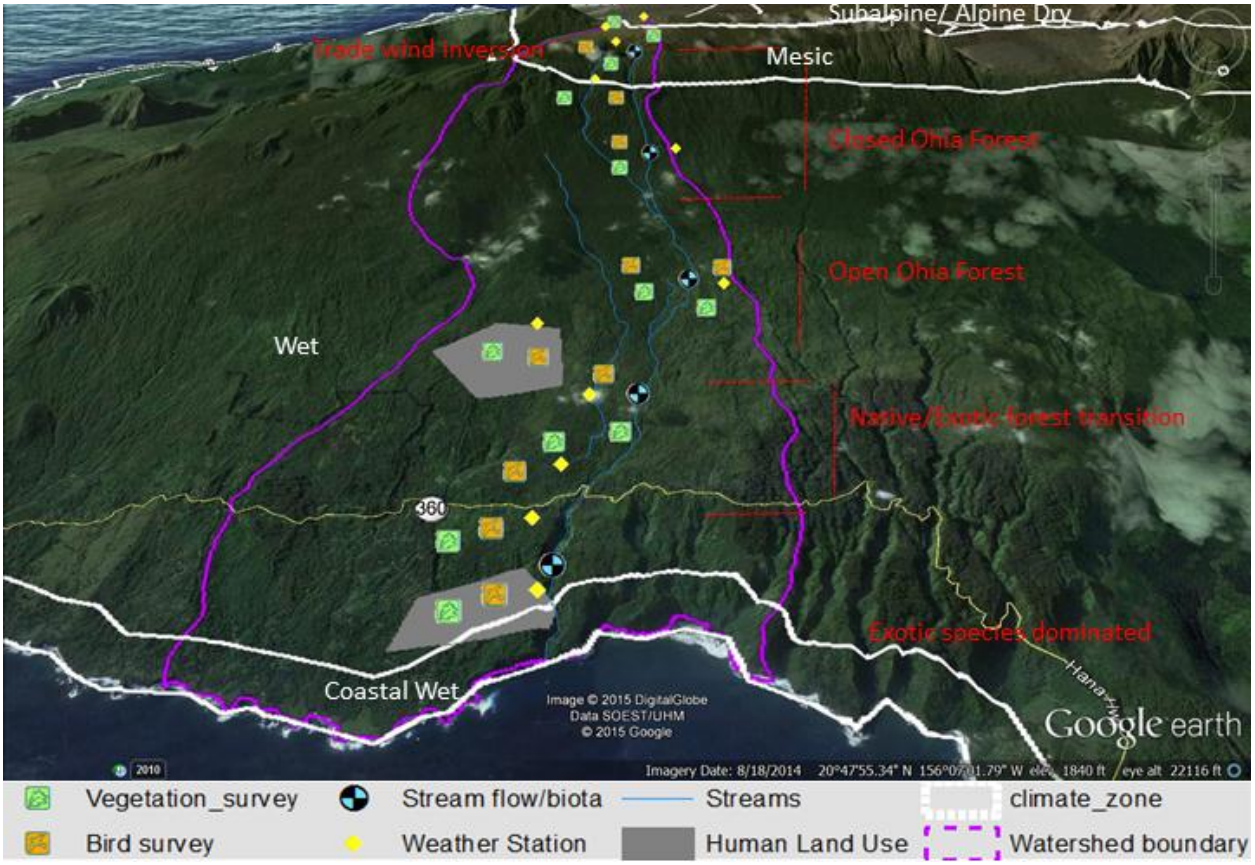

Figure 1. Climate change monitoring network transect example for the windward side of an island. Habitat boundaries are shown in white. Approximate climate zones and the Tradewind Inversion are indicated in red. Clusters of monitoring types are meant to be co-located but are pictured as separate for clarity.

