Workshop Report: A group assessment of coral-reef ecosystem condition across Tutuila, American Samoa, and modeling the individual contributions from human stressors

Dr. Peter Houk

In partnership with:

The Nature Conservancy
American Samoa Coral Reef Advisory Group (CRAG)

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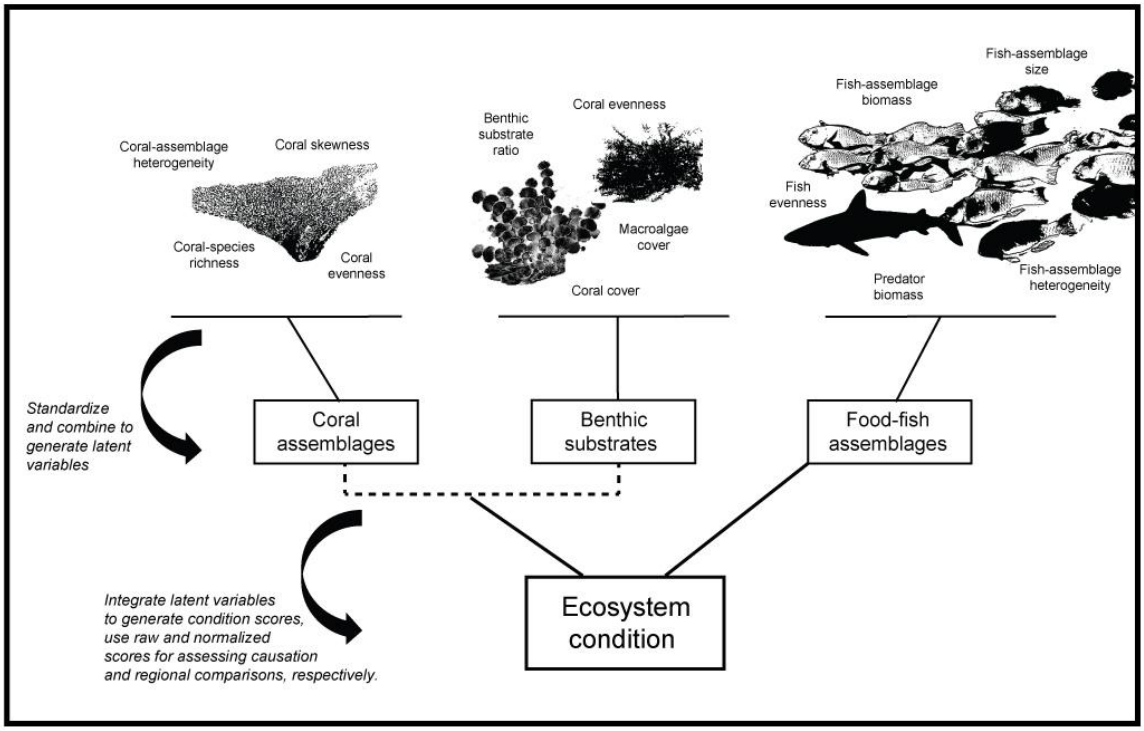
Pago Pago, American Samoa



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Workshop background and summary:

The present workshop represented the third collaborative session between Dr. Peter Houk (instructor) and numerous agencies that collect coral-reef and fisheries monitoring datasets, contribute to management decision making, and together have the mandate to report on the condition of coral-reef ecosystems across American Samoa. The initial workshop conducted in 2008 provided an introduction to database designs, data querying, and basic visualization of data queries using exemplary data from monitoring programs *outside* of American Samoa. Thus, the focus was on developing initial skillsets required for collecting and storing locally-derived data. Following this effort, this same group of agencies and individuals collected a series of standardized coral monitoring data in 2013. The 2013 datasets surveyed 15 sites around Tutuila that had previously been surveyed through partnerships between the American Samoa Environmental Protection Agency (ASEPA), Dr. Houk, and several other colleagues since 2003 (Houk et al. 2013). The initial report using these data investigated coral-reef recovery since Cyclone Heta in 2013, and evaluated ASEPA aquatic-life-use-support rankings following programmatic procedures.

