Coral Reef Climate Response through Collaborative Marine Spatial Planning: Creating Management Hotspots

PHASE 1 FINAL REPORT

Prepared for: Pacific Islands Climate Change Cooperative

Prepared by: University of Hawaii, Hawaii Coral Reef Initiative

Funding and Partnerships

This report was produced in cooperation with the Pacific Islands Climate Change Cooperative, with funding from the US Fish and Wildlife Service.

This project was conducted in partnership with the University of California, Santa Barbara McClintock lab and Stanford University, Center for Ocean Solutions. The report was prepared by Amber Meadows and Anne Chung (University of Hawaii, Hawaii Coral Reef Initiative).

Summary

Coral reef ecosystems in Hawaii have suffered high rates of mortality following the recent mass bleaching event. In order to prevent phase shifts to degraded reefs, strategies to increase reef resilience following disturbance such as bleaching must be developed. Herbivore management has been identified as a priority management action to increase reef resilience, and the goals of this project were to 1) synthesize climate and herbivore management spatial data layers and 2) utilize Marxan to identify prioritized areas for herbivore management in west Hawaii and Maui Nui.

1. The project team synthesized relevant climate and herbivore management spatial data layers from seven sources, and incorporated feedback from four experts with respect to feature and cost input configuration.
2. The project team conducted a preliminary Marxan analysis incorporating all currently available data layers representing intermediate progress as remaining feature and cost layers are being finalized.

The next steps of the project will be accomplished in cooperation with the Pacific Islands Climate Change Cooperative (PICCC), with funding from the US Fish and Wildlife Service in the project titled "Coral Reef Climate Response through Collaborative Marine Spatial Planning: Stakeholder Engagement"

- Finalize Marxan analysis to develop a series of heatmaps representing areas prioritized for management of herbivores
- Integrate Marxan outputs into SeaSketch as a platform for stakeholder feedback
- Develop and complete stakeholder workshops in two priority areas (West Hawaii and Maui) to revise Marxan outputs based on local knowledge
- Prepare a final report with finalized maps of potential areas for herbivore management and revisions from stakeholder workshops

Background

Coral reefs are important ecosystems in Hawaii, providing habitat for a diversity of marine life and supporting the economy through tourism and local livelihoods. In 2014 and 2015, Hawaii's reefs were severely impacted by the mass bleaching event that impacted many reefs globally, with coral mortality from this event on average being 49.7% in west Hawaii and 20-40% in Maui (Kramer et al. 2016, Sparks 2016). Bleaching events are predicted to increase in frequency, with mass bleaching predicted to become an annual occurrence in Hawaii by 2050 (van Hooidonk et al. 2014).

A major concern associated with bleaching events is the potential for regime shifts and reef decline that may be permanent depending on the reef's capacity for resilience. Research has shown that protection of herbivores from fishing pressure is projected to delay rates of coral loss under extreme bleaching regimes and other disturbance events (Hughes et al. 2007; Game et al. 2009; Edwards et al. 2011; McClanahan 2014), and herbivore management has been effectively used in Hawaii to reverse declines in coral cover. The Kahekili Herbivore Fisheries Management Area on Maui, established in 2009, led to an increase in herbivorous fish, stabilization of algae levels, and increased crustose coralline algae that provides substrate for coral settlement (Williams et al. 2016). High levels of herbivory can increase reef resilience through maintenance of open spaces on reefs, which allows remaining corals to recover from disturbance and new coral to settle in cleared areas (Marshall et al. 2006; Hughes et al. 2007; Mumby and Harborne 2010; Smith et al. 2010; Edwards et al. 2011). Additionally, spatial herbivore management was ranked as a high priority in the Coral Bleaching Recovery Plan (Rosinski et al. 2017), which critically analyzed which conventional management tools could be used to promote recovery following the mass bleaching event.

The objective of this project is to identify areas where herbivore management interventions would be the most effective in promoting coral reef recovery and resiliency following recent coral bleaching, and builds on previous efforts funded by the Office of Planning Coastal Zone Management Program that identified conservation features and targets that could be used to identify areas of importance for herbivore management in west Hawaii and Maui Nui. The goals of this project were to 1) synthesize climate and herbivore management spatial data layers and 2) utilize Marxan to identify prioritized areas for herbivore management in west Hawaii and Maui Nui.