Figure 1 depicts multiple habitat types/climate zones, areas of human land-use, and streams, in addition to the monitoring stations (divided into four categories). Also shown is the Tradewind Inversion and the area that is dominated by non-native species. Figure 2 depicts the transect for the leeward side of the island. The transect is similar, but there are fewer weather stations because rainfall gradient is reduced on the leeward side, and fewer stream flow gauges because stream flow is intermittent.

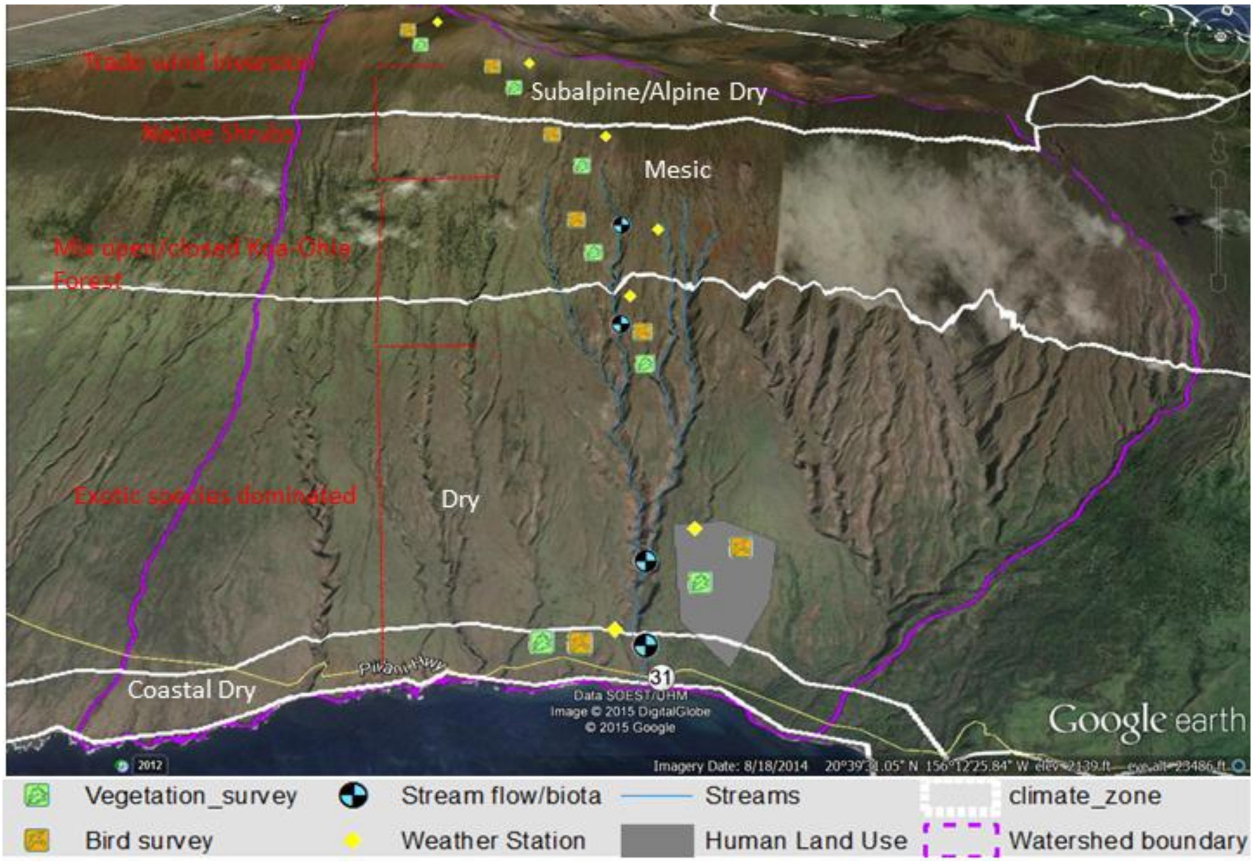

Figure 2. Climate change monitoring network transect example for the leeward side of an island. Habitat boundaries are shown in white. Approximate climate zones and the Tradewind Inversion are indicated in red. Clusters of monitoring types are meant to be co-located but are pictured as separate for clarity.

