FINAL REPORT - I***ntegrating detailed assessments of climate threats on Pacific coral reefs and responses of traditional Hawaiian communities into management planning***

1. ADMINISTRATIVE:

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Project Title I***ntegrating detailed assessments of climate threats on Pacific coral reefs and responses of traditional Hawaiian communities into management planning***

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Actual total cost	$108,000

2. PUBLIC SUMMARY:

Coral reefs are seriously threatened by ocean acidification and climate change impacts like coral bleaching. Importantly though, the degree of threat varies for different coral reef areas due to differences in local and regional climate drivers. Climate models are based on the scientific community's understanding of climate drivers and were used during this project to look forward or 'project' conditions in coral reef areas. The projections are global maps that depict changes in acidification and the frequency and severity of the temperature stress events that cause coral bleaching. The project team found that the date by which really severe bleaching is projected to occur annually varies with latitude. Beyond this date it is not likely that reefs would persist as coral-dominated systems. Reefs in higher latitudes are projected to experience severe bleaching annually later than lower-latitude reefs. Under the fossil-fuel aggressive emissions scenarios that characterize the current situation and emissions growth, all

reefs are seriously threatened by annual bleaching by the mid 2050's; most a decade or two earlier. Refugia from temperature stress are temporary in nature; locations have more time to be exposed to the effects of ocean acidification; there are no refugia from both threats. The projections produced are the subject of two papers in important scientific journals and form the current global standard for this type of research. For the first time, this project resulted in climate projections for coral reef areas being made available to the public via an interactive tool. The climate projections formed the focus of engagement with 2 native Hawaiian communities. Both communities expressed great interest in more personal interaction with researchers and managers and a preference for word-of-mouth type communication when climate impacts occur on coral reefs.

3. PROJECT REPORT

A. TECHNICAL SUMMARY: The technical summary should outline the goals of the original research project and provide a technical description of how these goals were or were not met, highlighting specific achievements. Please state major research accomplishments made possible by receiving PICCC funding. Please indicate how your research results contributed to the advancement of scientific knowledge and/or climate change adaptation regionally and/or nationally.

Coral reefs and the services they provide are seriously threatened by ocean acidification and climate change impacts like coral bleaching. We produced updated global projections for these key threats to coral reefs based on ensembles of IPCC AR5 climate models using the new RCP experiments. We also facilitated discussions with native Hawaiian community members on the results of the climate projections, in the hope of identifying culturally appropriate ways to communicate about climate impacts to corals. The project met all objectives resulting in two high-profile publications, a publicly accessible tool for coral reef managers, and the elicitation of the preferred format for communicating with native Hawaiian communities about climate impacts on corals. A technical summary of the updated projections we produced for coral reef areas based on ensembles of climate models is next, followed by a summary of the results of our facilitated discussions with native Hawaiian community members.

For all tropical reef locations, we project absolute and percentage changes in aragonite saturation state (Ωarag) for the period between 2006 and the onset of annual severe bleaching (thermal stress >8 degree heating weeks); a point at which it is difficult to believe reefs can persist as coral-dominated systems. Severe annual bleaching is projected to start 10-15 years later at high-latitude reefs than for reefs in low latitudes under RCP8.5. In these 10-15 years Ωarag keeps declining, and thus any benefits for high-latitude reefs of later onset of annual bleaching may be negated by the effects of acidification. There are no long-term refugia from the effects of both acidification and bleaching. Of all reef locations, 90% are projected to experience severe bleaching annually by 2055. Further, 5% declines in calcification are projected for all reef locations by 2034 under RCP8.5, assuming a 15% decline in calcification per unit of Ωarag. Drastic emissions cuts, such as those represented by RCP6.0, results in an average year for the onset of annual severe bleaching that is ~20 years later (2062 vs

2044). However, global emissions are tracking above the current worst-case scenario devised by the scientific community, as has happened in previous generations of emission scenarios. The projections of for conditions on coral reefs are dire but provide the most up-to-date assessment of what the changing climate and ocean acidification mean for the persistence of coral reefs. The publicly accessible interactive tool we produced that contains the projections can be found on the NOAA Coral Reef Watch website.

Facilitated discussions with native Hawaiian community members on Maui and Oahu revealed that word-of-mouth or personal communication is preferred for all news/information related to climate impacts on corals. This suggests that chains of communication linking managers/scientists and community leaders have to be established (where do they not already exist) and regularly used. A key finding from this part of our project is that among the community members we met with the base level understanding of climate change is low. It seemed to our group that basic information about climate change has to be shared and uptaken before specific information about climate impacts on corals can have meaning. When news is shared with community members that climate change will impact (or is impacting) corals, the information needs to be place-based, somewhat positive in nature, and be coupled with options for helpful actions.

