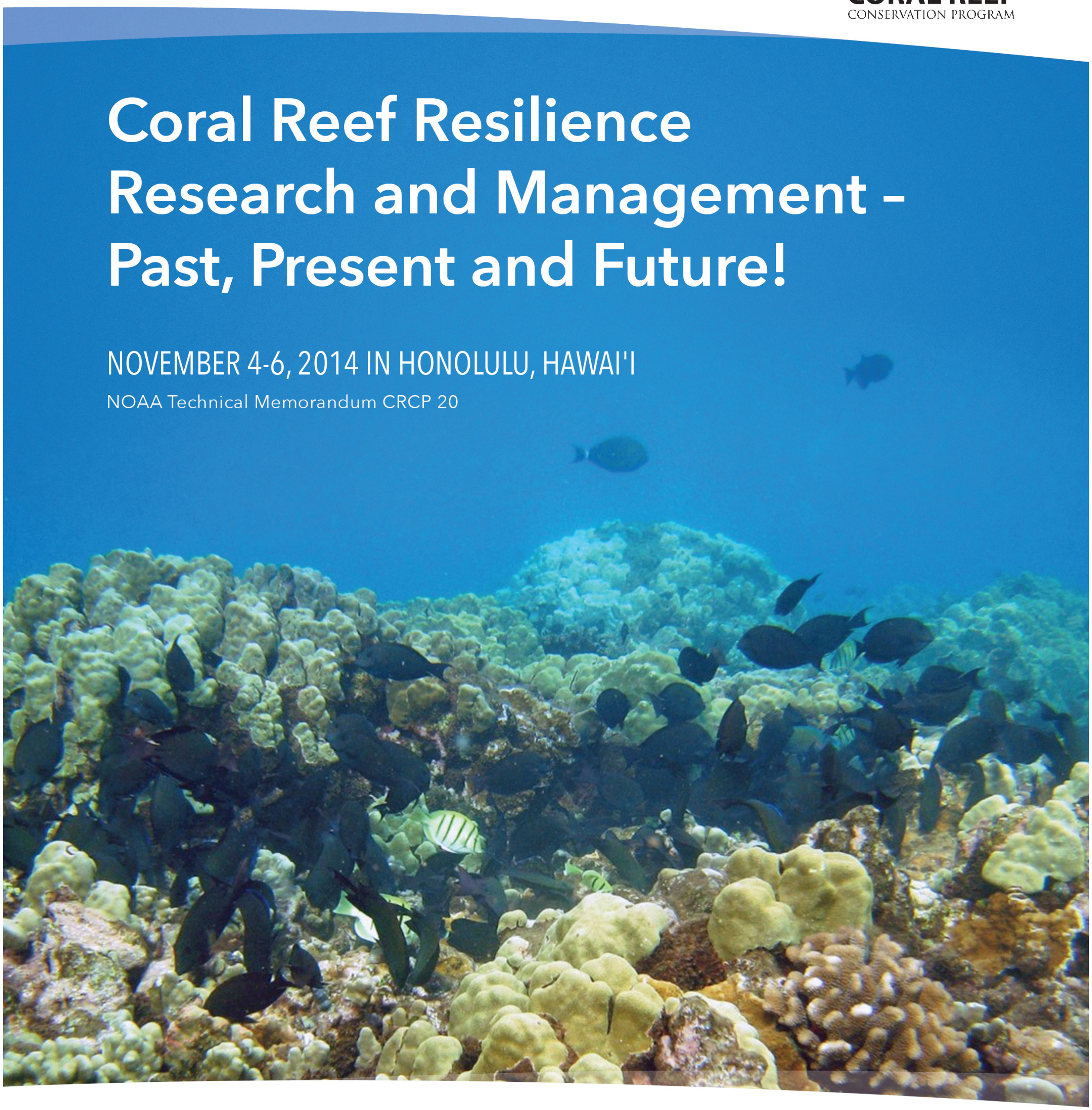
NOAA CORAL REEF CONSERVATION PROGRAM

Workshop Report



Coral Reef Resilience Research and Management – Past, Present and Future!

NOVEMBER 4-6, 2014 IN HONOLULU, HAWAI'I

NOAA Technical Memorandum CRCP 20

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Coral Reef Resilience Research and Management – Past, Present and Future! Workshop Report

Maynard, J., B. Parker, R. Beeden, J. Tamelander, P. McGowan, L. Gramer, S. Heron, M. Kendall, S. McKagan, E. McLeod, K. Oleson, and S. Pittman

National Oceanic and Atmospheric Administration
National Ocean Service
Office for Coastal Management
Coral Reef Conservation Program

May 2015

NOAA Technical Memorandum CRCP 20

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
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Maynard, J., B. Parker, R. Beeden, J. Tamelander, P. McGowan, L. Gramer, S. Heron, M. Kendall, S. McKagan, E. McLeod, K. Oleson, and S. Pittman. 2015. Coral Reef Resilience Research and Management – Past, Present and Future: Workshop Report. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 20. 47pp.

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ACKNOWLEDGEMENTS:
Travel and meeting costs for the workshop were primarily supported by funding from the NOAA Coral Reef Conservation Program. The Great Barrier Reef Marine Park Authority, The Nature Conservancy, and the United Nations Environmental Programme supported attendance costs for representatives from those organisations. Thank you to Chris Caldow (NOAA) and Paul Marshall (Reef Ecologic) for providing technical review of the document.

Cover Photo Credit: Darla White (Hawai'i Department of Aquatic Resources)
Group Photo Credit: Roger Beeden (Great Barrier Reef Marine Park Authority)

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Workshop Attendees

The table below lists all attendees of the workshop.

Last	First	Affiliation
Anders	Emma	Hawai‘i Department of Aquatic Resources
Beeden	Roger	Australian Great Barrier Reef Marine Park Authority
Conklin	Eric	The Nature Conservancy
Delevaux	Jade	University of Hawai‘i - Manoa
Donovan	Mary	University of Hawai‘i - Manoa
Gramer	Lew	NOAA Atlantic Oceanographic and Meteorological Laboratory
Harper	Doug	NOAA Office for Coastal Management
Heenan	Adel	NOAA PIFSC Coral Reef Ecosystems Division
Heron	Scott	NOAA Coral Reef Watch
Johnston	Lyza	CNMI Bureau of Environmental & Coastal Quality
Kendall	Matt	NOAA National Centers for Coastal Ocean Science Biogeography Branch
Kosaki	Randy	NOAA Papahānaumokuākea Marine National Monument
Lameier	Mike	NOAA NMFS Pacific Islands Regional Office
MacGowan	Petra	The Nature Conservancy
Martinez	Jonathon	NOAA Hawaiian Islands Humpback Whale National Marine Sanctuary
Maynard	Jeff	Marine Applied Research Center

McKagan	Steve	NOAA NMFS Pacific Islands Regional Office
McLeod	Lizzie	The Nature Conservancy
Oleson	Kirsten	University of Hawai'i - Manoa
Parker	Britt	NOAA Coral Reef Conservation Program
Pittman	Simon	NOAA National Centers for Coastal Ocean Science Biogeography Branch
Rosinski	Anne	Hawai'i Department of Aquatic Resources
Schumacher	Brett	NOAA PIFSC Coral Reef Ecosystems Division
Stamoulis	Kosta	University of Hawai'i - Manoa
Tamelander	Jerker	United Nations Environmental Programme
Teneva	Lida	Conservation International
Vargas-Angel	Bernardo	NOAA PIFSC Coral Reef Ecosystems Division
White	Darla	Hawai'i Department of Aquatic Resources

Attendees of the Coral Reef Resilience Research and Management Workshop. Photo taken November 4, 2014 in Honolulu, Hawai'i.