The total number of transects (and where they are located) was not determined at the workshop. Hawai’i and Kauai were put forward as high priority islands. These two islands are geographic end points among the main islands, they have had historic and current monitoring, and they display a range of elevation. Oahu was also suggested as high priority because of relevance for, and impact of, humans (see below). One disadvantage is that most monitoring programs in the state have not targeted Oahu. Nevertheless, implementing one or two transects on Oahu would be strategic. Maui is another priority island because of the intensity of monitoring and the long historical record (especially at Haleakala, Longman et al. 2015), as well as the large elevational gradient on the island.

Ideally, transects would be implemented on all five main islands. Given that funding is limited, priority should be given to implementing the six “critical” variables (what we have called Tier 1) as part of the monitoring transects. A staged approach to establishing monitoring transects will probably be necessary: starting with an initial subset of transects and ultimately instituting the full complement of monitoring transects. We emphasize that development of transects will proceed by building on existing monitoring efforts, selectively, in order to implement the vision for the network.

Constraints

Constraints to a successful CCMN must be considered. Constraints discussed at the workshop included sensitivity of data, access to monitoring sites, vandalism, and permitting requirements. Occurrence of threatened and endangered species and lack of cooperation from private landowners are also issues. An important constraint is the limited flexibility of agencies. There can often be difficulty in making and implementing strategic decisions. Lack of long-term commitment is an especially important challenge to implementing a CCMN. Another constraint is that influences on ecological systems other than climate change must also be measured to provide a complete understanding of change.

Many constraints revolve around funding. There are funding needs for the short-term (e.g., compilation of data; preliminary analysis), mid-term (including implementation of the network) and long-term (maintenance and providing output and specific CCMN products). Modest short-term funding needs may be covered by key participating agencies, but mid-term funding needs represent a serious challenge. Long-term funding will be addressed by the development and circulation of a major proposal. The group proposed that the best strategy for long term funding would be to develop a network that Hawai'i could not afford to lose and thus partner agencies and others would willingly invest in its long term operation and maintenance. It was recognized that achieving buy-in from agencies and groups (including NGOs) not represented at the workshop was of high priority. Success at bringing in additional partners will help achieve the long-term goal of sustained funding.

Future opportunities

While workshop participants provided initial sets of primary and secondary priority elements, there are some other areas that represent opportunities for a CCMN in the future. Further research may be needed to best determine the value of these additional, potential monitoring elements and how they may be incorporated into a future CCMN.

i. Additional information on invertebrates. Stream biota is already included as a desirable element of the CCMN, but other invertebrates may be considered as well. Further research into invertebrate indicators may be valuable.
ii. A sensitive indicator for lowland fauna has yet to be developed.
iii. There is an opportunity to include monitoring elements that capture estuaries and coastal habitat. There is an opportunity for a working group to augment the material that was prepared for, and discussed at, the workshop, which was limited to terrestrial systems.

iv. A monitoring element focused on waterbirds may be of value. Though the "core" framework developed in the workshop did not include waterbirds, there may be an opportunity to include them as an ancillary component.

Summary of recommendations and conclusions of the workshop

Key recommendations that emerged from the workshop include the following:

- Identification of six critical monitoring elements (rainfall, air temperature, wind, stream flow, vegetation, and birds) and six important, desirable elements (relative humidity, solar radiation, soil moisture, ground water level, water quality, and stream biota). These twelve elements together form the core set of CCMN elements with priority given to the six critical variables.

- Strategic establishment and development of the network is key and is described by specific recommendations below. At the same time, development of the network must proceed by small, but strategic steps, which build on existing monitoring efforts, but are guided by the overall vision.

- The long-term weather stations (see Appendix 3) form the backbone of the monitoring network, with additional critical variables building off of the former. Desirable elements will also build off the extensive long-term weather monitoring, as well as the other critical variables.