B. PURPOSE AND OBJECTIVES:

The original objectives were as follows:

1) To produce IPCC AR5 ensemble-based projections for all four RCP experiments for every month between now and 2100 for SST, surface pCO_2, and salinity
2) To use projections to derive degree heating weeks and aragonite saturation state for all reef pixels in the Pacific, enabling us to produce world-first up-to-date projections of reef futures combining the dual threat of coral bleaching events and ocean acidification.
3) To make projections available as maps within interactive web and Google Earth-based management tools complemented with interpretation and how-to-use guides.
4) To increase our understanding of how native Hawaiian communities will respond to coral reef degradation caused by climate change and to develop a communication plan.

These objectives were all met (see results section below) at least to a degree and were not added to or modified during the project.

For the upcoming four sections of the report, the project is set out as having two parts. Part 1 (‘Climate projections for coral reef areas’) includes all of the effort put towards meeting objective numbers 1-3(see above). Part 2 (‘Engagement with native Hawaiian community members’) includes work undertaken to meet objective 4.

C. ORGANIZATION AND APPROACH:

Part 1 – Climate projections for coral reef areas.

Our approaches to generating updated projections for coral reef areas using ensembles of IPCC AR5 climate models are comprehensively described within two publications; van Hooidonk et al. 2013a and van Hooidonk et al. 2014. The methods sections from these two papers are both included below.

From - Van Hooidonk, R., J. A. Maynard, and S. Planes. "Temporary refugia for coral reefs in a warming world." *Nature Climate Change* (2013).

References cited can be found in the publication.

Monthly SST temperature data were retrieved for each available GCM (Table S1 for list) from the World Climate Research Programme's (WCRP's) CMIP5 data set [3] for the relative concentration pathway experiments (RCP2.6 n=15, n=RCP4.5, n=11, RCP6.0, n=10, RCP8.5, n=16) (from http://www.esg.llnl.gov). The new RCPs are comparable to the previously used SRES scenarios, but with considerable refinements, such as a strong reduction in aerosol emissions. For a detailed description of the RCPs and how they differ see [25]. Although the spatial resolution in the new generation of GCMs has increased, the current resolution still does not represent small-scale process that influence local reef conditions such as upwelling or heating on reef flats. Dynamical and statistical downscaling approaches could resolve these issues but are either computationally expensive or introduce additional assumptions and therefore are not applicable to global assessments like those presented here. Statistical downscaling where satellite data is used to project temperatures at reef environments is possible [11] but even those techniques are limited by the spatial and temporal resolutions of the satellite data. Moreover, these statistical approaches train the downscaling model with observed data, data that can be dominated by short-term variability (such as diurnal or intraseasonal). The long-term variability is most important for projections of climate change impacts [26].

To match the start of each model with the observed climatology, the models' mean temperature were adjusted using observational data from the NOAA Optimal Interpolated SST V2 [27] obtained from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, (http://www.esrl.noaa.gov/psd/). Model bias was removed at each location by subtracting the 2006-2011 mean of each model and adding the mean of the OISST 1982-2005 climatology to the entire time series. To improve projections of thermal stress, the annual cycles were replaced with those from the observed climatology [19]. Missing values such as near-coast pixels were filled in using an interpolation routine that solves Poisson's equation via relaxation. This function uses the non missing data as boundaries and interpolates in the zonal direction.

From the 1982-2005 climatology the warmest month was selected at each location as the maximum monthly mean (MMM). Degree Heating Weeks (DHWs) start to accumulate when projected temperatures exceed the MMM; not the MMM+1ºC as in [28]. The positive anomalies for three months were added to get Degree Heating Months and then converted to DHWs by multiplying by 4.34. DHM to DHW conversion is necessary to compare model DHWs with a previously established optimal global bleaching threshold of 6 DHWs [29]. For each cell (1º x 1º) we project the year in which it has 10 (annual) and 2 projected 'bleaching conditions' (>6 DHWs) in a decade. Projections are shown for reef locations only, using the Merged reefbase/UNEP-WCMC and Millennium Coral Reef Mapping Project reefs database (http://imars.usf.edu/MC/index.html). Projections were made for each separate model and for each RCP experiment the median of all models was derived for each location. For each RCP experiment, maps for each of two bleaching scenarios (2x and 10x per decade) were produced using the NCAR Command Language (NCL version 6.0.0) developed by NCAR/CISL/VETS.

From – van Hooidonk, R., Maynard, J. A., Manzello, D., & Planes, S. (2014). Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global change biology*, *20*(1), 103-112.

References cited can be found in the publication.

Ensembles of climate models were used to generate projections of the year when severe coral bleaching events start to occur annually, and of changes in Ωarag. To produce the projections, monthly data for the following variables were obtained from fully coupled models in the Coupled Model Intercomparison Project 5 (CMIP5; http://pcmdi9.llnl.gov/esgf-web-fe/) for all four RCP experiments (Moss et al., 2010): sea surface temperature (SST), surface pressure of CO_2, pH and salinity. All modeled data were remapped to a 1º x 1º resolution grid. Model outputs were reduced to a sub-set of only reef locations. These were obtained from the UNEP-WCMC's Millennium Coral Reef Mapping Project Seascape (http://imars.usf.edu/MC/). A cell was counted as a reef cell if it contained any tropical coral reefs according to the original Seascape database. We have added in all of the main Hawaiian islands.