Workshop Summary

Background

Each year, subject to the availability of funds, the National Oceanic and Atmospheric Administration Coral Reef Conservation Program (NOAA CRCP) awards grants for applied research that informs conservation and management of coral reefs within the U.S. and abroad. During recent years, project funds have been awarded to scientists and managers working to increase our understanding of reef resilience and of the application of resilience thinking in management decision-making. This workshop's overarching purpose was for recent grantees working on resilience-related projects to meet and discuss synergies and complementarities among existing and planned projects and identify high priority next steps in resilience research and application in management.

Resilience is a term and concept used in many fields and contexts. Resilience has many definitions in the scientific literature, even when it is used specifically in the context of coral reef ecosystems. Standish and coauthors (2014) recognized that the concept of resilience, especially as it has grown in popularity, has become vague, varied and difficult to quantify. These authors attempted to clarify the concept from the ecological perspective in definition and its application to ecosystem management (see summary table below).

Ecological References	Definition
Hollings, 1973	Defines resilience as the capacity of an ecosystem to tolerate disturbance without switching to a qualitatively different state that is controlled by a different set of processes (often referred to as ecological resilience).
Pimm 1984	Defines resilience in terms of the time taken to return to the pre-disturbances state (often referred to engineering resilience; recovery)
Coral Reef References	**Definition**
Hoegh-Guldberg et al 2007	Defines coral reef resilience to disturbance in terms of recovery time (engineering resilience)
Hughes et al. 2007	Defines coral reef resilience to disturbance in terms of its capacity to absorb recurrent disturbances or shocks and adapt to change without fundamentally switching to an alternative steady state (ecological resilience)
Côte & Darling 2010 **McClanahan et al. 2012**	Define coral reef resilience as a two part process of resistance and recovery (involves both engineering and ecological resilience)*
**Note that a recent publication by Mumby et al 2014 also discusses these two forms of resilience in the ecological literature and their pros and cons noting that ecological resilience is ideal where an ecosystem risks losing its ability to recover and driving itself to an undesirable state while engineering resilience is useful where ecosystem recovery is commonplace.*	

Operationally, from a coral reef management perspective, resilience is the capacity of a reef to resist and/or recover in the future given its probable exposure regime *and* to maintain provision of ecosystem goods and services (Mumby et al. 2007). The first half of this definition speaks to ecological and engineering resilience and the second to the strong links between ecological and social resilience, especially in areas where communities are dependent on reefs for food security and livelihoods. It is this combination of factors that is of interest to the Coral Program.

For the purposes of this report we also use the term 'resilience-based management' to mean the application of resilience theory, thinking and tools to deliver ecosystem-based management outcomes into the future. Used in this way resilience-based management serves as an approach that managers can take to evaluate whether existing or new actions are likely to maintain ecosystems and the goods and services that they provide as the climate changes. Our intention in using the term resilience-based management is to serve as a practical 'short-hand'; to reduce terminology confusion (see Mumby et al. 2014) while highlighting the vital importance of considering future conditions and consequences when making contemporary management decisions. Our use of the term is consistent with its use in Bestelmeyer & Briske (2012) in regards to rangeland management in the United States. *"We argue that progression from steady-state management to ecosystem management has served the rangeland profession well, but that further development toward resilience-based management is required to ensure that ecosystem services are sustained in an era of rapid change. Resilience-based management embraces the inevitability of change and emphasizes that management should seek to guide change to benefit society."* The key differences in steady-state, ecosystem, and resilience-based management are summarized in the table below (Bestelmeyer and Briske, 2012). More information on resilience based approaches to managing coral reef ecosystems can be found in Appendix 4 in the Theme 5 summary (pgs. 40-44).

Table 2. Seven distinguishing attributes of steady state, ecosystem, and resilience-based management models (modified from Chapin et al. 2009).

	Steady state management	**Ecosystem management**	**Resilience-based management**
Ecological models	Succession-retrogression	State-and-transition, rangeland health	Multiple social-ecological systems/novel ecosystems
Reference condition	Historic climax plant community	Historic climax plant community, including historical range of variation	Landscapes with maximum options for ecosystem services
Role of humans	Use ecosystems	Part of ecosystems	Direct trajectories of ecosystem change
Ecosystem services	Meat and fiber products	Several ecosystem services	Options for diverse ecosystem services
Management goals	Sustain maximum yield of commodities	Sustain multiple uses	Sustain capacity of social-ecological systems to support human well-being
Science-management linkages	Top-down from management agencies	Top-down from management agencies	Multiscaled social learning institutions
Knowledge systems	Management experience and agricultural experiments	Multidisciplinary science and ecological experiments	Collaborative groups, spatially references, updatable database systems

The Coral Program Goals and Objectives (2010-2015) address three primary threats to coral reef ecosystems: climate change impacts, fishing impacts, and the impacts of land-based sources of pollution. The first Climate Change goal is to: "Increase coral reef resilience to climate change and ocean acidification through effective management strategies." The CRCP has funded projects working to meet this goal in a range of applied research fields that relate to resilience, data product development, and assessments to inform management decisions. As examples, projects have been funded to enhance our understanding of connectivity among reefs and reef areas, produce historical analyses and climate model projections of climate-related threats, and undertake field-based assessments of resilience potential.

Workshop goals

This workshop represents the first gathering of resilience grantees and coral reef managers funded by NOAA CRCP. The Great Barrier Reef Marine Park Authority (GBRMPA), The Nature Conservancy (TNC), and the United Nations Environmental Programme (UNEP) provided additional support for this workshop. The primary workshop goals were:

1. To bring together NOAA scientists, external partners and managers who are currently engaged in assessing and managing reefs for resilience in a changing climate to create the opportunity for face-to-face dialogue and review recent advances.
2. Identify priority research, products, and collaborative projects, and make plans to advance this body of work over coming years in direct partnership with coral reef managers.

A secondary goal was to: ensure that work across CRCP and partner programs is complementary and that efforts are contributing to and being informed by efforts in other parts of the world.

Meeting structure and discussion themes

The workshop was held November 4-6, 2014 in Honolulu, Hawai'i and was attended by 28 scientists and managers from nearly as many management agencies, universities, and conservation organizations. During the first day of the workshop, CRCP grantees conducting resilience research, managers, and program leads from TNC, GBRMPA and UNEP all delivered presentations describing project results, ongoing research, activities and future plans (see full agenda in Appendix 1). Facilitated discussions were the focus of the second and third days of the workshop with 2-3 hours devoted to each of five themes. These themes were collaboratively set with participants prior to the workshop to cover both existing research funded by the CRCP and new research opportunities and management needs. The five themes were:

- **Theme 1: Mapping Environmental Disturbance/Exposure** - Historic and projected future exposure of coral reefs to thermal stress/bleaching, cyclones and ocean acidification.
- **Theme 2: Field Based Resilience Assessments (includes Herbivorous Fish)** - Field and desktop-based analyses of relative resilience potential resulting in maps and informed conservation planning.
- **Theme 3: Connectivity** - State of science in developing high-resolution connectivity maps in coral reef areas.