In 2015, a second workshop was initiated through these same partnerships, with the addition of The Nature Conservancy who funded the collaboration as part of their programmatic grant with the National Oceanic and Atmospheric Administration Coral Program. The workshop represented a logical progression of previous analytical themes that were introduced in 2008. Topics covered were relational database development, advanced data querying using univariate and multivariate approaches, assessment of statistical power, and evaluation and planning for monitoring program designs. In addition to new topics being introduced in 2015, the workshop used locally-derived data, with outputs directly relevant to the participants. The workshop focused on two datasets: 1) decadal monitoring of coral, benthic substrate, and fish assemblages collected by Dr. Houk in partnership with American Samoa Environmental Protection Agency (ASEPA), and other affiliated ASCRAG agencies since 2003, and 2) the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Ecosystem Division (CRED) fish datasets collected from Tutuila in both 2010 and 2012 graciously provided by NOAA-CRED scientists. The workshop began with a review of previous concepts, and then advanced into the above noted topics. The format of the workshop included hands-on presentations and exercises conducted simultaneously by both Dr. Houk and participants. However, each day also included independent and group exercises for participants to showcase their skills and present back to the group. Beyond analytical skillsets, key outcomes also included a deeper understanding of coral-reef and fish assemblage dynamics across Tutuila since 2003 developed from the perspective of two different datasets. Last, the workshop was presented in a generalized format with relevance to both terrestrial and marine scientists and managers, as keen interest during the workshop clearly existed across resource managers.

The evaluations from the 2015 workshop highlighted the utility of the collaborative network, and the desire to further efforts. Specifically, there was a desire to have the working group take a standardized approach towards evaluating coral-reef ecosystem condition, and the individual contributions of environmental factors and human stressors in driving condition. This is desirable because as programs continue collecting datasets, findings can be compared in an objective, standardized manner, and eventually a consensus can be approached for prioritizing management efforts that maximize effectiveness. Using the recently published work pertaining to the Micronesia Challenge (Houk et al. 2015), a framework for the 2016 workshop emerged. The accomplishments of the present workshop included: (i) using the skillsets gained in previous workshops to calculate a series of biological metrics that together constitute 'coral-reef ecosystem condition' (Figure 1), (ii) standardize biological metrics pertaining to the fish, coral, and benthic assemblages to come up with a 'score' that was indicative of their health, (iii) use all existing GIS data to develop proxies to both natural environmental factors and human stressors, including wave energy, watershed size, human populations, disturbed land, and distances from both boat-and-vehicle-based fishing access, (iv) standardize environmental datasets so they can be

combined in interactive data models, (v) introduce and build regression models that describe how environments and proxies to local stressors drive reef condition, and (vi) learn how to use advanced graphing techniques to display compelling results. These accomplishments are described further in the daily activities below.

Daily Activities:

- Day 1 and 2 activities included a describing the coral-reef condition evaluation process and creating a list of biological metrics that needed to be extracted from each of the datasets (Figure 1). Individual biological metrics were extracted using data querying techniques from previous workshops. This began as a group step-by-step process, but expanded into more efficient, small-group work in the afternoon. Each small group developed several metrics pertaining to one of the datasets and then reported back to the group on their querying techniques and results. Deriving metrics required the use of both univariate and multivariate approaches to data analysis using MS Excel and PRIMER/PERMANOVA software (Figure 2). Metrics were last combined to evaluate ecosystem condition (Figure 3). Useful discussion and question/answer followed.

- Day 3 focused upon environmental variables that can be used to predict reef condition. Data layers were gathered in the ArcGIS environment and used to derive numerous environmental predictors: long-term wave energy incident on each reef pixel, watershed sizes, land use and human populations, and distances to boat and vehicle access from main launching/starting points (Figure 3). These metrics were investigated together as a group, and for the sake of time, data from only a subset of sites were generated during the workshop. Dr. Houk and graduate students at UOG evaluated the environmental data from remaining sites for use in regression modeling. All GIS layers were shared among participants.

- Day 4 introduced the R-program platform to participants, and started with a discussion on the statistical requirements of regression modeling (Figure 4). We used a forward, step-wise procedure given that we had many environmental variables that contributed both individually and synergistically to ecosystem condition. The manual, step-wise procedure was initiated with the group, but sub-groups were again designated to evaluate key steps along the way. This process allowed all participants to generate their own scripts (i.e., code) for present and future use. Best fit models highlighted the strong contributions of wave energy (up to 20% of the variance explained), fishing access (up to 50% of the variance explained), and disturbed land (up to 20% of the variance explained) in predicting the condition of ecosystem condition (Figure 5).