- The strategic location of monitoring sites is a key feature of the network. This includes emphasis on the value of co-locating monitoring elements. Biotic monitoring may be added to sites where weather monitoring or stream flow monitoring has been conducted, but in other cases, the converse may be the case. Co-location must be guided by principles described below.

- It is important to capture gradients of interest; this principle will guide location. Elevation, rainfall, habitat, and human influence are some key gradients, especially in areas where substantial change is expected to occur.

- Establishment of strategically placed "monitoring transects" among the main islands is a key organizing principle for the CCMN. Ideally there would be at least two transects per island, with up to five islands hosting transects; expansion should occur strategically.

- The value of established monitoring programs was recognized, though such programs have rarely had climate change monitoring as their objective. The network needs to capture the historic value of the monitoring conducted at these sites; historic monitoring sites will not be easily relocated by the respective monitoring agency. For example, the network may seek to establish new climate monitoring stations near historic biological monitoring, especially if weather at the site is not well characterized.

- Comparability and integration of data should be maximized. This will include adopting standard protocols to collect and process data, which will assure data stability, longevity, accuracy, and reliability. In some cases protocols will need to be developed. In other cases, well established protocols developed by one agency should be broadly used by others to ensure data compatibility.

- There is a need for more frequent monitoring for biotic populations: annual monitoring for animals and every two to several years for plants. Current monitoring programs are not well-suited to detect changes in trend or extreme events resulting in strong annual deviations.

- Use statistical modeling of biological responses to climate variables to inform the design and strategic growth of the CCMN, which could reveal proxies for biological responses.

- The CCMN should facilitate the development of mechanistic (causal) models based on results from statistical models. It is important to analyze stressors and mediators, not just the drivers, but also the immediate response variables. Such results will help inform management, including threatened and endangered species recovery.

- Develop the network to support collection of demographic and environmental data, so as to facilitate demographic modeling and analyses for key species. An important goal should be to increase the number of plant and bird species for which demographic models, including climate-change effects, are developed. These models can be validated with data from the CCMN.

- The network must establish centralized database management with the capacity (including staff) and resources to operate it. This includes the informatics capacity to provide analytical results and reports as well as raw and summary data.

- Development of CCMN products is key. This will include annual reports but also deeper analyses which are released at periodic intervals. It is important that such products include, but are not limited to, human implications.

- Being able to export data in a common format, for each monitoring element, is a critical objective.

- Establish a working group for each monitoring element or group of elements.

- The value of existing monitoring must be enhanced and made clear to potential funders.

- Establishing a lead entity, a Steering Committee, and a Technical Assistance Team are key next steps, as described below.

Looking Ahead: Strategy and Tactics for the Short- and Long-Term

During the workshop the participants discussed some of the pieces for a preliminary roadmap for developing and implementing a climate change monitoring network for Hawai'i. This section enhances that outline and makes recommendations to ensure that the network is created and successfully implemented, as well as providing a suggested timeline.

Steering Committee

The formation of a steering committee is an essential first step towards forming a successful Hawaiian climate change monitoring network. The steering committee will provide leadership, strategic planning and resources.

Steering committee composition

The composition of the steering committee is critical to ensuring success. We recommend that the steering committee be comprised of management level representatives from agencies that either collect climate change monitoring data, use the data for analyses or derived product creation, or use the data and derived products to inform management and support decision making. Candidate agencies that should be represented on the steering committee include USGS, the University of Hawai'i, Bureau of Water Services, NOAA, National Park Service, the USFWS, USFS, State of Hawai'i Division of Aquatic Resources, State of Hawai'i Division of Forestry and Wildlife, PICCC and the PICSC. Other agencies should be added as is deemed strategically necessary. Representatives should be at a sufficient level in the agency to approve staff participation in activities towards development of the climate change network (i.e., technical assistance team, see below) and to potentially approve the allocation of resources (funding, supplies, and infrastructure) towards the network.