- **Theme 4: Land-based Sources of Pollution** - Current approaches to map and assess LBSP, run-off, and dilution once in the marine environment.
- **Theme 5: Managers Use of Resilience Assessments and Reporting** - Using a dynamic understanding of reef condition and exposure to target/inform management actions and reef report cards and outlooks.

During each theme discussion, two session leaders reviewed the research (themes 1-4) or management activity (theme 5) and facilitated a discussion driven towards identifying next steps. By 'next steps' we mean tractable needed actions and activities that will advance the thinking and research and/or the application of research within these areas by managers. Our facilitated discussions are summarized in Appendix 4 for each of the five themes. For each theme, a 1-2 page overview of the research area and recent research led by workshop attendees is described first, followed by the identified key next steps. The highest priority next steps for each theme are summarized below. A sixth crosscutting theme, Training and Capacity Building, was also discussed during each of the theme sessions and during a concluding session.

In planning the workshop, it was our intent to also have a theme on social ecological resilience. We all recognize there are key linkages between coral reef ecosystems and dependent human communities, as well as linkages between reef health and the resilience of coastal communities. However, scheduling conflicts and funding did not allow for key social scientists and partners to be attend the workshop. Identifying priority next steps for a 'Social-Ecological Resilience' theme was identified as a priority next for a future workshop.

High priority next steps

The key next steps summarized here were identified as high priority because they meet one or more of the following criteria: critically needed and foundational to important steps that will follow, actionable now, or possible with limited resources. The identified next steps will advance resilience science and application and take the form of activities such as: developing specific data products, guidance for managers on assessments and use of information in decision-making, and case studies to build an evidence base for resilience based management. Many of these high priority key next steps will require new funding and partnerships. Workshop participants have already identified some activities that are underway as part of existing projects or that can be achieved with existing funding. Attendees estimated total project costs for the great majority of these to be around $50K U.S. or less; we use * to denote next steps likely to be more resource-intensive. The other next steps identified for each of the five working themes can be found at the conclusion of the 2-4 page theme summaries presented in Appendix 4.

Theme 1 – Mapping Environmental Disturbance/Exposure

1. Plan for the NOAA Coral Reef Watch (CRW) website to become a 'one-stop-shop' for all information related to near-real-time, historic and projected future exposure of coral reefs to environmental disturbances. This needs to involve presenting links within the website to all other relevant products and ensuring that guidance for managers is available for all types of information made available.

2. Develop guidance for managers on how to use exposure data layers in spatial planning following the development of a template such that guidance is complete and consistent for every spatial data layer presented on the NOAA CRW site.

3. *Produce statistically downscaled climate model projections of global bleaching and annual bleaching conditions.

4. Develop a webpage within the NOAA Coral Reef Watch website that makes all historic and projected future exposure data layers available as raster grids and/or netcdf files to facilitate use in spatial planning exercises with guidance on how to combine exposure layers.

Theme 2 – Field-based resilience assessments (includes herbivorous fish)

1. Develop guidance with real world examples for all parts of the process of undertaking a resilience assessment and using assessment results to target management actions and inform conservation planning. This guidance needs to include: selecting indicators, using any existing data in the assessment, analyzing the data, presenting and reporting on the results, and descriptions of options for completing an assessment at different resource levels.

Theme 3 – Connectivity

1. Define simple and inexpensive ways to establish a basic understanding of larval retention and connectivity potential and develop guidance for these approaches.

2. Seek to define "how much connectivity is enough" to maintain genetic versus demographic connectivity. Defining such values should ultimately replace present studies that only describe relative connectivity strength among locations.

3. *Refine regionally specific guidance (based on 1 and 2) on spatial density and size for area based management initiatives where intensive circulation modeling/studies or genetic connectivity data are not available. This goes beyond traditional efforts to show linkages between MPAs by expanding the analysis to include linkages between all types of place based management, including but not limited to: priority watersheds, restricted areas, LMMAs, MPAs, high use and high enforcement areas, etc.

4. Develop case studies that describe: 1) how to include connectivity information to expand/enhance field-based assessments of ecological resilience, and 2) the actions managers can take once connectivity at any or all scales is better understood.

Theme 4 – Land-based sources of pollution

1. Compile a list of evidence-based water quality standards with exceedance threshold values for key stressors that are relevant to coral reefs (e.g., toxins, sediment, bacteria, salinity, total max daily loadings). Multiple threshold values may need to be defined to correspond to multiple measurement types (e.g., in situ, remotely-sensed). This list needs to be made publicly accessible and a group or groups needs to be accountable for keeping the list updated.

2. Consistent and coordinated reporting on water quality status and trends for parameters that are meaningful to coral reef health (see above) are required.

3. *Write a review of the tools and approaches for spatial modeling of land-based sources of pollution to produce a concise guide with estimates of resource requirements, case studies and links to required software.

4. *Regional and global studies are needed to examine the linkage between the following: 1) historical changes in land cover, 2) ocean color/water quality, and 3) coral reef condition. This will inform 'what if' scenarios to help communicate the consequences of land cover change for coral reef health.

5. *More evidence is needed to assess the effectiveness of spatial proxies in representing the distribution of threats from watershed to marine water quality and coral reef condition. For example, direct measurements of water quality and benthic communities are needed (water samples and ocean color data, dispersal models) to link the landscape models, such as a Landscape Development Intensity index to coral condition.

Theme 5 - Managers Use of Resilience Assessments and Reporting

1. Define 'resilience-based management' in the context of ecosystem-based management/coral reef management and communicate why it will enable managers and policy makers to deliver conservation and ecosystem service outcomes in a changing climate.

2. Develop a case study driven evidence base to support the use of resilience assessments and resilience-based management actions.

3. Develop guidelines for operationalizing resilience-based management.

4. Describe how integrated monitoring and evaluation is a requirement for effective resilience-based management and how managers can adapt their current monitoring programs to inform resilience-based management.

Theme 6 – Training and Capacity Building

The overarching conclusions from our cross-cutting theme discussion on training and capacity building are as follows: 1) more and better guidance is required for the application of resilience science from *all* of the topics (themes 1-4) in management, which needs to include reporting and information dissemination (theme 5), and 2) virtual guidance needs to continue to be complemented with face-to-face training and mentorship opportunities, especially for managers working in remote areas. The consensus was that the new guidance should mostly be presented within TNC's Reef Resilience Toolkit (www.reefresilience.org) with attribution to the source of the materials and that development of the guidance requires expanding upon existing content. In addition, there may be instances where guidance may need to be prepared as stand-alone products and/or publications to best serve certain audiences or end user groups. The Reef Resilience Toolkit, Forum, and Online Courses are a very well-known, respected source of the latest scientific information distilled for coral reef managers, the content of which is driven my manager's needs. A range of case studies were identified (see Appendix 3) that would present complete examples with lessons learned of the application of the new thinking and research discussed during the five main theme sessions. New guidance can also include new pages within the toolkit, more video-based summaries of toolkit content and case studies, as well as tutorials and updated relevant reference lists (as in our Appendix 4). Many attendees agreed to work with TNC's Reef Resilience Program to develop new guidance during the coming year; these agreements and plans can be seen as a major outcome of the workshop (see feedback within Appendix 3). The high priority next steps are:

1. Keep guidance content current within key delivery mechanisms like TNC's Reef Resilience toolkit, including most relevant tools and resources and lists current references for various working themes (such as the five covered during this workshop).

2. Undertake a comprehensive review of past and current programs that provide guidance and train coral reef managers. The review should result in a report that describes strengths and weaknesses and provides recommendations as to what kinds of guidance and training programs are needed by managers. The review also needs to identify key stumbling blocks to management actions and what the key features of these programs should be both with respect to content and coordination (see also step 3).