To calculate DHWs all available models (at the time of writing) that archived SST were used (see Table S1); totaling 25, 35, 17, and 33 models for RCPs 2.5, 4.5, 6.0 and 8.5, respectively. To calculate Ωarag only the models that produce all of the following variables were used: SST, surface pressure of CO_2, pH and salinity (Table S2). This ensures input variables for calculating Ωarag are not sourced from different models, rather an Ωarag projection is produced for a single model prior to model outputs being combined into our ensembles. Total model counts for Ωarag are 7, 8, 4 and 9 for RCP experiments 2.5, 4.5, 6.0 and 8.5, respectively (Tables S1, S2). Model outputs were adjusted to the mean and annual cycle of observations of SST based on the OISST V2 1982-2005 climatology (as in van Hooidonk & Huber, 2012; van Hooidonk et al., 2013).

Degree Heating Months were calculated by summing the positive anomalies above the warmest monthly temperature from the OISST V2 1982-2005 climatology (Reynolds et al., 2002) for each 3-month period. Degree Heating Months are then converted to DHWs by multiplying by 4.35 (see also Donner et al., 2005; van Hooidonk et al., 2013). The output for the projections we present is the year when DHWs exceed 8 every single year in the next ten years; referred to here as the onset of annual severe coral bleaching.

Aragonite saturation state was computed by adopting the routines in the Matlab program CO2SYS (http://cdiac.ornl.gov/oceans/CO2rprt.html) with K1 and K2 constants used from Mehrbach(1973), refit by Dickson (1987).

Several outputs were generated for the acidification projections including: a) the value for Ωarag when 8 DHWs start to occur annually (see above), b) the decline in Ωarag from 2006 to the year when 8 DHWs start to occur annually, and c) the decline in Ωarag expressed as a percentage of the 2006 values. From these data we calculate declines in calcification (as percentages) compared to 2006 rates by using the mean reduction per unit of Ωarag from the meta-analysis presented in Chan and Connolly (2013) of 15%. We also show the extreme ends of the meta-analysis outcomes in that study, the mean ± 1 stdev; 7% and 23% per unit reduction in Ωarag.

Previously, a latitudinal gradient was found in the projected onset of annual bleaching (van Hooidonk et al., 2013) therefore we group reef locations here in latitudinal ranges. Reef locations are grouped in the following 6 latitudinal ranges; -4 to 4º, and on both sides of the equator from 4 to 8º, 8-12º, 12-16º, 16-20º, and for all latitudes higher than 20º. For these latitudinal 'reef areas' we graph the mean ± 1 stdev of the year when 8 DHWs start to occur annually and the percentage change in Ωarag between 2006 and that year. We also track temperature stress and acidification through time and the spread between the models (as standard deviation of the mean of all models at each time step) for the latitudinal reef areas from 2010 to 2100 for RCP8.5.

Part 2 – Engagement with native Hawaiian community members

We chaired meetings on Maui and Oahu whereby we presented Part 1 results to native Hawaiian community members. A 20-minute presentation on projected climate change impacts on Hawaiian coral reefs was followed by a facilitated discussion. Our intent was to describe the climate change projections developed during the first part of the project. This intent was matched by our hope that we could gain insight into how native Hawaiians would prefer: 1) to hear that climate change impacts are occurring on reefs, and 2) that reef condition is gravely threatened by climate change and acidification in the coming decades.

D. PROJECT RESULTS:

Part 1 – Climate projections for coral reef areas.

We have developed bleaching and acidification projections for all of the world's coral reef locations under all four RCP experiments. The RCP experiments from the IPCC CMIP5 (or 'AR5') are akin to the older SRES scenarios and are 2.6, 4.5, 6.0 and 8.5, which all relate to differences in radiative forcing. Each RCP experiment describes future conditions and is shaped by rates of greenhouse gas emissions outputs increases as well as whether emissions stabilize. The figure below helps explain the RCPs (Fig. 1).