Synthesis of Spatial Data Relevant to Climate Effects and Herbivore Management

Marxan is a decision support tool that can be used to identify priority areas for conservation action. The software requires preparation of several input parameters to guide this process, including spatial data for conservation features and cost inputs. Conservation features are the spatial layers that contain data pertaining to what should be conserved in the reserve network. Cost inputs represent the consequences, as defined by the user, of including a particular feature in the reserve network. Marxan works by evaluating the relative value and cost of including a specific area in a network in an iterative process that compares millions of design alternatives, and optimizes solutions by selecting areas of high conservation value associated with the lowest possible cost. Spatial data representing conservation features and cost inputs must be compiled and prepared by the user prior to Marxan analysis.

Data were acquired from a total of seven sources to represent the features and costs to be included in the Marxan analysis (Table 1). In order to ensure inclusion of the most relevant data layers, existing Marxan frameworks were referenced from previous work involving Marxan network design (Green et al. 2007). Feature layers were designed to capture habitat essential to herbivore life cycles and coral reef rich areas, as well as high existing and potential herbivore biomass and vulnerability to bleaching. Feature data layers included those describing benthic habitat, special areas, and herbivore biomass. The target associated with these features indicates the goal amount of each feature to be included in the final network. Marxan uses these target values to determine how much of a particular feature is to be included in the final network.

Cost layers aimed to capture the growing threat of climate change through indicators of heat stress (both acute and chronic), and other local anthropogenic threats such as land-based pollution from sediment/nutrients and non-commercial fishing effort. Cost layers included those describing global impacts from increasing ocean temperatures and local impacts from land-based anthropogenic threats and fishing pressure. Data sources for cost and feature layers included NOAA National Centers for Coastal Ocean Science (NCCOS), NOAA Coral Reef Watch, Hawaii Monitoring and Research Collaborative (HIMARC), United Nations Environment Programme (UNEP), and the Ocean Tipping Points (OTP) project. All data are handled according to the data management plan developed for this project (Appendix A).

Expert Feedback

Following initial data synthesis, the project team reached out to four experts and managers from related projects to seek feedback on data content and structure with respect to Marxan analysis. Those who provided input included Joey Lecky at NOAA, who conducted spatial analyses for the OTP project; Hal Koike, the biostatistician for DAR; and Alison Green and John Knowles with The Nature Conservancy (TNC), who have worked on several spatial management projects involving Marxan in the Caribbean and around the world. This feedback is summarized below.

Design Principles for Herbivore Management in Hawaii

- Existing design principles for marine managed areas (MMA) in general should be refined to fit both the herbivore specific and Hawaii specific contexts, while incorporating standard aspects of spatial management that contribute to success.

Input Content and Organization

- As much as possible, data inputs and classifications should be justified through review and reference of relevant literature.
- In some cases, it may be better to use existing data with gaps rather than interpolated data; interpolated data for fine-scale features such as habitat complexity become artificially smooth through interpolation, and hold less meaning in Marxan analysis.
- Features that represent potential negative impacts to the resulting areas of interest should be normalized and combined into a single cost surface rather than included as separate features for Marxan input.

Setting Feature Targets

- Since Marxan analysis is an iterative process, targets should be given as a range of values rather than a single value; this provides flexibility in the analysis process, and allows targets that are not met to be reasonably lowered, while targets that are consistently met can be increased.

Utilizing Marxan Modeling to Identify Priority Hotspots for Herbivore Management

A preliminary Marxan analysis was conducted using all currently available feature data. Once spatial data for conservation features and cost inputs have been synthesized, they must be further prepared for input into the Marxan program. Cost features must be standardized and combined into a single cost surface that Marxan can evaluate against the value of conservation features. In addition, the overall network area must be divided into subunits called planning units, which provide Marxan with a grid of cells that can be assigned a relative feature value and cost for determining inclusion in the final reserve network. In this case, a planning unit layer was developed using hexagon shaped units with an area of 0.65 km^2 per unit spanning the coastlines of Maui Nui (the islands of Maui, Molokai, Lanai, and Kahoolawe) and West Hawaii out to 7.5 km (Figure 1). This configuration provided units that share a boundary with all surrounding units, and a fine enough resolution to provide a detailed analysis of the study area, while including the farthest extent of existing management area boundaries. ArcGIS tabulation tools were then used to determine the amount of each conservation feature contained within each planning unit, as well as the cost of including each planning unit in the reserve network.