3. Organize a workshop following on from step 2 to review and finalize the recommendations and discuss considerations related to sharing costs and coordination efforts across programs and agencies.

It should be noted that as with all activities suggested within the workshop report, coral reef managers and those that are users of the data products, guidance, etc. are an integral part of any team moving forward. Given the goal of products to be tailored to management application and the results of resilience assessments to be used in decision making, scientist-manager partnerships are imperative to this process.

Participant feedback

Workshop participants were overwhelmingly positive about their experience during the meeting (see comments from participants in Appendix 2). Participants commented at length about how useful and productive the meeting was and expressed commitments to partner on undertaking and delivering on all of the identified high priority next steps (see above). Participants were really enthusiastic about meeting new collaborators, excited to share the results of recent work, and especially liked that the meeting focused on the identification of tractable next steps for us to collaborate on undertaking and delivering on. Participants also mentioned that the discussions provided valuable overviews of new science, involved identifying new ways to communicate and share plans, and were highly relevant to local management of their reef resources.

Conclusions

The workshop chairs and attendees all considered the workshop to be a spectacular success and considered the required investment of time and energy to be very well spent. Everyone that attended the workshop: met someone they had exchanged emails with but had never seen, was exposed to work they had not heard of or had not fully understood prior to the meeting, had their perspective changed in an important way about something they have been working on related to resilience and its application during recent years, or made commitments to each other and to managers to help advance resilience-related research and its application in management. Speaking to the last point, participants extensively discussed how rapidly resilience research and its application is advancing and that, as a consequence, we all and our programs have to be adaptive and flexible as well as continue to work highly collaboratively. Collaboration is especially important in today's funding climate and will certainly be required to complete the ~25 high priority next steps identified just above. All of these high priority next steps are actionable now and needed and most are not resource-intensive.

Coral reef managers and scientists working in developing countries attended a workshop convened by UNEP under a similar theme entitled *Scientific Workshop on Coral Reef Resilience in Planning and Decision-support Frameworks: Towards Greater Use of Reef Resilience Data in Planning and Management* (April 2014 in Phuket, Thailand). Many of the high priority next steps identified in this workshop were also identified in Phuket (report available through UNEP). The high degree of overlap in these two lists of next steps emphasizes the urgency and importance of the identified next steps and gives us confidence that advances that are made would be applied in both the developed and developing world. Key next steps identified in Phuket included the following actions, to be pursued through collaboration with relevant partners:

- Communication and policy outreach elaborating the case for using coral reef resilience science in planning and management, and how it can strengthen ecosystem management and ICZM;
- Guidance to support application of resilience science in planning and management, going beyond MPAs and considering cross-sectoral planning processes such as marine spatial planning. This may include guidance to resilience indicators and use of existing monitoring and other data in resilience assessments;
- Work towards enhanced access to existing large scale exposure and predictive resilience data, as well as guidance on its use;
- Pilot implementation to demonstrate the use of resilience science in planning and management processes at different scales, generating case studies that can be shared and replicated;

- A follow up workshop to review progress, share experiences and support further development.

Attendees intend to undertake delivering on as many of the next steps as possible during the coming two years. Total progress made and progress rates will depend, as always, on the kinds and levels of support made available as in-kind contributions and through competitively awarded grants and contracts. To this end, participants agreed to continue collaborating on both acquiring resources and identifying cost-sharing opportunities. Most importantly, representatives from all of the major programs confirmed they are dedicated to supporting applied research over the coming years that will be guided by the identified high priority next steps to support resilience based management. The strength and consistency among attendees of this commitment demonstrates the value for all programs present of the NOAA CRCP having taken the lead on coordinating the workshop. Indeed, attendees and the broader coral reef management community are already reaping the benefits of having met to discuss potential synergies among recently funded projects. As examples: connectivity information will be built into soon-to-be-released field assessments of reef resilience in the west Pacific, information on historic and projected future exposure to thermal stress is being built into spatial conservation planning in Indonesia, forward-looking reef reporting templates are being collaboratively developed, and the merit of various proxies for water quality are being reviewed to increase rigor and use within both resilience assessments and watershed management planning. These are only four from among a dozen or more other similar examples from the networking and discussions held during the workshop.

Attendees agreed that a similar workshop needs to be coordinated every 2-3 years and that the next workshop could coincide with the 2016 ICRS in Honolulu. Further, an email list-serve of attendees was created enabling everyone to stay in touch. Britt Parker of NOAA CRCP will request summaries of projects and questions/concerns from all attendees every 6 months and will work with attendees to produce a brief summary. These 6-monthly summaries will help the NOAA CRCP and the other major programs present such as TNC, GBRMPA, and UNEP to continue to identify synergies among projects and thus reduce overlap and maximize complementarity and collaboration.

References

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Appendix 1 – Workshop Agenda

The following goals, agenda and workshop themes formed the guiding structure for workshop discussions.

Coral Reef Resilience Research and Management – Past, Present and Future!
NOAA Coral Reef Conservation Program
November 4-6
Hawaiʻi Prince Hotel Waikiki (100 Holomana Street)
Honolulu, Hawaiʻi

Workshop Goals:

- To bring together NOAA scientists, external partners and managers who are currently engaged in assessing and managing reefs for resilience in a changing climate to create the opportunity for face-to-face dialogue and review recent advances.
- Identify priority research, products, and collaborative projects, and make plans to advance this body of work over coming years in direct partnership with coral reef managers.
- Ensure that work across CRCP and partner programs is complementary and that efforts are contributing to and being informed by efforts in other parts of the world.

TUES - 4 NOV 2014	**Haleakala/Kilauea Meeting room**
TIME	**Session**
8:45 – 9:00	**REGISTRATION, SIGN-IN AND COFFEE**
SESSION 1	**INTRODUCTIONS & MEETING OVERVIEW**
9:00 – 9:30	**WELCOME** • Participant introductions (Name, Affiliation) – Britt Parker • Meeting Overview and Housekeeping – Britt Parker/Jeff Maynard • Questions?
SESSION 2	**PROGRAM OVERVIEWS**
9:30 – 10:45	**PRESENTATIONS & DISCUSSION** • NOAA Coral Reef Conservation Program – Britt Parker (10 min) • TNC Reef Resilience Program – Petra McGowan (15 min) • UNEP Coral Reef Unit – Jerker Tamelander (15 min) • Great Barrier Reef Marine Park Authority – Roger Beeden (15 min) • Oceans Tipping Points Project – Mary Donovan (10 min)
10:45 – 11:00	**BREAK**
SESSION 3	**CURRENT WORK ACROSS THE 6 WORKING MEETING THEMES**
11:00 – 12:20	**PRESENTATIONS & DISCUSSION**