- Day 5 also used the R platform to teach participants the basic uses of the powerful graphing packagage ‘ggplot’. We focused on general graphics at first, and finally expanded to creating graphs that best depicted the correlation structure of our biological and environmental metrics, and our best-fit regression models (Figure 6).

Figure 1. *Pictoral representation of the process used to evaluate coral-reef ecosystem condition, and latent variables describing the status of coral, benthic, and fish assemblages.*

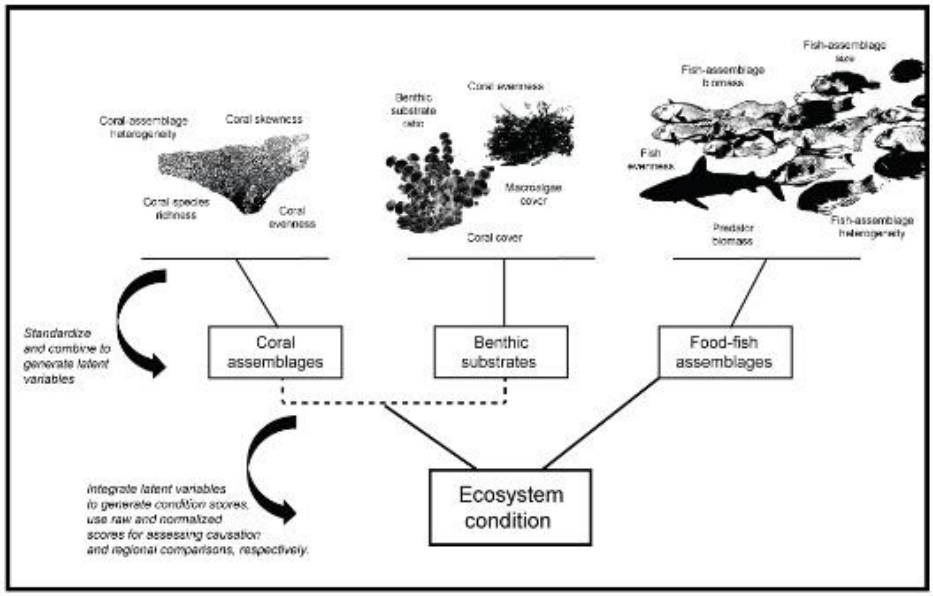


Figure 2. *Assessment of total fish biomass histograms for a suite of monitoring sites on the south coastline of Tutuila derived from Pivot Tables in MS Excel (left). Examining cumulative species dominance curves for the same set of sites. Both fish biomass and fish assemblage evenness represent metrics that were used to evaluate ecosystem condition.*

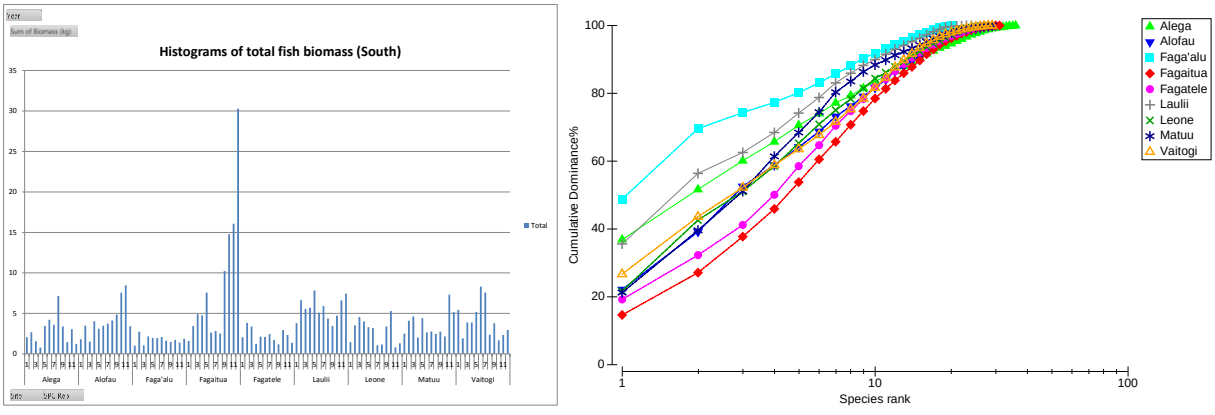


Figure 3. *Map of the monitoring locations with red circle sizes proportional to the ecosystem condition scores shown in Fig. 1. Figure also highlights land-use categories for developing proxies to watershed pollution. In addition to land-use shown here, pollution proxies incorporated human population within each watershed based upon the most recent census for American Samoa.*