Additional input files summarizing this data and other input parameters (such as number of runs and iterations) were generated using the ArcMarxan Toolbox in ArcGIS. These input files were then incorporated into a companion program, Zonae Cogito, which provides a simple user interface for the Marxan software. Additional parameters were calibrated to define penalties for missed feature targets (species penalty factor) and to achieve the desired level of clumping for selected cells (boundary length modifier). A preliminary Marxan analysis was then run to produce a draft set of solutions representing priority areas for management. Separate analyses were conducted for Maui Nui and West Hawaii to account for ecological connectivity considerations, as the West Hawaii study area is both geographically and ecologically distinct from the islands within the Maui Nui complex. Following Marxan analysis, the selection frequency, or the percentage of time a particular planning unit was selected for inclusion in the network during the iterative process, was used to generate a heat map showing hotspots representing the relative importance of each planning unit for inclusion in the network with respect to conservation value and cost (Figure 2). Planning units selected with a high frequency are considered more important to include in the final reserve network.

The heat map included in this report represents intermediate progress towards developing final maps incorporating all data layers and stakeholder feedback. The analysis in this report included all currently available data layers and a proxy cost surface representing non-commercial fishing effort. In order to incorporate expert feedback and properly prepare relevant input features and cost data, the final Marxan heatmap displaying hotspots for management consideration will be produced upon finalization of layers in development. Once all feature and cost layers have been finalized, a full Marxan analysis can be conducted that considers additional scenarios and produces more refined and meaningful results regarding identification of priority areas for herbivore management.

Next Steps

The next steps for this project include completing development of spatial data layers still needed for the Marxan analysis. Once all spatial data inputs have been finalized, multiple Marxan scenarios can be run to produce a series of heatmaps representing areas prioritized for herbivore management. These products can then be added to the SeaSketch platform to be shared with stakeholders and incorporate their feedback. The project team will also be engaging with stakeholders through workshops in the priority areas of West Hawaii and Maui, and will maintain communication with DAR and the 30x30 spatial planning effort throughout the process. In our communications thus far, there is a shared goal of integrating the results of this project into a statewide Marxan analysis as part of the 30x30 Initiative, which is led by DAR.

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Table 1. Current list of data layers and sources to be used in Marxan analysis. For sources "In Development", references have been contacted to acquire and prepare the data.