TUES - 4 NOV 2014	Haleakala/Kilauea Meeting room
TIME	**Session**
	• Thermal Stress History and Projected Future Exposure – Scott Heron/Jeff Maynard (20 min) • Overview of CNMI Field-based Resilience Assessment – Jeff Maynard/Steve McKagan (20 min) • Herbivores and some results from the Kahekili Herbivore Fisheries Management Area – Adel Heenan (20 min) • NOAA Coral Reef Ecosystem Division Data Informing Assessments – Bernardo Vargas-Angel/Brett Schumacher (20 min)
12:20 – 1:15	**LUNCH**
1:15– 2:35	**PRESENTATIONS & DISCUSSION** • USVI Reef Resilience Framework – Simon Pittman (20 min) • LBSP in the Oceans Tipping Point project – Kirsten Oleson (20 min) • Connectivity – Matt Kendall (20 min) • TNC Training and Capacity Building for Reef Resilience – Lizzie McLeod (20 min)
2:35 – 2:45	**BREAK**
2:45 – 3:15	**PRESENTATIONS & DISCUSSION** • Dynamic Understanding of Exposure to Disturbances and Reef Health Informing Resilience-based Management & Citizen Science – Roger Beeden (30 min)
SESSION 4	**Q&A, THEME WORKING SESSION INTRODUCTION, AND WHAT'S NEXT?**
3:15 – 4:30	**DISCUSSION** • Follow up Q and A for Presenters • Introduction of Theme Breakout Sessions and Schedule for Days 2 and 3
5:00	**HAPPY HOUR AND DINNER (HULA GIRL GRILL – 2335 KALAKAUA AVE WAIKIKI ABOVE DUKE'S)**

WED - 5 NOV 2014	Haleakala/Kilauea Meeting room
TIME	**Session**
8:30 – 8:40	**WELCOME AND DIRECTIONS TO BREAK OUT SESSIONS**
SESSION 5	**THEME 1**: MAPPING ENVIRONMENTAL DISTURBANCE/EXPOSURE - HISTORIC AND PROJECTED FUTURE EXPOSURE OF CORAL REEFS TO THERMAL STRESS/BLEACHING, CYCLONES AND OCEAN ACIDIFICATION. **THEME 2:** FIELD BASED RESILIENCE ASSESSMENTS (INCLUDES HERBIVOROUS FISH) - FIELD AND DESKTOP-BASED ANALYSES OF RELATIVE RESILIENCE POTENTIAL RESULTING IN MAPS AND INFORMED CONSERVATION PLANNING.
8:40 – 10:10	Theme 1: Mapping Environmental Disturbance/Exposure – Scott Heron/Jeff Maynard

WED - 5 NOV 2014	Haleakala/Kilauea Meeting room
TIME	**Session**
10:10 – 10:30	**BREAK**
10:30 – 12:00	Theme 2: Field-based Resilience Assessments – Jeff Maynard/Steve McKagan
12:00 – 1:00	**LUNCH**
SESSION 6	**THEME 3:** CONNECTIVITY - STATE OF SCIENCE IN DEVELOPING HIGH-RESOLUTION CONNECTIVITY MAPS IN CORAL REEF AREAS. **THEME 4:** LAND-BASED SOURCES OF POLLUTION - CURRENT APPROACHES TO MAP AND ASSESS LBSP, RUN-OFF, AND DILUTION ONCE IN THE MARINE ENVIRONMENT.
1:00 – 2:30	Theme 3: Connectivity – Matt Kendall/Lew Gramer
2:30-2:45	**BREAK**
2:45 – 4:15	Theme 4: LBSP – Simon Pittman/Kirsten Oleson
4:15 - 4:30	**WRAP UP AND CLOSING**

THURS -6 NOV 2014	Hakone Restaurant
TIME	**Session**
8:30 – 8:40	**WELCOME AND DIRECTIONS TO BREAK OUT SESSIONS**
8:40 – 9:00	Presentation: Outlook Reporting – Paul Marshall (given by Jeff Maynard) (15 min)
SESSION 7	**THEME 5:** MANAGERS USE OF RESILIENCE ASSESSMENT & REPORTING - USING A DYNAMIC UNDERSTANDING OF REEF CONDITION AND EXPOSURE TO TARGET/INFORM MANAGEMENT ACTIONS AND REEF REPORT CARDS AND OUTLOOKS. **THEME 6:** TRAINING AND CAPACITY BUILDING - EFFORTS TO BUILD THE CAPACITY OF MANAGERS TO UNDERTAKE RESILIENCE-BASED MANAGEMENT AND STAKEHOLDERS/CITIZEN SCIENTISTS TO PARTICIPATE.
9:00 – 10:30	Theme 5: Managers Use of Resilience Assessments & Reporting – Roger Beeden/Britt Parker
10:30 – 10:45	**BREAK**
10:45 – 12:15	Theme 6: Training and Capacity Building – Petra McGowan/Lizzie McLeod
SESSION 8	**MEETING CONCLUSION**
12:15 – 12:30	• Meeting Conclusion and Next Steps/Action Items – Jeff Maynard/Britt Parker • Resilience Song – Performed by Scott Heron
12:30 – 1:30	**LUNCH**
1:30 – 3:00	**MEETING ROOM OPEN FOR PIS AND PARTNERS TO MEET ON SPECIFIC PROJECTS**
3:00	BRIEF MEETING SESSION LEADS (LOCATION TBD)

Appendix 2 - Feedback from Workshop Attendees

Feedback on the workshop is provided below from attendees that offered summaries of their experience during the workshop and associated evening meetings (presented in no particular order).

Darla White of the Hawai‘i Division of Aquatic Resources – *"This meeting was very beneficial to me on many levels, both as a manager practitioner and field scientist. This meeting was a super download/exchange of updated information on resilience, relevant resources, upcoming releases, and recent experiences and lessons learned. All of the work presented and discussions is relevant to how we manage reefs in Hawai‘i to support resilience. I was able to talk with several people that will help me to undertake or assist with resilience assessments on the reefs of Maui and to form new partnerships and expand my network.'*

Dr. Scott Heron of NOAA Coral Reef Watch – *"I found that bringing together key people working in the area of resilience for application in coral reef management was timely and informative for my personal work program. We identified key next steps related to my development of graphics and tools that describe historic exposure of coral reef areas to thermal stress events. I also enjoyed and benefited from our discussions on tractable ways for the group of applied research scientists and managers working in this area to communicate and share ideas and plans."*

Roger Beeden of the Great Barrier Reef Marine Park Authority – *"This workshop provided a valuable overview of the science underpinning the resilience -based management of coral reefs, and examples of resilience assessments of coral reefs. There was excellent, robust and practical discussion of how resilience theory can be translated into practice in the short and long term, which resulted in the identification of tractable next steps. I learned of several examples of the application of resilience thinking from other parts of the world that are going to be directly relevant to my day to day work and to ongoing refinement of the GBRMPA's strategic objectives. I also found it very helpful to discuss the collaborative ways in which resilience-based management can be defined for decision makers, managers and stakeholders and how such information is and can be delivered across multiple platforms. Ongoing collaborations among this group will help us share the results of GBRMPA's work with the global community of practitioners."*

Dr. Kirsten Oleson of the University of Hawai‘i-Manoa – *"The discussion between managers and scientists was detailed and pragmatic. As a scientist interested in producing results that managers can use, I found the managers' perspectives and insights about the products they need and the modes of delivery very helpful. I enjoyed contributing to discussions that resulted in new ideas of how we can collectively deliver management-relevant products effectively."*

Dr. Matt Kendall of the NOAA Biogeography Branch – "*It was terrific to hear during the meeting how my personal research focus fits with the range of other applied research being conducted in the area of applying resilience thinking to coral reef management and conservation efforts. My mission in attending was accomplished in that I met new collaborators and identified several promising collaborative projects. As examples, I will be pursuing plans to integrate some* *of my transport simulation results with the field-based resilience assessment results from that NOAA CRCP project. I will also be working with groups like TNC to provide information on low-tech ways to get an initial understanding of connectivity. Lastly, I am looking forward to working more closely with UH on studies of reef fish connectivity in Hawai'i.*