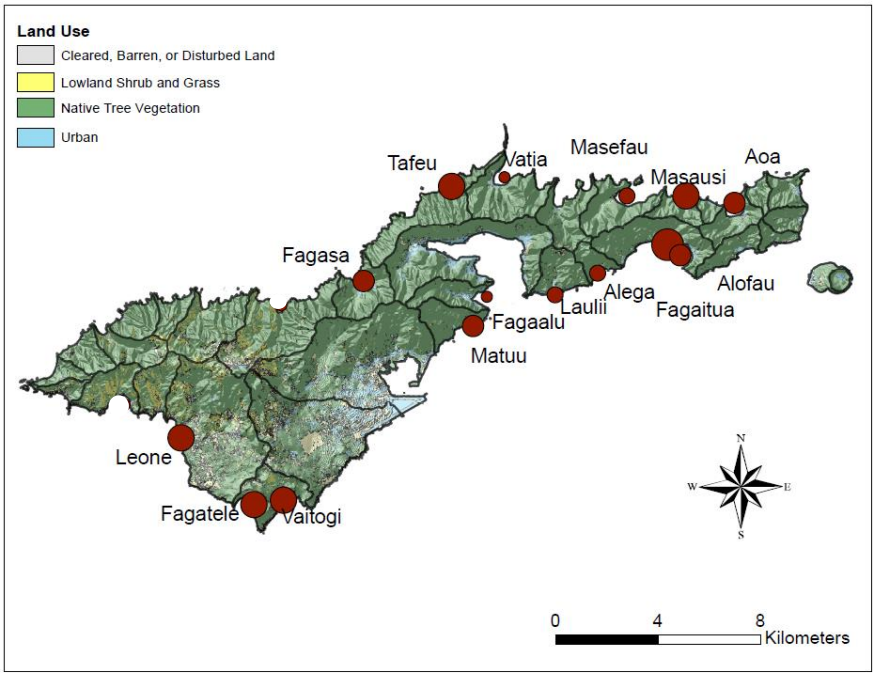


Figure 4. *Screenshot of the Rstudio software environment used to develop and examine ecosystem condition metrics. Here, the code, output, and graphics used to create correlations of the individual metrics that comprised coral-assemblage condition are shown.*