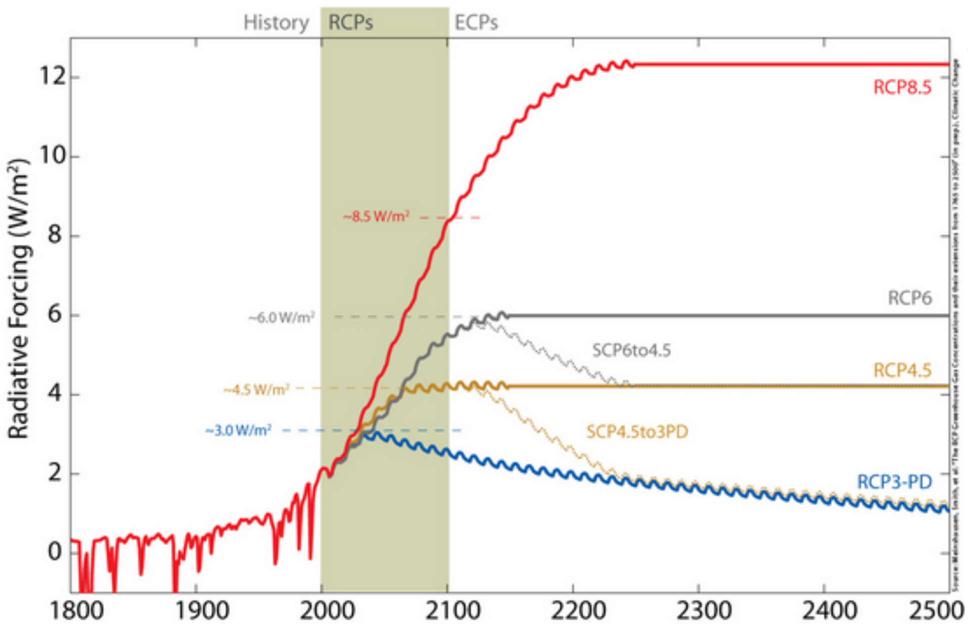


Fig. Global Anthropogenic Radiative Forcing for the high RCP8.5, the medium-high RCP6, the medium-low RCP4.5 and the low RCP3-PD. In addition, two supplementary extensions are shown, connecting RCP6.0 levels to RCP4.5 levels by 2250 (SCP6TO45) or RCP45 levels to RCP3PD concentrations and forcings (SCP45to3PD). No uncertainty ranges are shown and reported, as for creating the recommendation datasets for CMIP5, central estimates have been assumed closely in line with central estimates in IPCC AR4.

Fig. 1. Radiative forcing differences among the IPCC CMIP5 (AR5) Representative Concentration Pathway (RCP) experiments. In RCP experiments 8.5, 6.0 and 4.5 emissions grow until 2100, the last year used in our projections. Emissions continue to increase only to ~2030 in RCP2.5, at which point they decline (source: http://www.pik-potsdam.de/~mmalte/rcps/)

We have developed all of the following bleaching and acidification scenarios for all four RCP experiments. For bleaching, we have four scenarios: 1) 6 Degree Heating Weeks (DHWs) are experienced 2 times per decade, 2) 8 DHWs are experienced 2 times per decade, 3) 6 DHWs are experienced 10 times per decade, and 4) 8 DHWs are experienced 10 times per decade. Providing projections for all scenarios ensures we project conditions likely to cause bleaching at sites all along the sensitivity continuum. Sites highly sensitive to bleaching may experience bleaching regularly during a decade in which 6 DHWs are expected twice or more times. Sites that are not expected to be sensitive to bleaching may not experience bleaching regularly until 8 DHWs are experienced annually. For all bleaching scenarios, a year is the final output and this is the year in which a decade starts that contains either the 2x or 10x occurrence of bleaching conditions (depending on the scenario). Years are then assigned to a colour via a colour ramp we have developed with a unique colour for each decade between 2010-2100. An example output is shown just below as Fig. 2 and the models included for each RCP experiment are shown in Appendix 1.

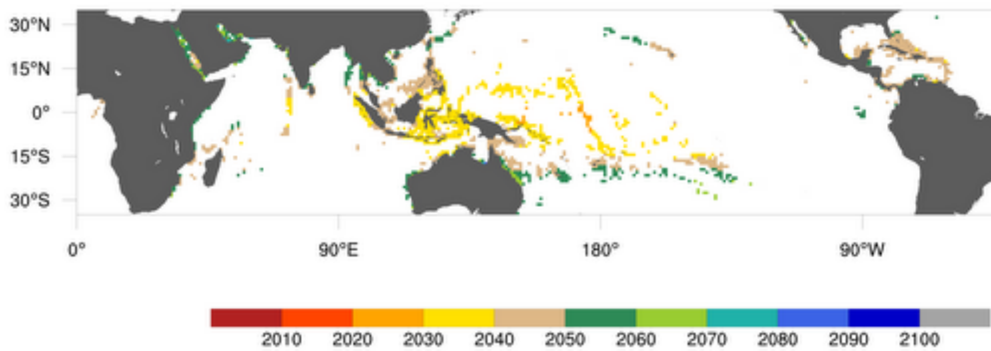


Fig. 2. Example image output from our project work showing the year in which 8DHWs are projected to occur annually based on RCP8.5. This output suggests that conditions more severe than the conditions that have caused bleaching in NWHI in the past will occur annually in the main Hawaiian islands in the 2040s and in NWHI in the 2050s.