Steve McKagan of NOAA Fisheries Pacific Islands Regional Office – *"I learned a great deal about resilience as a concept and about the diversity of ways in which people are applying resilience thinking in management efforts. I also met several researchers and managers that I will collaborate with over the coming years in advancing work in the Micronesia region. I enjoyed sharing some of the recent results of our field-based assessments of resilience from CNMI and our plans to share that work in a peer-reviewed paper and project report, both of which will benefit from insights gained during the meeting."*

Dr. Brett Schumacher of NOAA Coral Reef Ecosystem Division – *"The most valuable part of the meeting for me was meeting people that I previously only knew as names from emails. Meeting discussions resulted in the generation of new project ideas that I will be working on with some of the other attendees. I especially benefited from hearing about the state of work in research areas like connectivity and land-based sources of pollution that I needed to understand more comprehensively for my own work on Hawai'i-based resilience assessments and spatial planning."*

Dr. Jerker Tamelander of UNEP - *"I found it important and extremely useful that so many tractable next steps for members of this working group were identified during the meeting discussions. I was pleased to see that several of the identified highest-priority next steps were also described as priorities by remote area and developing country managers that attended a resilience workshop I chaired in Phuket earlier this year. These meetings provide a great foundation upon which UNEP's coral reef program can now build. I am looking forward to following up with many of the other attendees and to continuing our discussions and advancing our collaborative work."*

Dr. Jon Martinez of the Hawaiian Islands Humpback Whale National Marine Sanctuary – *"I found the meeting extremely helpful as a newcomer to the field of applying resilience thinking and field-based resilience assessments in management. I felt I benefited from the discussions in three primary ways. 1) The meeting gave me a sense of the state of the application, capabilities and technical workings of resilience assessments. 2) I now better understand the current capabilities of remote sensing with respect to providing information on spatial variation in the historic exposure of reef habitats to disturbances. 3) This stimulated my thinking on how field-based resilience assessments could apply to coral reef management beyond the project a group of us will be undertaking next year for west Kona."*

Dr. Lizzie McLeod of The Nature Conservancy – *"I feel this meeting has resulted in many prospects for new collaborations between TNC's Reef Resilience program and applied research scientists and managers that are advancing resilience thinking and products."*

Dr. Simon Pittman of the NOAA Biogeography Branch – *"It was great to spend time discussing the challenges of undertaking and applying reef resilience research with a group of* *pro-active, problem solving scientists and managers. Having an opportunity to interact face-to-face on such a wide range of relevant and interconnected subjects all aimed at addressing a common challenge was exciting and very useful. The sessions stimulated ideas for new interdisciplinary approaches and resulted in my meeting new collaborators. The forward-looking perspective that dominated the workshop was refreshing and overall the sessions have given me fresh impetus for my resilience-based management projects."*

Emma Anders of the Hawai'i Dept. of Aquatic Resources – *"I enjoyed discussing the challenges of undertaking and applying reef resilience research with a group of pro-active, problem-solving scientists and managers. I thought it was exciting and useful to have an opportunity to interact face-to-face on such a wide range of relevant and interconnected subjects all aimed at addressing our common challenge of applying resilience thinking. The sessions stimulated ideas for new interdisciplinary approaches and I met many new collaborators. The forward-looking perspective that dominated the workshop was refreshing and overall the sessions have given me fresh impetus for my resilience-based management projects."*

Dr. Lyza Johnston of the CNMI Bureau of Environmental and Coastal Quality – *"As a newcomer to the coral reef management arena who is based on a small, relatively remote island, this workshop was incredibly valuable in terms of connecting face-to-face with other managers and top researchers from around the world. I learned a lot about the current state of resilience research and the challenges of and progress towards resilience based coral reef management. I was particularly excited about the tools that are available and being developed (e.g. the TNC Reef Resilience Toolkit) that will make it easier for managers to assess resilience and potential climate change impacts, adapt monitoring and management strategies accordingly, and connect with other practitioners and experts.*

Appendix 3 – Topics for New Case Studies within TNC RR Toolkit

A number of case studies were identified during the workshop and report development to be placed in the TNC Reef Resilience (R2) Toolkit. TNC has an updated template available for any author of case studies and have agreed to work with authors in developing case studies.

Already completed:

1. Monitoring Coral Reef Communities in Hawaii's First Herbivore Protection Area (Ivor Williams; Darla White; Adel Heenan) http://www.reefresilience.org/case-studies/hawaii-fisheries-management/

To be developed and assigned during workshop:

1. Incident response OR Exposure mapping/response GBR (Roger Beeden)
2. LBSP research/work - application to management of GBR (Jeff Maynard; Roger Beeden)
3. HI Bleaching Response 2014 (Anne Rosinski)
4. Management actions (e.g., temp closures) using NOAA CRW SST data (Scott Heron)
5. USVI Reef Resilience Framework (Simon Pittman)

Suggested for development:

1. NOAA Habitat Blueprint Initiative and Resilience – Describe key habitats, key threats, SMART objectives: how well do government and community priorities fit with resilience evaluation? Plan to fund a resilience assessment in West Hawaiʻi. Restoration options => actions – co-management, community buy in components.
2. Coral bleaching events provide an opportunity to implement resilience-based management actions. For example targeting additional protection of herbivores to sites that have had a resilience assessment. RBM objectives might be to protect high resistance sites, aid the recovery of low resilience sites, and prioritize sites with high value that have particular resilience characteristics. Example case study – Great Barrier Reef, Keppel Bay 2006 coral bleaching event led to a community based resilience assessment and targeted actions (anchoring restrictions) to reduce human pressures at high and low resilience sites.
3. Great Barrier Reef, Australia (Keppel Bay and more recently analysis of Reef Health Incident Response System data) - GBRMPA is using participatory capacity, strategy, monitoring, assessment and evaluation measures to inform resilience-based management of the world's largest coral reef ecosystem.

4. Bahamas – MPA designed based on resilience based on manuscript from Ecology Letters 2011 - Mumby, PJ, et al. (2011). Reserve design for uncertain responses of coral reefs to climate change. *Ecology Letters*, *14*(2), 132-140.
5. Consider a case study from other sectors (e.g., health, financial, other natural resource management) that illustrate that RBM is not new and is already being implemented in other sectors.

Appendix 4 – Overviews of Theme Discussions and Next Steps

Theme 1: Mapping Environmental Disturbance/Exposure

Session Leads: Dr. Scott Heron and Dr. Jeffrey Maynard

Overview and Relevant Case Examples from Workshop Attendees

In combination with sensitivity, exposure to environmental disturbances and stressors yields potential impact in the classic widely adopted IPCC vulnerability assessment framework. Potential impact is then moderated by adaptive capacity to yield the assessment of vulnerability. The sensitivity and adaptive capacity terms can be seen as resilience, and variation in exposure to disturbances among coral reef sites or areas determines what the sites or areas have had to and will have to be resilient to. Information on sensitivity and adaptive capacity (assessed resilience) is only ever going to be available from a small percentage of the sites/areas within a management jurisdiction. This is due to the high costs and logistical constraints associated with surveying coral reefs. Participatory monitoring networks, like Eye on the Reef in the Great Barrier Reef (Beeden et al. 2014), can reduce these costs and ensure managers regularly receive information on coral reef community condition and composition. The information is still only available from far less than half of the sites in the management jurisdiction. In contrast, information on historic, near real-time and projected future exposure to environmental disturbances is available now for all reef locations in the world at a 4-5km resolution. In essence, understanding spatial variation in historic exposure to environmental disturbances provides a lens through which we can better understand and more meaningfully compare the current community condition and composition of coral reefs. Better understanding of projected future exposure to disturbances enables comparisons among reefs or reef areas in the challenges posed for the resilience of these reefs or reef areas as the climate changes. In combination, understanding historic *and* projected future exposure to disturbances provides an improved understanding of spatial variation in vulnerability and can inform conservation planning. We can identify and preferentially protect relative refugia as well as support (and plan to support) recovery processes at locations more frequently exposed to disturbances.