Feature Category	Feature	Contribution to Spatial Network	Target	Source	Source Link	Status
Habitat	Aggregate Reef	Habitat with high coral cover or importance to herbivore life cycle	30-60%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Spur and Groove	Habitat with high coral cover or importance to herbivore life cycle	30-60%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Scattered Coral/Rock	Habitat with high coral cover or importance to herbivore life cycle	30-60%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Rock/Boulder	Habitat with high coral cover or importance to herbivore life cycle	30-60%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Pavement	Habitat with high coral cover or importance to herbivore life cycle	<30%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Pavement with Sand Channels	Habitat with high coral cover or importance to herbivore life cycle	<30%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
	Sand	Habitat with high coral cover or importance to herbivore life cycle	<30%	NOAA NCCOS 2007 Benthic Habitat Layer	https://products.coastalscience.noaa.gov/collections/benthic/e97hawaii/data2007.aspx	Ready for input
Special Areas	Aggregate Reef with Low Climate Vulnerability	Represents reefs with greater potential for survival with respect to climate change	>60%	NOAA NCCOS 2007 benthic habitat data combined with UNEP data	http://pre-uneplive.unep.org/theme/index/19#data	In Development
	Aggregate Reef with High Recent Mortality (from bleaching event)	Represents reefs targeted for recovery from bleaching impacts	>60%	NOAA NCCOS 2007 benthic habitat data combined with layers in development	N/A	In Development
	Grazer Juvenile Habitat	Represents key herbivore functional group life stages and essential habitat	>60%	In Development	N/A	Source Contacted
	Grazer Spawning Habitat	Represents key herbivore functional group life stages and essential habitat	>60%	In Development	N/A	Source Contacted
	Scraper Juvenile Habitat	Represents key herbivore functional group life stages and essential habitat	>60%	In Development	N/A	Source Contacted
	Scraper Spawning Habitat	Represents key herbivore functional group life stages and essential habitat	>60%	In Development	N/A	Source Contacted
Fisheries	Herbivore Biomass	Areas with sufficient herbivore populations to drive recovery and resilience	>60%	HIMARC	N/A	In Development
	Present Resource Fish Biomass	Areas with the highest current biomass (represents preservation goal)	30-60%	In Development	N/A	In Development
	Potential Gain in Resource Fish Biomass	Areas that would benefit the most from herbivore protection (recovery goal)	30-60%	In Development	N/A	In Development
Cost Category	**Feature**	**Contribution to Marxan**	**Goal**	**Source**		**Status**
Global Impacts	Irradiance (long term mean)	Avoidance of areas with high heat stress	Minimize in Marxan Analysis	Ocean Tipping Points	http://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data	To be integrated into total cost layer
	SST (long term mean)	Avoidance of areas with high heat stress		Ocean Tipping Points	http://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data	To be integrated into total cost layer
	Sum of Degree Heating Weeks 2013-2017	Avoidance of areas with high heat stress		NOAA Coral Reef Watch	https://coralreefwatch.noaa.gov/satellite/bleaching5km/index_composites_5km.php	To be integrated into total cost layer
Local Impacts	Nutrients (Effluent)	Avoidance of areas with high land-based anthropogenic threats		Ocean Tipping Points	http://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data	To be integrated into total cost layer
	Sediments	Avoidance of areas with high land-based anthropogenic threats		Ocean Tipping Points	http://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data	To be integrated into total cost layer
	Herbivore Fishing Catch (non-commercial net and spear)	Avoidance of areas with high conflict between resource protection and use		Ocean Tipping Points	http://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data	To be integrated into total cost layer