In the final tool we created for managers we present 8 acidification scenarios; 4 for absolute change, 3 for percent change, and 1 for calcification. Most previous published work on ocean acidification as it relates to coral reefs focuses on aragonite saturation state (Omega-A). Numerous thresholds have been suggested for Omega-A as being the points beyond which either coral skeletons are weakened and/or the balance tips towards net erosion rather than net accretion. Thresholds used include 3.5, 3.25, 3, and in extreme cases 2.75. We see all of this as highly problematic because the current Omega-A differs all over the world and the diurnal variation is as great as the variation expected in 'average' conditions between now and 2100. For consistency with some of the previous work we have produced projections of the years in which Omega-A drops below and then never rises above the following absolute thresholds: 3.5, 3.25, 3.0, 2.75, and 2.5. Supplementarily, given every location is starting from a different base Omega-A, we have produced world-first projections showing % change in Omega-A. We have calculated the year in which the following % decreases have occurred based on decadal averages – 15%, 20, 25, 30, 35, and 40% - for all four RCP experiments.

Fortunately, research on the relationship between acidification and calcification advanced greatly during the grant period. A group in Australia that our team has worked with in the past published a meta-analysis that provided an average rate of calcification decline for each unit decline in Omega-A (Chan and Connolly 2013). The meta-analysis is based on previously published work (27 studies) and presented an average rate of 15%, with the lower and higher extremes based on standard deviation being 7 and 23%. Knowing this, we were able to produce projections for all coral reef areas of declines in calcification under the different RCP scenarios (a world-first). In the tool made publicly available to managers we only show the projections that calculate calcification reductions by multiplying declines in Omega-A to 15%. In total, we produced 32 images for the acidification projections. An example is shown below as Fig. 3.

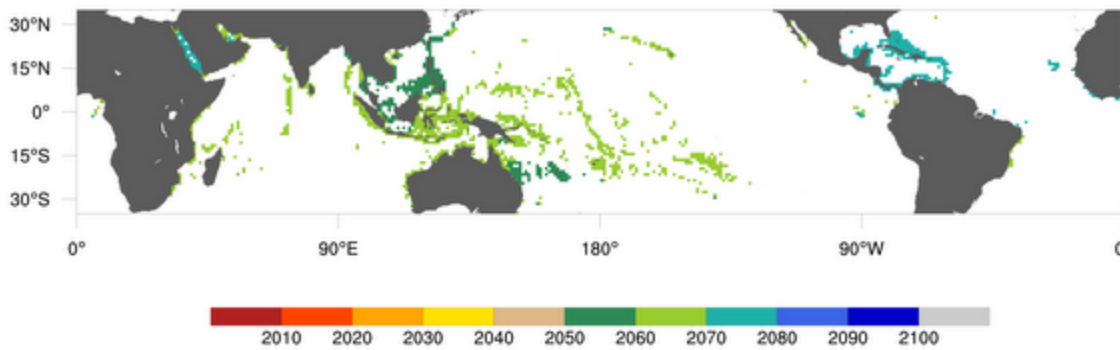


Fig. 3. Year in which aragonite saturation state is projected to have decreased by 25% under RCP8.5. This change is projected to occur for all reef locations by the 2070's (example of the type of projection produced – many more figures are available in the project publications (see outputs section)).

We have a grand total of 56 of the images seen in Figures 2 and 3 in the tool we produced for managers. The tool is a a KMZ file that enables our full image suite to be viewed through Google Earth. We see the tool as being the hallmark output produced by our team during the grant period. The tool represents the first time that climate change projections for coral reef areas have been made publicly accessible. We involved PICCC in the development of the tool and revised our 'About this tool' text inside the Google Earth file as well as our website text following input from more than nearly 2-dozen people in total outside the lead group. Jeff Burgett of PICCC coordinated a review of the tool by managers and scientists in Hawaii. Five reviewers provided comments that improved our presentation of the projections and the text we used to describe the tool. Nearly all reviewers wanted us to cull the methods in our introductory text, better describe the differences among the RCPs, and explain how the images could be used. There were also various requests that could not be met that would have resulted in our having many pages of introductory text. The main example here is that we decided to refer users/viewers to other publications that comprehensively summarise climate change impacts on coral reefs so that we could focus on the projections. At final reporting an email was sent to reviewers that worked with the PICCC to thank them for their assistance with the project and to provide a link to the final website for the tool.

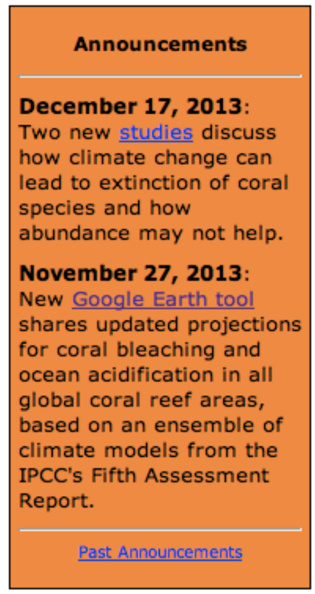
When the tool was close to being published a debate arose as to where the tool should be hosted. The lead team of PIs and PICCC staff all initially thought that the tool would be hosted on the PICCC website. This was possible, even though the PICCC website was being re-designed late in our grant period. However, in the end, the decision was made to have the tool hosted on the NOAA Coral Reef Watch (CRW) pages. We communicated with PICCC at several points in the decision-making process and our rationale for having the tool hosted on the CRW site included all of the following:

1. CRW is the world's authority on providing images to the coral reef community that present the relationship, known or suspected, between environmental conditions and the state of coral reefs.