Workshop discussions focused on three recent advances made by workshop attendees in mapping environmental disturbance/exposure: mapping historic exposure to thermal stress, mapping exposure to heavy seas generated by cyclones, and statistical downscaling of climate model projections.

Mapping exposure to thermal stress: The National Fish and Wildlife Foundation (NFWF) Coral Reef Conservation Fund and NOAA CRCP awarded a grant to Heron, Maynard and Eakin to produce tools for managers describing spatial variation in temperature variability, return period and onset timing. Temperature variability ranked number 2 in the analysis presented within McClanahan et al. (2012), which ranked 31 resilience indicators. Some experimental and field evidence suggests that reefs where temperatures have greater variability are more likely to resist bleaching when temperatures are anomalously warm enough to cause bleaching (Guest et al. 2012). Temperature variability can be measured as the standard deviation of temperatures during the warm season and also of temperatures from the full year – for some locations, inter-annual variability exceeds intra-annual variability (e.g., along the equator; Donner 2011). Heron et al. calculate both of these measures of variability for all coral reef locations at 4-km resolution using the NOAA Pathfinder v5.2 SST dataset. The project leads greatly expanded the scope of this project while underway and identified ~50 temperature stress metrics that characterize the thermal history at coral reef sites with respect to exposure to thermal stress severe enough to cause bleaching. Heron et al. are preparing a manuscript describing the project results with submission planned by March/April of 2015. The manuscript describes spatial variation within and among reef regions in the following (from 1985-2012): frequency of thermal stress events (severe enough to cause bleaching; Degree Heating Weeks≥4 °C-weeks); mean onset month of thermal stress events, rate of temperature increase (in °C/decade) for the 3 month warm season (centered on the climatologically warmest month), rate of temperature increase (in °C/decade) for annual temperatures, and standard deviation in temperature in the warm season, and in the warmest month. The project team is making all results available on this website: http://coralreefwatch.noaa.gov/satellite/thermal_history/th_index.php.

The plan (pre-workshop) was to have the images available in static form as maps and to present the images for viewing through the interactive Google Earth™ platform. We discussed making the data available as ArcGIS raster grids so they can more easily be used in spatial planning processes. We also discussed developing guidance such that the conservation community understands how to use the data to inform planning decisions. We will need a template for this guidance so that guidance produced for exposure data layers is standardized. The conservation community will need to be engaged on refining the guidance template and on refining the guidance as it becomes available and starts to be used.

Mapping exposure to heavy seas generated by cyclones: Workshop attendees have been collaborating over recent years with Dr. Marjetta Puotinen (Australian Institute of Marine Science). Dr. Puotinen processes information on cyclone characteristics and track via a model that estimates the likelihood coral reefs (4-km resolution) have been exposed to heavy seas (2 and 4 m) and for what duration. This capability has led to spatial data and maps for the GBR that depict spatial variation in historic exposure to heavy seas generated by cyclones for 1985-2014. Dr. Puotinen's model can also be used immediately after a cyclone to assess spatial variation in the likelihood of catastrophic damage, which can be used to optimize survey efforts and target actions to support recovery. Currently, the maps of historic exposure to heavy seas generated by cyclones are only available for NE Australia (Great Barrier Reef and Coral Sea). Global products similar to those described above for thermal stress can be developed. Managers can use these products to shape the lens through which they assess the current condition of reefs in their area; i.e., aid with understanding the drivers of differences in condition. However, >2000 cyclones have produced gale force (>17 m/s) winds near coral reefs since 1985 so running all cyclones through the model to assess spatial variation in frequency of exposure and average return period (as examples) would be resource-intensive.

Statistical downscaling of climate model projections: Pacific Island Climate Change Cooperative (PICCC) and NOAA CRCP funded the development of the IPCC AR5 global climate model projections of thermal stress and ocean acidification via grants to Drs. Maynard and van Hooidonk for all of the IPCC's RCP emissions scenarios. These model-resolution (1° x 1°) projections use the CMIP5 suite of climate models and present: 1) the projected timing of the onset of annual and 2x per decade bleaching (6 DHWs) and severe bleaching (8 DHWs) conditions, and 2) changes in aragonite saturation state (absolute and percentage) and calcification between 2010 and 2100 and between 2010 and the timing of the onset of severe bleaching conditions under the emissions-intensive RCP8.5. These data are all available in static and interactive form on the Coral Reef Watch website at: http://coralreefwatch.noaa.gov/climate/projections/piccc_oa_and_bleaching/index.php. The model-resolution projections inform global policy and raise awareness but are too coarse to inform decisions at the local-scale, which is where/how nearly all management and conservation decisions are made. The project team developed a method for statistically downscaling the climate model projections to a higher resolution (4-km) for a study of the greater Caribbean funded by the NOAA CRCP (there are over 570 four-km pixels in a 1° climate model pixel). The team found great spatial variation in the timing of the onset of bleaching and severe bleaching conditions within roughly half of the climate model pixels in the Caribbean. The implication is that statistical downscaling of model projections can be used to inform local-scale conservation planning. The project team hopes to produce statistically downscaled model projections for all of the world's coral reefs in 2015.

While reviewing these recent advances, the workshop attendees developed a list of the variables for which we have near-real time, historic or projected future exposure to environmental disturbance information for all coral reefs. These include: temperature stress (in relation to bleaching and disease), acidification, wind speed, and GCM-resolution projections of temperature stress and acidification. A list was also produced of the variables for which we know information is available and thus possible to include in a 'one-stop-shop' website for exposure information. These include all of the following: climate indices such as ENSO; heavy seas generated by cyclones; statistical downscaling of climate model projections; ocean color-based proxies for productivity nutrients, sediments, clarity, including freshwater inundation; waves in terms of average wave height and other metrics like average max wave; salinity/rainfall; irradiance; currents; sea level; and low stand exposure. This effort should also include an exploration of combinations of data (remotely sensed, *in situ*, etc.) from across NOAA and external partners that could be developed into information layers to provide further insight into reef condition and potential resilience. Workshop attendees discussed prioritizing these variables and working towards information on all of these being presented on the NOAA Coral Reef Watch website (see below).

Key Next Steps

Next steps presented in italics are high priorities and are also presented in the workshop summary.

1. *Plan for the NOAA Coral Reef Watch (CRW) website to become a 'one-stop-shop' for all information related to near-real-time, historic and projected future exposure of coral reefs to environmental disturbances. This needs to involve presenting links within the website to all other relevant products and ensuring that guidance for*

managers is available for all types of information made available.