Steering committee functions

Strategic planning

The creation of a CCMN in Hawai'i will require broad support from a network of institutions. That support can best be achieved by accomplishing outcomes that are deemed to be of value to these institutions. Although the use of a CCMN in Hawai'i was explicitly discussed on the first day of the workshop and arose throughout, we did not take the time to specifically lay out a clear set of outcomes that would result from a CCMN. To this end we recommend that one of the first functions of the steering committee will be to develop a clear set of outcomes that the CCMN would seek to achieve. We strongly recommend that the outcomes emphasize benefits to both human and natural systems where possible. These outcomes provide the rationale for creating a CCMN and need to be easily described to potential funders. Example outcomes, some of which were discussed at the workshop, include:

- Management and restoration of habitat for native species will be more efficient and effective in the future as we will have a better understanding of how Hawaiian species respond to climatic changes.
- Successful adaptation measures are implemented to prepare for climate related changes to patterns of natural hazards such as fire and flooding,
- Working lands are maintained in production as managers are adequately prepared for climate change.
- University of Hawai'i researchers conduct cutting edge research on climate change and climate change impacts.
- Water managers are able to ensure sufficient supplies for both human and natural systems.

These and other outcomes serve as a basis for working backwards to identify objectives that the committee will use to achieve the outcomes. Example objectives include: an annual report of climate change and impacts in Hawai'i, creation of an informatics system to store, curate and deliver data and derived products, development of decision support tools to facilitate climate change adaptation planning, and the production of in-depth reports on selected targets at periodic intervals (e.g., 5 years).

The steering committee will need to identify short term activities (e.g., preliminary compilation and characterization of data, developing a 2-4 page document to elicit financial support) that will support meeting the objectives, and the inputs and resources (money, database manager and system administrator, equipment, new partnerships) that will be needed to conduct these activities. This logic model for the CCMN will thus serve as guide for subsequent steering committee activities.

Establishing the Technical Assistance Team

Critical technical decisions will be necessary early on in the development of the CCMN that will require the formation of a technical assistance team. The technical assistance team will be formed by the steering committee and should include experts in monitoring and analysis of the critical monitoring elements. The technical assistance team will be initially tasked with identifying and prioritizing the optimal sites for the core monitoring network as well as evaluating and/or developing standardized protocols for each of the monitoring elements (see details above) by convening a working group for each element. The technical assistance team will also make recommendations regarding monitoring elements not prioritized in the workshop.

The technical assistance team will also need to identify analyses and products that can be used to achieve the objectives set forth by the steering committee. The consideration of these analyses should occur in tandem with the siting of the network and the development of monitoring protocols because those decisions will necessarily affect the types of analyses and products that can be delivered from the network.

Systems analyst and data manager

At the workshop, participants agreed that "a functional network will require resources to support centralized data management." The steering committee will need to determine how to fund these positions, what the job description will entail, and where the positions will be housed. At a coarse level, the positions will be responsible for acquiring, curating and delivering the data collected by, and further processed through the network. Workshop participants agreed that the data needs to be accessible in standard formats so that the information from different monitoring elements can be easily integrated within and outside the network

Funding

Initial activities will be most successful if funding is available to support participation in the steering committee and technical assistance team. The steering committee should look to provide or raise funding to support these activities. Potential sources of funding include internal institutional funds and developing proposals that would be directed towards initial activities.

Medium term funding proposal

Workshop participants identified the need to develop a funding proposal to support short to medium term activities. We recommend that the steering committee and the technical assistance team jointly develop this proposal. We also recommend that the proposal be developed so that smaller pieces of the network could be funded individually and then combined at a later date with other elements of the network as funding becomes available. The core monitoring network will require funds to create new monitoring stations and to collect the data where there is no ongoing efforts.

A moderate to longer term objective will be to expand the network beyond the core sites and tier 1 monitoring elements. We anticipate that initially funding will be a constraint and that a limited number of transects can be implemented throughout the islands. Once the core transects are established, the steering committee will need to prioritize where and how more monitoring occurs (more transects vs. more elements).