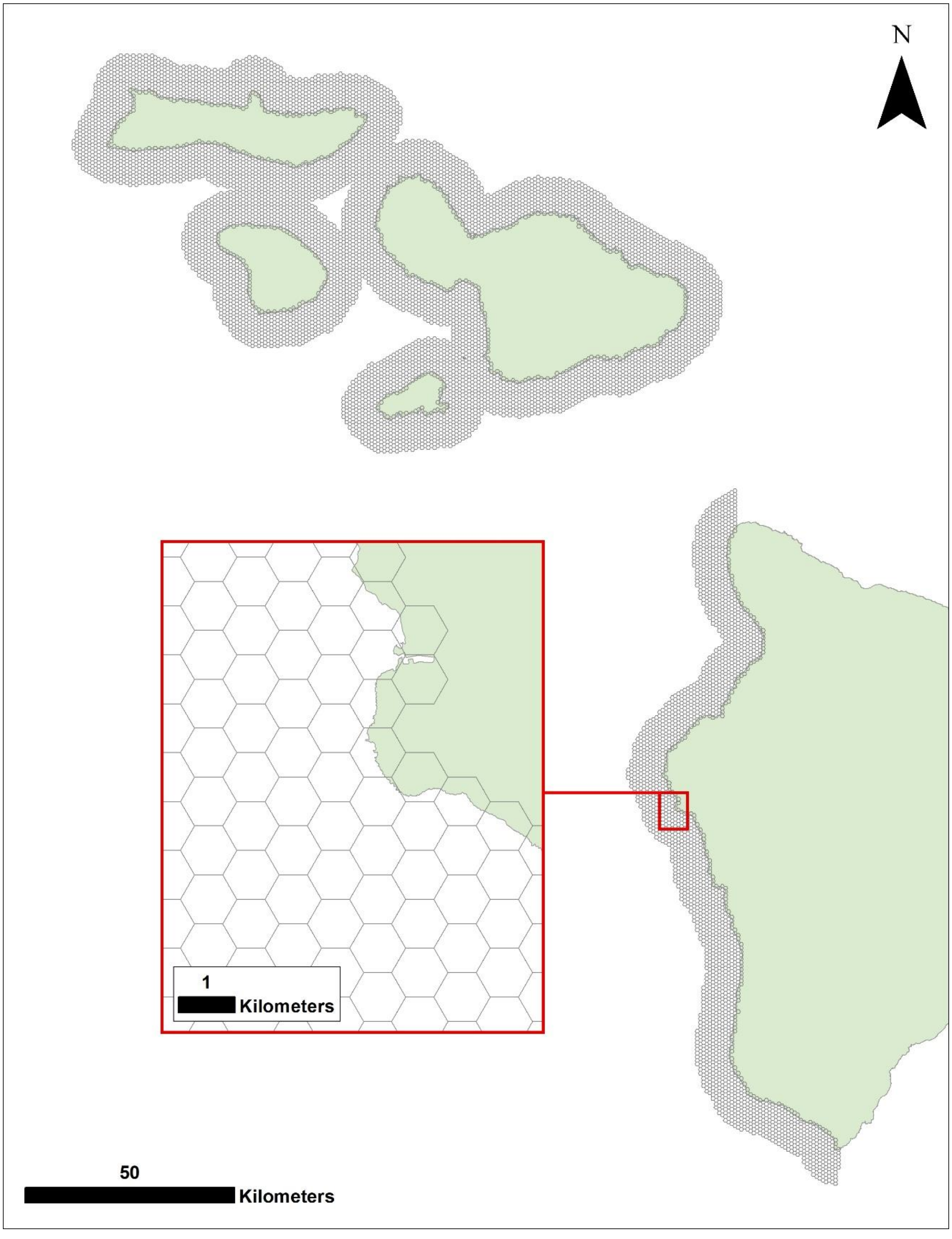

Figure 1. Map of the Maui Nui and West Hawaii Study areas (main) and close-up of the hexagonal planning units (inset).

Figure 2. Draft heatmap showing priority areas identified in Maui Nui and West Hawaii during the preliminary Marxan analysis. Features included in this analysis included all habitat features, with non-commercial fishing effort used as a proxy for the cost layers in development.

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Appendix A: Data Management Plan
Spatial Herbivore Management Project

Centralized data management is necessary to support the large and diverse amount of information needed to support the Marxan analysis and mapping of potential herbivore enhancement areas. The Spatial Herbivore Management work will involve the synthesis of a suite of geospatial data sets to 1) support Marxan analysis efforts; 2) application of SeaSketch in engagement meetings and 3) visualize and communicate results using map products. The challenges of multi-media, multi-scale, multi-temporal data will require a data management system that will foster collaboration between state and federal partners, facilitate data management and discovery, and provide a portal for visualization and data dissemination.

The project followed the NCCWSC/CSC Data Sharing Policy, which requires data and associated products to be shared publically, and the development of a data management plan. The proposed data management plan will provide all collaborators with specific guidance, through data standards and protocols, to ensure all project-associated data are acquired, stored, validated, processed, analyzed, archived and distributed to collaborators and the public while ensuring data accuracy, security and longevity. The overall data management plan will follow 6 main phases of development and implementation (Figure 1).