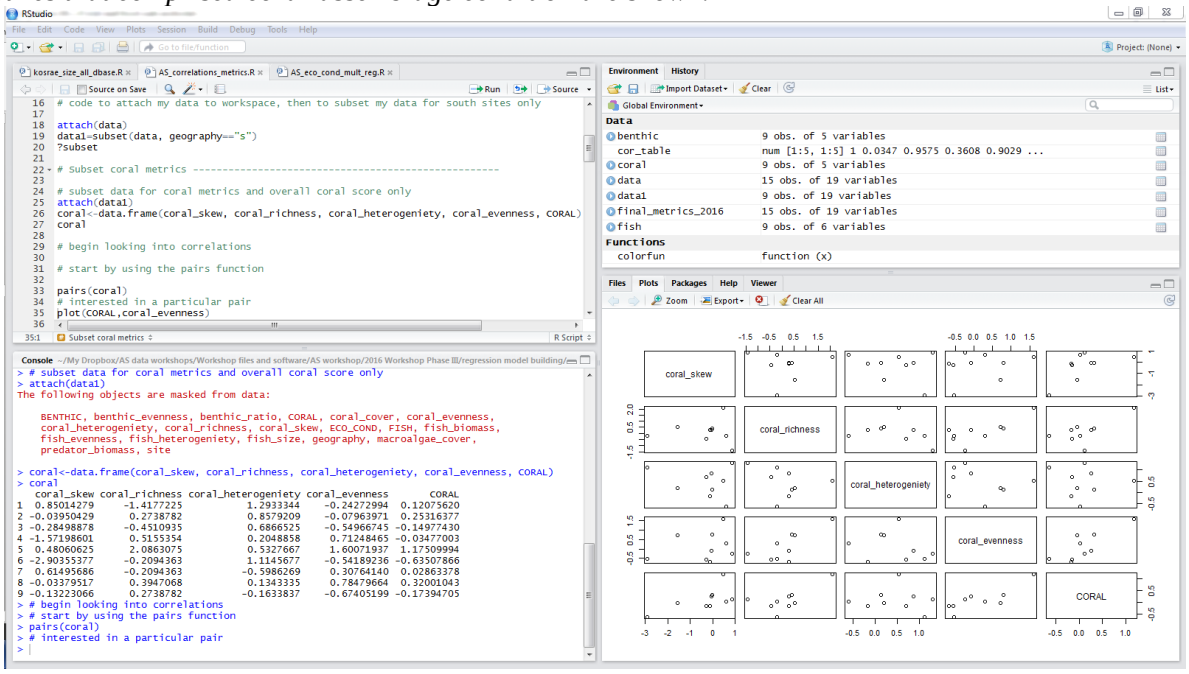


Figure 5. *An enhanced figure showing the same correlation structure among the metrics used to describe the condition of coral assemblages. Here, red colors indicate negative associations, white indicate neutral associations, and blue indicates positive associations. In addition the tighter the ellipse, the stronger the covariance between any two metrics. This is one example of how we took basic information and transformed the results into compelling figures.*

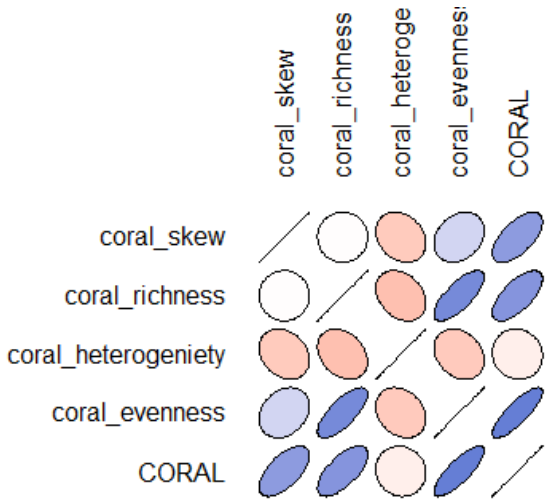
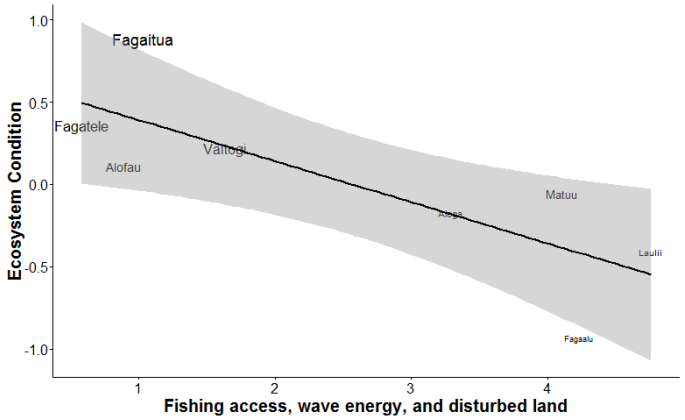


Figure 6. *Final graphic of the workshop displaying the drivers of ecosystem condition. Regression modeling discovered that (i) up to 29% of the variance in ecosystem condition could be attributed to wave energy alone, (ii) up to 56% attributed to proxies to fishing pressure, and (iii) up to 17% attributed to proxies to pollution for the sites on the south side of Tutuila shown on the graphic. This is highlighted as an output product that depicted how we transformed technical knowledge generated from data analyses into user-friendly graphics. Site names are scaled in accordance with their ecosystem condition scores. Axes represent standardized values.*



Summary and Future Directions:

One of the most difficult aspects of local resource monitoring and management programs is to have access to all the emerging tools and expertise that aid in processing and visualizing data. Beyond having access to these tools, working through a question-driven analytical process was a desirable outcome for transferring both knowledge contained within datasets and skills needed to extract this knowledge into the future. Concomitant with planning for the 2016 workshop, collaborative partnerships between UOG, ASEPA, and AS Division of Marine and Wildlife Resources were successful in acquiring a United States Environmental Protection Agency Region IX grant to generate new monitoring data during 2016/2017, and to improve the water quality data available in American Samoa. Details are still being developed, however, key steps will include the collection and synthesis of new datasets using a similar framework applied here. In addition, we hope to expand upon the products available to stakeholders and generate both a peer-reviewed study describing our findings and several outreach materials for use in outreach.