Closing

At the close of the workshop in June, participants were excited, engaged and ready to move forward on creating a climate change monitoring network in Hawai'i while recognizing the challenges that lie ahead. Our intention is that the recommendations and road map that we provide here will sustain that engagement and enthusiasm and lead to strategic growth and the broadening of support for network development.

Timeline of Next Steps

Task	Target	September 2015	Fall 2015	Winter 2016	Summer 2016	Ongoing
Review final report	Align on final report recommendations	x				
Form Steering Committee	Raise initial funding; identify important outcomes and logic model; include additional partners		x	x		
Form technical assistance team	Identify locations of core sites; define monitoring protocols to be used for each element; identify initial analyses needed for objectives; estimate costs of CCMN implementation			x	x	x
Hold two day workshop to develop major proposal	Funding for implementation of the core network is in place.				x	x

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Appendix 1

Workshop participants

Steve Anthony, USGS Water Science Center, Jeff Burgett, Pacific Islands Climate Change Cooperative, Abby Frazier, University of Hawai'i, Patrick Grady, Pacific Islands Climate Change Cooperative, Jim Jacobi, USGS, Jeremy Kimura, Commission of Water Resource Management, Scott Kichmann, National Park Service, Kevin Kodama, NOAA, Greg Kudray, Point Blue Conservation Science, Ryan Longman, University of Hawai'i, Rich Mackenzie, USFS, Nancy Matsumoto, Bureau of Water Resources, Ian Morrison, NOAA, Nadav Nur, Point Blue Conservation Science, Delwyn Oki, USGS, Olivia Schubert, PICCC, Ayron Strauch, Gordon Tribble, USGS, Jared Underwood, USFWS, Sam Veloz, Point Blue Conservation Science, and Sharon Ziegler-Chong, Hawai'i Cooperative Studies Unit.

Facilitator: Elizabeth Kent

Appendix 2

Table 1. Information on available monitoring datasets, relevant to the CCMN for Hawai'i.

Element	Variable	Agency or Organization	Data Location
Air temperature	Air temperature	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/climate.cfm
Air Temperature	Air Temperature	National Weather Service	www.ncdc.noaa.gov
Air Temperature	Air Temperature	University of Wisconsin-Madison, UH-Manoa	Contact shotchkiss@wisc.edu
Air Temperature	Air Temperature	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov
Air Temperature	Air Temperature	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov
Landbirds	Avian species composition, distribution, density and habitat	US Geological Survey, University of Hawaii - Hilo.	https://www.sciencebase.gov/catalog/item/54c2db46e4b043905e0185cb
Landbirds	Density	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov
Landbirds	Avian species composition, distribution, density and habitat	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/landbirds.cfm
Rainfall	Rainfall	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/climate.cfm
Rainfall	Rainfall	National Weather Service	www.ncdc.noaa.gov
Rainfall	Rainfall	USGS Pacific Islands Water Science Center and many Federal, State, and local agencies	http://nwis.waterdata.usgs.gov/hi/nwis/inventory?site_tp_cd=AT&format=station_list&sort_key=site_no&group_key=NONE&list_of_search_criteria=site_tp_cd
Rainfall	Rainfall	University of Wisconsin-Madison, UH-Manoa	Contact shotchkiss@wisc.edu
Rainfall	Rainfall	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov