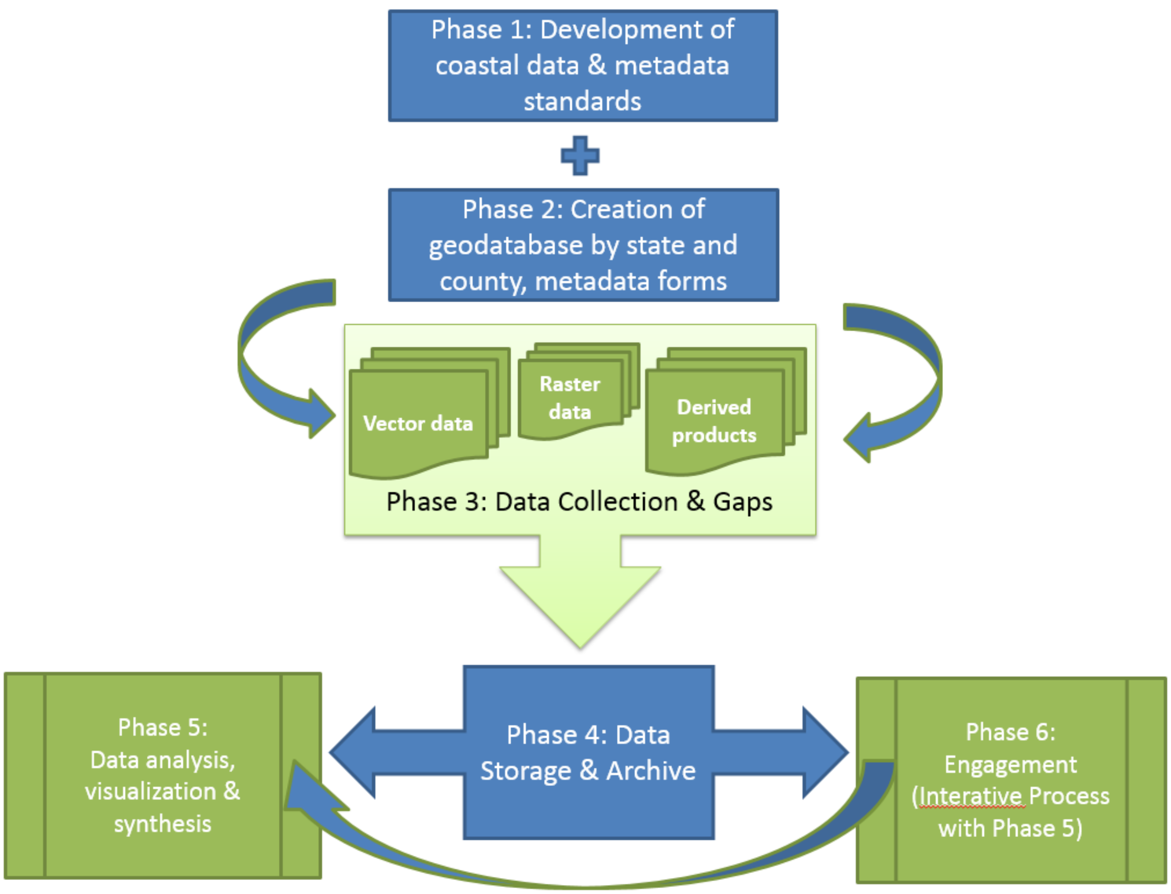

Figure 1. Summary diagram of the 6 main phases of the data management plan that addresses 1) the development of coastal data and metadata standards (Phase 1-2); 2) data management protocols that will be implemented during data collection (Phase 3and 3) the workflow that follows storing and archiving data to ensure effective transfer of information to support data analysis and engagement efforts.

1. Data and Metadata Standards

The implementation of data standards will allow for future scalability and regional comparison for our proposed engagement work and synchronized science across the study areas. Initially a strong emphasis will be placed on the creation of a robust data management plan, which will provide the framework by which all coastal data will be acquired, maintained and potentially shared with collaborators and the key engagement staff. Data and metadata standards will be established following the Federal Geographic Data Committee (FDGC) standards. FGDC standards will be applied in all data documentation and metadata efforts in order to facilitate data sharing between networks, organizations, software platforms. The creation and implementation of a Spatial Herbivore Management metadata standard protocol at the advent of the project will allow our data to be linked and searchable in broader databases in ecoinfomatics, such as the Knowledge Network for Biocomplexity.

2. Data Sets Tracked During Input Phase of Project

Coastal Vector Data

The below list details existing input data sets and new input data sets for the PICC project duration. Following the PICCC data management guidelines this project will compile the following information in the metadata: source for data, any restrictions on its reuse, and processing or workflow steps that transform the existing data into a new dataset. For new input datasets, the team will also document details on how data were collected, prepared, reviewed, and assessed for accuracy, models, custom software/code and web tools and project data outputs. All existing and new data will be assessed for quality and accuracy.