2. CRW staff include IT professionals that build and maintain database and web-dissemmination systems – they could easily build the website and debug and test it.

3. Maintaining websites can be resource-intensive and CRW already has the ongoing mandate to ensure their website pages and the tools presented are either operational (full 24-hr support) or 'best-effort operational' (back up within 24 hrs).

In summary, for no cost whatsoever, the world's authority in this working area presented our work on their webpages and will maintain the site forever without any of our group or PICCC ever having to do anything (http://coralreefwatch.noaa.gov/climate/projections/piccc_oa_and_bleaching/index.php). Further, they allowed the lead PI on the project, Jeff Maynard, to write all website text, and PICCC is acknowledged as the project main funder within the text and is even in the web address/link for the site. This was all made possible through links between the lead PI, CRW staff and the head of the NOAA Coral Reef Conservation Program, John Christensen, who asked CRW to meet our request in a timely fashion. CRW also agreed to put a teaser on the front page of the website and to leave it up for 6 months (see right). Google audits their pages and hundreds of people have accessed the site already. The site was advertised on Coral-List as well as email list-serves run by TNC and NOAA that reach a total of >5000 people in the coral reef scientific and management community.



Announcements

December 17, 2013: Two new studies discuss how climate change can lead to extinction of coral species and how abundance may not help.

November 27, 2013: New Google Earth tool shares updated projections for coral bleaching and ocean acidification in all global coral reef areas, based on an ensemble of climate models from the IPCC's Fifth Assessment Report.

Past Announcements

A picture of the website for the tool appears below as Figure 4.

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
DOC > NOAA > NESDIS > STAR > CRW

Coral Reef Watch
CRTF | CRCP | CREIOS | CoRIS

CRW Home
Product Overview
Near-Real-Time Data
Experimental Products
Research Activities
Projections: OA/Bleaching
Ocean Acidification
Hydrodynamic Modeling
Paleoclimatology
High-resolution SST
Decision Support System
QCed Bleaching Obs
Outreach/Educati
Research Partnerships
Publication List
Report Bleaching
About Us

Projections of Coral Bleaching and Ocean Acidification for Coral Reef Areas (based on ensembles of IPCC AR5 climate models)

Click on the image above to save or launch Google Earth product

Coral reefs and the services they provide are seriously threatened by ocean acidification and climate change impacts like coral bleaching. Here, updated global projections for these key threats to coral reefs are presented based on ensembles of the IPCC Fifth Assessment Report (AR5) climate models using the new Representative Concentration Pathway (RCP) experiments. More information can be found on the IPCC's new RCPs here.

All projections presented within van Hooidonk et al. (2013) are shown in a Google Earth file (a kmz file, ~1.2MB) presented on this web page. We encourage all viewers to read the Contents Description found at the 'About this product' page at the top of the file directory structure containing the images (see "My Places" in the left-hand side of the Google Earth interface).

The methods and the names of models used in the projections can be found here.

Problems viewing the file are likely to have one of three causes: 1) you need to clear everything from your 'My Places' folder or need to de-select anything saved there; 2) you need to download the most current version of Google Earth from this link; or 3) the limitations of your PC or graphics card don't allow for the file to be viewed.

This research was made possible by a grant to the authors of van Hooidonk et al. (2013) by the Pacific Islands Climate Change Cooperative.

Any information used from these projections should be cited as 'van Hooidonk et al. (2013)' and images screen captured from the Google Earth file should always appear with 'adapted from van Hooidonk et al. (2013)' if used in presentations or reports.

For questions about the projections and methods please email Ruben van Hooidonk at ruben.van.hooidonk@noaa.gov.

References

van Hooidonk R, Maynard J, Manzello D, Planes S (2013) Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global Change Biology*, doi: 10.1111/gcb.12394.

van Hooidonk R, Maynard J, Planes S (2013) Temporary refugia for coral reefs in a warming world. *Nature Climate Change*, 3, 508-511, doi: 10.1038/nclimate1829.

Figure 4.NOAA Coral Reef Watch website presenting our team's bleaching and acidification projections for coral reef areas (http://coralreefwatch.noaa.gov/climate/projections/piccc_oa_and_bleaching/index.php).

The research undertaken to develop the projections, the projections themselves, and the tool created for managers was all published in two of the top journals in this field: *Nature Climate Change* and *Global Change Biology.* The papers and the publicly accessible tool demonstrate our commitment to solidify advances made during the grant within the literature and to make our work available to the general public.