Element	**Variable**	**Agency or Organization**	**Data Location**
Rainfall	Rainfall	The University of Hawaii at Hilo, The USDA Forest Service, The University of Hawaii at Manoa; University of California - Los Angeles	Contact Creighton Litton, Christian Giardina
Stream flow	Stream levels	National Weather Service	www.ncdc.noaa.gov
Streamflow	Streamflow	USGS Pacific Islands Water Science Center and many Federal, State, and local agencies	http://waterdata.usgs.gov/hi/nwis/sw/
Vegetation	Species presence/absence, substrate type, understory cover, canopy height, large tree density, snag density, tree fern characteristics, shrub density, downed wood characteristics	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/focal_communities.cfm
Vegetation	Haleakala silversword demography	UH, Haleakala National Park, PICCC, PICSC	Contact Paul Krushelnycky, pauldk@hawaii.edu
Vegetation	Understory, priority weeds	TNC, Maui	Contact kfay@tnc.org.
Vegetation	Vegetation cover/ composition	Kauai Watershed Alliance	Contact hawpcoordinator@gmail.com
Vegetation	Vegetation cover/ composition	University of Wisconsin-Madison, UH-Manoa	Contact shotchkiss@wisc.edu

Element	**Variable**	**Agency or Organization**	**Data Location**
Vegetation	Plant size, growth and mortality (all trees great than 1 cm DBH	The University of Hawaii at Hilo, The USDA Forest Service, The University of Hawaii at Manoa; University of California - Los Angeles	Contact Creighton Litton, Christian Giardina
Water quality	Fecal bacteria	USDA Forest Service, Institute of Pacific Islands Forestry (Host),USDA Forest Service Pacific Northwest Research Statin (partner), Watershed Professionals Network (Partner), UH Manoa (Partner), UH Hilo (Partner), Kamehameha Schools (Partner), Michigan State University (partner), Principia College (partner), University of British Columbia (partner)	Contact Richard Mackenzie
Wind speed/ direction	Wind speed/ direction	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/climate.cfm
Wind speed/ direction	Wind speed/ direction	National Weather Service	www.ncdc.noaa.gov
Wind speed/ direction	wind speed and direction	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov

Element	Variable	Agency or Organization	Data Location
Wind speed/ direction	Wind speed/ direction	The University of Hawaii at Hilo, The USDA Forest Service, The University of Hawaii at Manoa; University of California - Los Angeles	Contact Creighton Litton, Christian Giardina
Groundwater	Well water depth, salinity	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/groundwater.cfm
Groundwater	Groundwater levels	USGS Pacific Islands Water Science Center and many Federal, State, and local agencies	http://waterdata.usgs.gov/hi/nwis/gw/
Relative humidity	Relative humidity	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/climate.cfm
Relative humidity	Relative humidity	University of Wisconsin-Madison, UH-Manoa	Contact shotchkiss@wisc.edu
Relative humidity	Relative humidity	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov
Relative humidity	Relative humidity	The University of Hawaii at Hilo, The USDA Forest Service, The University of Hawaii at Manoa; University of California - Los Angeles	Contact Creighton Litton, Christian Giardina
Soil moisture	soil moisture	University of Wisconsin-Madison, UH-Manoa	Contact shotchkiss@wisc.edu
Solar radiation	solar radiation	National Weather Service, USFWS I&M	Contact jared_underwood@fws.gov

Element	Variable	Agency or Organization	Data Location
Solar radiation	solar radiation	The University of Hawaii at Hilo, The USDA Forest Service, The University of Hawaii at Manoa; University of California - Los Angeles	Contact Creighton Litton, Christian Giardina
Stream biota	Shrimp, fish, snails	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/stream.cfm
Stream biota	Shrimp, gobies, food web structure, benthic invertebrate community structure and production	USDA Forest Service, Institute of Pacific Islands Forestry (Host),USDA Forest Service Pacific Northwest Research Statin (partner), Watershed Professionals Network (Partner), UH Manoa (Partner), UH Hilo (Partner), Kamehameha Schools (Partner), Michigan State University (partner), Principia College (partner), University of British Columbia (partner)	Contact Richard Mackenzie
Water quality	Temperature, conductivity/salinity, pH, dissolved oxygen, turbidity, total dissolved N, total dissolved P, nitrate, chlorophyll	National Park Service	http://science.nature.nps.gov/im/units/pacn/monitor/water_quality.cfm
Water quality	Turbidity, depth, nutrients, total suspended solids	East Maui Watershed Partnership	Inquire with pr@eastmauiwatershed.org