The data themes for this project are diverse and vector data types include:

- Data and project footprint shapefile per PICCC data management guidelines
- Geomorphological structure
  - Colonized hard bottom
  - Uncolonized hard bottom
  - Sand
- Biological cover
  - CCA
  - Macroalgae cover
  - Live coral cover
- Natural refuges
  - Nurseryhabitat
  - Rugosity
  - Waves
  - Depth
- Resilience/Resistant populations
  - Anthropogenic threats
  - Fishing catch
  - Commerical –line, net, spear, total
  - Noncommercial shorebased –line, net, spear, total
  - Noncommercial boatbased –line, net, spear, total
  - Total noncommercial

    - High/low nutrients
    - Invasive algae
    - High/low sediment
- Herbivore biomass
    - Herbivore species
    - Herbivore functional groups
    - Reef fish total biomass
    - Herbivore biomass
    - High/low herbivore potential
      Change in herbivores (past and present)

The geodatabase will be managed and stored initially at COS and then transferred to HCRI for long term storage.

Remotely Sensed Raster Data
Remotely sensed data types for this project will include satellite-derived observations and model output of wave height and period. A spatial database will be created to manage all remotely sensed data and FGDC metadata standards will be followed for proper documentation.

- Environmental threats
    - Irradiance
    - SST –NOAA Coral Reef Watch 5km products
    - Climate vulnerability/bleaching projections

3. Data Archiving

The data archive will be stored in three modules containing the 1) coastal vector data; 2) remotely sensed data and 3) derived products. These modules will be developed, maintained, and archived in one central location (COS), with a backup at a separate location (HCRI). This data archival approach will allow greater flexibility in accommodating the unique demands of each modular set of data and allow for ease of modification without affecting the functionality of other modular databases.

4. Metadata and Citations

Metadata will be created for all new data sets following the Federal Geographic Data Committee (FGDC) standards. The project-level metadata will be created to describe such attributes as the actors, scope, purpose, methods, timeline, and geographic footprint of the project.

Citation information for each dataset will be included in its metadata. Users should also cite the date that data were accessed or retrieved from PICCC sources. We will clearly state that “the PICCC cannot vouch for the data or analyses derived from these data after the data have been retrieved from PICCC sources.”

5. File Structure and Naming Conventions

The following file structure will be implemented across all project phases to facilitate interactive modeling efforts.

1. Spatial Herbivore Management
    1.1. Kona
        1.1.1. Data
            1.1.1.1. Vector
            1.1.1.2. Raster
        1.1.2.
    1.2. Maui

6. Data Dissemination and Outreach

The team will work closely with the PICCC Data Steward to identify specific data collections and derived data products that will be required for submission at the conclusion of the project, including the use of recommended data and metadata standards. As the project nears completion, the project team will once again consult with the PICCC Data Steward to review and assist in formatting of data and preparation of metadata for transmission to the PICCC Data Steward.

At the completion of the project all derived data sets will be shared with PacIOOS (www.pacioos.hawaii.edu) for public distribution. PacIOOS empowers ocean users and stakeholders in the Pacific Islands by providing accurate and reliable coastal and ocean information, tools, and services that are easy to access and use. In addition, the project team will work with PICCC to evaluate the use of the PICCC data exploration tool for additional data dissemination and outreach efforts (http://piccc.databasin.org/).

Appendix B. Contacts for Spatial Data Sources

Contacts for sources of feature and cost layers, as well as layers currently being developed.

Feature Source	Contact Name
NOAA NCCOS 2007	Tim Battista, John Christensen
UNEP	Jeff Maynard
HIMARC	Mary Donovan
Ocean Tipping Points	Lisa Wedding
NOAA Coral Reef Watch	Mark Eakin
Features In Development	**Contact Name**
Bleaching Mortality (NOAA)	Bernardo Vargas-Angel
Current and Potential Gain in Resource Fish Biomass	Kosta Stamoulis
Grazer and Scraper Habitat for Juveniles and Spawners	Jade Delevaux