In total, our projections represent the sum total of some 15 months of person-hours spread across three people; mostly Drs. Maynard and van Hooidonk. We began our preparations last July such that the work could be completed in 6-8 months once the grant funds were transferred. We ended up heavily over-spent despite having some funds from Part 2 (see overview below) of our project that we could use to help with final development of our Google Earth tool and website. In the end, roughly a third of our time spent working towards the project deliverables was covered by complementary research grants to the lead PI meaning our total in-kind contribution was far greater than expected. Our full directory of images and file associated with the projections have been made available to the PICCC and all requirements of our team's Data Management Plans have been met.

Part 2 – Engagement with native Hawaiian community members

In the second part of our project work, we held meetings with native Hawaiian community members in Lahaina, Maui and in Honolulu. When the project was initially conceived the leadership team thought that participants at the meetings would provide us with suggestions for 1 and 2 (just listed) that would mean we could develop some communications products. However, we did not receive any recommendations for communication products that could feasibly be developed with the limited resources (5-10K) we had for this project phase. In total, these resources represented less than 10% of the grant funds so we shifted them to be able to maximize delivery in the parts of our work where it became clear we could achieve the most – the phases described above that culminated in the development of our Google Earth tool. Even so, much was learned during the meetings we held and Papahanaumokuakea Marine National Monument (PMNM) will undertake the word-of-mouth communication with community leaders during bleaching events suggested by many of the meeting participants.

Below, we summarize the two meetings by describing the number of attendees and then listing comments brought up by participants that form: suggestions for climate change communications, 'do's and don'ts' of communication, recommended strategies for building resiliency and questions that arose. As introduction, it is worth pointing out that we found the base-level understanding of climate change among meeting participants to be poor, certainly far poorer than we were expecting. This meant that it was extremely difficult to focus discussions on *how to communicate with native Hawaiians about climate change impacts on coral reefs*. Participants wanted to focus on understanding climate change and felt all communications about climate change should focus on expected highly localized impacts and impacts on seafood security, both of which are essentially unknown. Therein was the only potentially actionable (for our funding amount) communication product recommended; a 'fact sheet'. The facts desired though, as above, related to highly localized impacts on the secondary

effects climate change impacts on reefs would have on food security, which was far from the focus of our study. As above, facilitating the meetings posed challenges for meeting facilitators but in the end commitments were made to continue the discussions during upcoming years and to increase word-of-mouth/personal communication between managers and community leaders. We saw this as a positive outcome and all participants expressed their gratitude at being given the opportunity to learn of our work and discuss communication strategies.
PICCC staff should note number 36 from our notes taken during the Lahaina meeting.

Communicating about Climate Change Impacts on Coral Reefs in Hawaiʻi

Presentations developed by Jeff Maynard and delivered by Randy Kosaki & Heidi Schuttenberg
Facilitation & Notes: Keoni Kuoha

Perspectives from Lahaina (Sep 3, 2013)

Demographics

Number of participants: 15
Approximate median age: 45
Native Hawaiian participants: ≈ 90%

How to make climate change communications relevant to Native Hawaiians:

1. use instruments that matter (ex. cultural practitioner as data collection tool)
2. use metrics or indicators that matter (ex. fishponds)
3. use a relevant scale (the big picture is not as relevant, because the ability to make a difference is small)
4. build relationships
5. create incentives (ex. grant funding)
6. put culture first and science second

What are some communication tools relevant to Native Hawaiians?

7. primary and secondary school curriculum
8. local news
9. word-of-mouth
10. “key” people that speak on the subject; local people whom others recognize
11. face-to-face meetings and discussions; “old style”
12. computer applications and games

What are some of the dos and don’ts of communications with Native Hawaiians?

13. Don’t formulate research questions and communication goals and methods in a vacuum.
14. Don’t have outside scientists come in.
15. Do create partnerships with Native Hawaiians to formulate and implement research.
16. Do work with locals.
17. Do choose projects that are relevant to Native Hawaiians.

18. Do be transparent in action and intention.
19. Do have someone who is acculturated to Hawaiian modes of communication.
20. Do utilize traditional Hawaiian knowledge.
21. Do have a local base for data collection and decision-making.
22. Do report data that is location specific.
23. Do focus on local solutions.
24. Do recognize that the knowledge that is attained from someone belongs to that someone.
25. Do recognize that each island and each community in Hawaiʻi is unique.

What are some strategies to building resiliency?

26. Close down everything. Put a kapu on access to vulnerable resources until such time as human impact upon those resources is understood and mitigated.
27. Bring back and support the natural system.
28. Ask large companies and land owners to change their unsustainable behaviors.
29. Change public perceptions in order to change the political will to make changes that build resiliency.
30. Recognize that fresh water is important to ocean ecosystems.
31. Create an adopt-a-scientist program with communities in order to build more meaningful partnerships between different knowledge keepers in order to address climate change impacts.
32. Develop curriculum through which children can help impact the behaviors of their parents.
33. Educate decision-makers and opinion shapers.
34. Strengthen enforcement measures to support climate change resiliency.