In conclusion, the present workshop bolstered the analytical skillsets of resource managers in American Samoa. There was an appreciation for this line of guidance, and specifically for improving the ability to interpret datasets to approach common questions. What is the health of our reefs? What are the most plausible drivers of poor reef health? How do management priorities differ spatially around Tutuila? What are the thresholds in environmental stressors for resilient reefs? We answered these questions from the perspective of one dataset in 2013, and aim to address the same questions with ongoing data being collected to provide more confidence to our findings.

Last, the feedback and insight provided by the participants to the instructor was also greatly appreciated, and will benefit monitoring programs across Micronesia with whom the instructor has longstanding relationships with.

References:

Houk, P., Benavente, D., Johnson, S. 2013. Watershed-based coral-reef monitoring activities across Tutuila, American Samoa: Summary of decadal trends and 2013 assessment. Technical Report submitted to the American Samoa Environmental Protection Agency, Pago Pago. 37 pp.

Houk, P. et al. The Micronesia Challenge: Assessing the relative contribution of stressors on coral reefs to facilitate science-to-management feedback. PloS one 10, e0130823 (2015).

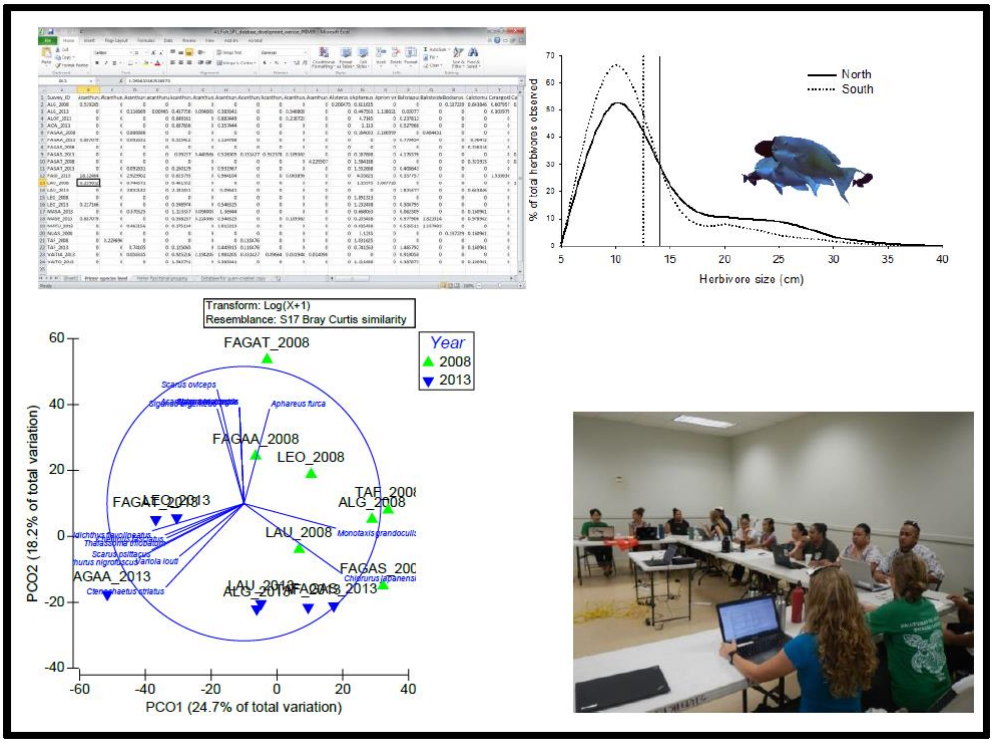
Acknowledgements:

Thanks to the American Samoa Division of Marine and Wildlife Resources for assisting with the workshop logistics, especially Alice Lawrence, Mareike Sudek, and Mia Comeros. Thanks also to Liz Terk, The Nature Conservancy, for logistical support with the workshop and for administering the evaluations. Conversations between numerous local biologists, TNC, and the author were instrumental in guiding the workshop agenda. Most importantly, thanks to all the participants. This report was prepared by the author for The Nature Conservancy under award #NA13NOS4820145 from the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA, the NOAA Coral Reef Conservation Program, or the U.S. Department of Commerce.

Appendix 1. Workshop agenda.