Appendix 3

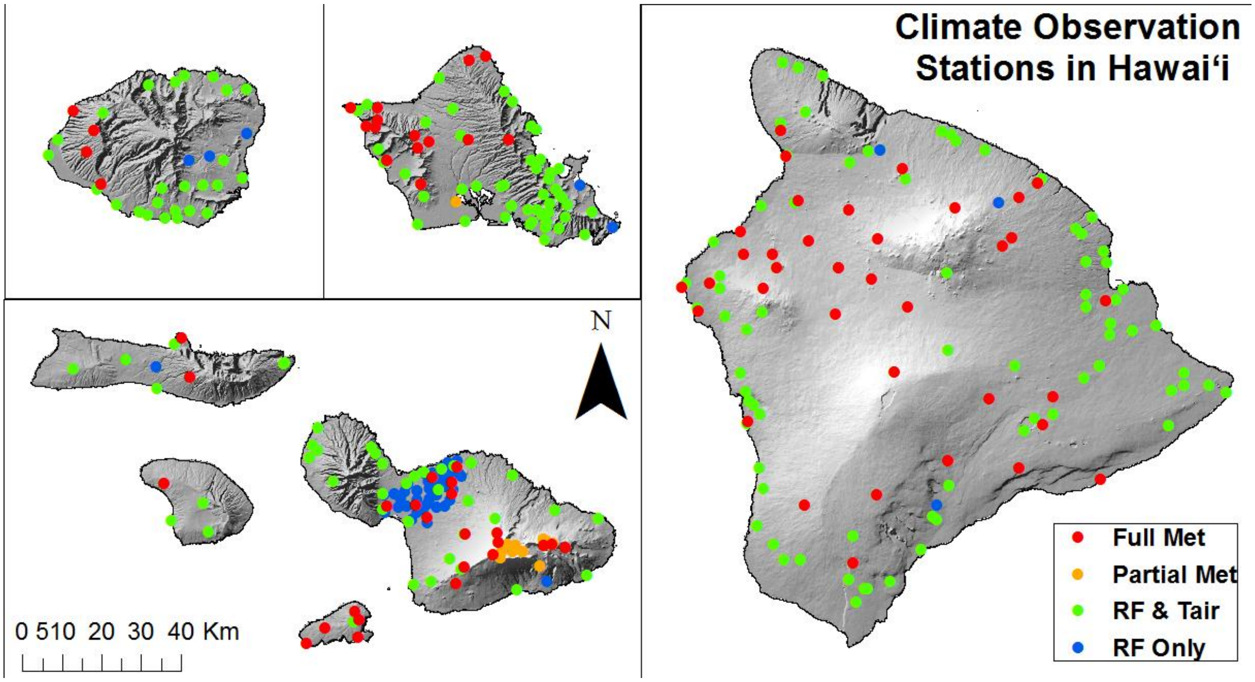

Figure 1. Distribution of climate observation stations for Hawaiian islands active for at least part of 2014. Blue symbols = rainfall only (n = 53). Green = rainfall and air temperature only (n = 189). Orange = "Partial Meteorology" = rainfall, temperature, and relative humidity, no solar radiation; may have wind speed (n = 20). Red = "Full Meteorology" = rainfall, temperature, wind speed (the three designated critical climate elements); relative humidity, soil moisture, and solar radiation (three additional desirable climate elements); as well as many other variables of interest (soil temperature, surface temperature, energy and water fluxes, net radiation, longwave radiation, photosynthetic active radiation, diffuse radiation, and leaf wetness; n = 95). Note patchy distribution of meteorological ("partial" and "full") stations. This Figure can be compared with Figure 1 and Table 1 of Point Blue Phase 1 Report (Kudray et al. 2014), which shows distribution in relation to climate zones.