Some questions that came out of the meeting:

35. What is the impact of bleaching events on food species?
36. How is the feedback provided at this meeting going to impact communication strategies at PICCC?

Perspectives from Mānoa (Sep 24, 2013)

Demographics

Number of participants: 14
Approximate median age: 25
Native Hawaiian participants: ≈ 60%

How to make climate change communications relevant to Native Hawaiians:

1. focus on food security
2. focus on solutions

What are some communication tools relevant to Native Hawaiians?

1. communication networks supported by government agencies, NGOs, regional organizations (ex. IPMEN, CI Coral Triangle)
2. social media with images and interviews
3. fact sheets describing projected highly localized impacts on food security
4. infomercials
5. storytelling
6. performing arts
7. early childhood education

What are some relevant sources of climate change information?

8. national meteorological services
9. the people that are utilizing ocean resources

What are some of the dos and don'ts of communications with Native Hawaiians?

10. Do be clear on the connection between climate change and the impacts people will experience.
11. Do enable people to tell their own stories through media, like video.

What are some strategies to building resiliency?

12. Bring together a range of people from different sectors of the community (ex. students, tourism).

Some questions that came out of the Lahaina meeting:

13. What is the time between a bleaching event and the point where there is an impact upon food species?
14. How will climate change affect the shoreline?
15. How might climate change impact the presence of ciguatera in fish?
16. What is the economic impact of climate change on our islands and communities?
17. Can coral bleaching or ocean acidification have impacts on terrestrial ecosystems?
18. Does ocean acidification affect the chemistry of precipitation?
19. What is the potential positive impact of climate change?

E. ANALYSIS AND FINDINGS:

Project accomplishments include 2 high-profile scientific publications, an interactive publicly accessible tool describing projected climate impacts on coral reefs, and 2 facilitated discussions with native Hawaiian communities.

F. CONCLUSIONS AND RECOMMENDATIONS:

The key project results are as follows:

Part 1 - The future is bleak for coral reefs under the fossil-fuel aggressive emissions scenario that characterizes current conditions. The timing and degree to which bleaching and acidification threatens reefs varies greatly spatially. Our projections provide the most up-to-date and comprehensive understanding of spatial variability in the threats posed to reefs by climate change and acidification. For the first time, such projections have been made available to the public.

Part 2 – Native Hawaiian community members express a strong preference for word-of-mouth communication between managers/scientists and community members. This suggest that 'chains of communication' linking managers/scientists with community leaders have to be both established and used. The preference for a greater frequency of personal communication isn't new but does highlight the need for development of talking points that describe anticipated climate impacts to Hawaiian ecosystems. For any communication about climate change to be impactful, information needs to be place-based, be somewhat positive in nature, and be coupled with options for helpful actions.

Climate research is highly complex and undertaking and then reporting on scientific research always includes overcoming obstacles. Many problems were encountered and then overcome; too many to list here. However, all project tasks were completed. If we were to undertake the project again, we might not have terribly under-estimated the time-intensiveness of some of the tasks.

We are interested in running new projections that would take account of the relationships between aragonite saturation state and the calcification rates of key calcifying algae like *Halimeda*. This was first proposed to us by Jeff Burgett and is definitely a fruitful area of research given the importance of calcifying algae to reef systems. The two lead PIs, Drs. Maynard and van Hooidonk will explore this idea further during this coming year and will report back to PICCC about any progress made. We have a NOAA Climate Program Office grant through Cornell University that will have the lead PI, Jeff Maynard, exploring the relationships between temperature stress and coral disease. Research in this area is expected to result in the identification of marine disease hotspots based on projections of future conditions.

A key outcome of our project work is that anticipated future impacts in coral reef areas can be described quantitatively by anyone willing to read our papers and quickly learn how to use the interactive tool. This means that policy and decision-makers anywhere can show the projections for their area either to other policy and decision-makers or to the public. We have created a greater understanding of what the future may hold for coral reefs and a greater capacity to communicate about the future of coral reefs. We have many links to authors of the IPCC reports and our work is certain to feature in upcoming versions of the IPCC's Summary for Policymakers.

G. OUTREACH:

We would have liked to undertake more outreach but simply couldn't with the resources we had during the project tenure. Highly non-technical summaries of our work are urgently needed and we are interested in pursuing grant opportunities to develop a high school student curriculum that describes climate change impacts using coral reefs as a case study. The current EPA Education grants represent one potential funding opportunity to develop such a curriculum.

H. SCIENCE OUTPUTS:

van Hooidonk, R., Maynard, J. A., Manzello, D., & Planes, S. (2014). Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global change biology*, *20*(1), 103-112.

van Hooidonk, R., J. A. Maynard, and S. Planes. "Temporary refugia for coral reefs in a warming world." *Nature Climate Change* (2013).

We have presented our work informally in Australia, Hawaii, the mainland US and France. We will present the work at conferences during this and next year and at the next International Coral Reef Symposium in Hawaii.