Phase III Coral Monitoring Workshop

Evaluating coral-reef ecosystem condition and the relative contribution of localized stressors across Tutuila, American Samoa



Instructor: Dr. Peter Houk, University of Guam Marine Lab

Partner organizations: AS Division of Marine and Wildlife Resources, AS Environmental Protection Agency, AS Coral Reef Advisory Group, The Nature Conservancy, and the National Oceanic & Atmospheric Administration

February, 2016

Background and Introduction:

In 2008, an initial analytical workshop was held to improve the capacity and skills of coral-reef and wildlife monitoring programs in American Samoa. The initial workshop provided an introduction to database designs, data querying, and basic visualization of data queries using exemplary data from coral-reef monitoring programs *outside* of American Samoa. Between 2009 and 2015, numerous efforts have begun to produce standardized coral-reef monitoring datasets. The American Samoa Environmental Protection Agency (ASEPA) coral-monitoring datasets were of particular interest to managers because they have now spanned across a decade, and encompass a time frame when differential recovery from a natural disturbance (cyclone Heta) occurred. In addition, the program was designed to address localized questions at the site level (i.e., why are some reefs recovering faster than others?, what are the potential contributions of localized stressors?). In this spirit, analytical partnerships were again initiated in 2015. The 2015 workshop utilized the ASEPA dataset and a second long-standing dataset collected by the NOAA Coral Reef Ecosystem Division. The workshop began with a review of previous concepts, and then advanced several key topics: conducting advanced database querying for user-defined needs, assessing statistical power and sampling designs to figure out what questions can and can't be answered, how to build compelling and professional graphics to display data, and finally explored multivariate approaches towards data assessments. The skills being developed in the workshop were presented in a generalized format with relevance to both terrestrial and marine scientists and managers, despite the outcomes being relevant to coral reefs and fisheries. At the end of the workshop, three desired next steps were highlighted by resource managers and scientists. The present workshop focuses on the highest priority need, which is to focus in on 1-2 datasets that are central to local efforts and build an analytical framework to address pressing questions. Pressing needs that would be addressed include: 1) establishing a defendable framework to assess overall ecosystem condition to coral reefs based upon both datasets, and 2) building a causative analysis to determine the relative contribution of local stressors in driving the ecosystem condition scores being generated. We aim to isolate upon two key localized stressors with greatest relevance to AS reefs, fishing pressure and pollution stress. The end result of the workshop would be a defendable assessment of ecosystem condition and the contributions of localized stressors, as well as a framework to continue to do this as more datasets become available.

Agenda

February 2016

Day 1. Intro to workshop. Foundation and history for evaluating 'health' or 'condition' on coral reefs. Review and define metrics that will be used to evaluate 'health'. Use skillsets learned in last workshop to generate individual metrics (Pivot Tables/PRIMER). Review things when needed. Compile all individual metrics for ASEPA sites, discuss their integration and weighting.

Day 2. Finish up individual metrics for ASEPA sites, should have metrics associated with: 1) coral assemblages, 2) fish assemblages, and 3) benthic substrates. Metrics will initially be developed following an approach used in Micronesia, relevant to the Micronesia Challenge (Houk et al. 2015 – url below). Criteria adaption for AS needs/requirements will be discussed and approached with new datasets on Day 5.

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0130823

Day 3. Develop standardized metrics of localized stressors using mainly GIS frameworks. Please have a few computers with ArcGIS installed, I will have all layers needed. Metrics will be develop for natural environmental drivers (i.e., wave exposure), fishing pressure, and land-based pollution. We will discuss and use a combination of GIS tools and local knowledge to produce defendable metrics of local stress across Tutuila.

Day 4 and 5. Using the framework developed, we will create a stepwise process to 'score' each coral reef where monitoring data exists. This process will be relevant to all datasets, and datasets into the future. Using the block of data generated in days 1 to 3, we will learn best approaches for performing multiple regression modeling to examine the extent to which local stressors and natural environments can predict ecosystem condition. This example is specific to coral reefs, but model building using the R software platform can be general to other audiences as well. Together, the analytical outputs serve as key information that serves to monitoring and management of reefs.

Day 4 and 5. Work with DMWR and others who have datasets and formatting needs. Begin paving the way to use these datasets in the same evaluation of 'condition', contrast and compare findings across datasets for robustness.

Contact. Dr. Peter Houk, University of Guam Marine Lab

Software. 1) Excel, prefer 2010 or higher; 2) PRIMER/PERMANOVA, from last workshop; 3) ArcGIS, just a few machines with interested individuals who use this environment; 4) R software (free, https://www.cran.r-project.org/); Rstudio software, easy interface to use R (https://www.rstudio.com/); Download and install packages in R (ggplot2, ellipse, and maybe a few others that need internet if possible). Internet access would be excellent if possible for day 3-4 with regression modeling especially.