2. *Develop guidance for managers on how to use exposure data layers in spatial planning following the development of a template such that guidance is complete and consistent for every spatial data layer presented on the NOAA CRW site.*

3. **Produce statistically downscaled climate model projections of global bleaching and annual bleaching conditions.*

4. *Develop a webpage within the NOAA Coral Reef Watch website that makes all historic and projected future exposure data layers available as raster grids and/or netcdf files to facilitate use in spatial planning exercises with guidance on how to combine exposure layers.*

5. Write a review/guide to the types of information currently available related to historic, near-real time and projected future exposure of coral reef areas to environmental disturbances. The guide needs to be inclusive of the resolution of the data and what the resolution may be within five years based on currently funded work/research efforts. This document could be inclusive of the types of users likely to find the information useful and present guidance (see previous item) on how to use the information in spatial planning exercises or communications and outreach.

6. Lead a participatory process resulting in our prioritizing all of the various information layers that could be made available to the scientific and management community based on potential utility in decision-making processes and outreach.

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Theme 2: Field-Based Resilience Assessments (includes Herbivorous Fish)

Session Leads: Dr. Jeffrey Maynard and Steven McKagan

Overview and Relevant Case Examples from Workshop Attendees

Interest has escalated in recent years in undertaking field-based assessments of ecological resilience potential in coral reef areas. Assessing resilience potential was first conceptually developed within a *Conservation Biology* paper written by Salm and West in 2003. These authors made the case that there are characteristics of coral reefs (physical and ecological) that result in gradients within management areas in the likelihood of resisting and/or recovering from disturbances such as coral bleaching. These characteristics, which we have come to refer to as 'resilience indicators', are variables that can be assessed. Obura and Grimsditch then led a multi-author report published by the IUCN in 2009 (with other partners like the NOAA CRCP) that first described how to undertake a resilience assessment. The IUCN (2009) report was meant to serve as a guide but has been difficult to apply and use because >60 resilience indicators are recommended and clear guidance is not provided on how to select or scale indicators or how to produce a final resilience score, rank sites, and use the scores and rankings to make decisions. In 2012, a group of authors (including many workshop attendees) wrote a review of ~30 of the 60 indicators presented in IUCN (2009) thought to have the strongest relationships with the processes that underlie resistance and resilience (McClanahan et al. 2012). The McClanahan review helped prioritize indicators and recommended a site selection framework for undertaking resilience assessments using only 11 indicators. These indicators are as follows: resistant coral species, temperature variability, nutrients (pollution), sedimentation, coral diversity, herbivore biomass, physical human impacts, coral disease, macroalgae, recruitment, and fishing pressure.

Since the McClanahan review was published, TNC has updated their Reef Resilience toolkit to include new guidance on undertaking resilience assessments, which includes a PowerPoint-based tutorial on analyzing data once the field assessments are complete.

The first field/desktop-based implementations of the framework recommended within McClanahan et al. 2012 occurred in CNMI under funding provided by NOAA CRCP and PICSC (to the session leads) and in Hawai'i (led by Brett Schumacher with funding from the CRCP and NMFS), as well as in Palau and Indonesia (by the session lead and collaborators with funding from CRCP and TNC). The most recent applied research in this area, conducted in CNMI, involved assessing the resilience potential of 84 sites near the islands of Saipan, Tinian, Aguijan, and Rota. The study leads compared the resilience potential of the surveyed sites within and among the islands and developed decision-support frameworks that identified sites that warrant management attention/focus based on combinations of resilience potential and anthropogenic stress. The report on the portion of the CNMI study undertaken in 2012 in Saipan can be found here:
http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/204/CoRIS_204_Saipan_Resilience_ReportandAppendix_Maynard_McKagan_2012.pdf. Reports on the current work will become available by April of 2015.

TNC and NOAA CRCP have also completed an assessment of relative resilience potential for coral reef sites near St. Croix, USVI. The report on this assessment is available by request from Kemit Amon-Lewis of TNC. During the St. Croix assessment the study leads (Maynard and Amon-Lewis) led a participatory process for selecting indicators based on the McClanahan et al. 2012 survey results and data availability. Attendees expressed interest in the indicator selection process used because similar processes will have to be led for any area for which an assessment is going to be completed.

The impression from workshop attendees is that reef managers everywhere are interested in undertaking resilience assessments but need much more guidance on how to determine: if and why an assessment should be undertaken, how and how frequently to do the assessment, and how to make management decisions following an assessment. The CNMI study leads have described (in recent presentations to funders) the process of undertaking an assessment as having the following 5 steps:

1. Deciding to undertake the assessment
2. Selecting indicators
3. Undertaking the assessment
4. Analyzing the data
5. Developing management recommendations

There was agreement that more guidance is needed for all 5 parts of the process (listed above). Attendees debated whether there was value in producing a report similar to that produced by IUCN in 2009 as a way to compile all of the guidance for undertaking resilience assessments and making management decisions once assessments are complete. Attendees felt the guidance could take the form of further expansions to TNC's toolkit and/or a guidance document that compiles all existing guidance and analysis examples into a new guidance document. It will be especially important to link resilience assessment results to management decision-making processes. The team leading the resilience assessments undertaken in CNMI have made progress in that area using queries of assessment results to target a range of different types of management actions. The team's work was in review at the time of publication of this report (Maynard et al. in review) but will be published open access later this year and available by request from this report's lead authors.

Next Steps

Workshop attendees identified next steps related to preparing new/more guidance for managers for all of the 5 parts of the resilience assessment process listed above. All of the next steps identified for this workshop theme involve developing guidance. Developing all of this guidance is going to require a participatory process involving managers and the output(s) will need a consistent presentation format/style and may need to all be combined within one output and/or delivered via the same mechanism.

Next steps presented in italics are high priorities and are also presented in the workshop summary.

1. *Develop guidance with real world examples for all parts of the process of undertaking a resilience assessment and using assessment results to target management actions and inform conservation planning. This guidance needs to include: selecting indicators, using any existing data in the assessment, analyzing the data, presenting and reporting on the results, and descriptions of options for completing an assessment at different resource levels.*

1. Deciding to undertake the assessment

Develop a decision tree that helps managers assess whether they have access to the resources and expertise to undertake a resilience assessment.

The decision tree should be complemented by a comprehensive list of the various ways that resilience assessment information can be used so that what the assessment can and cannot achieve is very clear.

The relevant TNC toolkit pages need to be updated to describe the value of one-off versus repeated assessments.

2. Selecting indicators

Organize a participatory process that results in a group agreeing on a core set of resilience indicators to be used all over the world. Lists for each of the various reef regions may also be useful. This process needs to result in the lists as well as guidance on how managers and collaborating scientists can select indicators to be used in their assessment.

Develop an interactive tool based on the results of the above that helps people to select indicators and to document their process.

3. Undertaking the assessment

Develop guidance describing how to undertake the assessments retrospectively (i.e., using existing data) and for when new data collection is planned. The guidance needs to include how to evaluate existing data to determine if a retrospective resilience assessment is possible and a table that pairs recommended methods and units with the various resilience indicators and describes a process for selecting from among the methods options.

4. Analyzing the data

Develop guidance describing the range of ways data can be analyzed such that a continuous value is produced for each resilience indicator (if this is possible). Guidance exists describing how to complete the data analysis within Excel and PowerPoint-based tutorials. Few have seen that guidance so attendees and others need to review and help expand/improve upon it.

Develop a tool that helps people analyze their fish observational data to better understand functional impact.

5. Developing management recommendations

Describe the rationale managers can use to make various management decisions following resilience assessments. This is expected to become available in papers and reports over the coming months but will need to be summarized in the same format and style as the guidance for the other four parts of the process. Examples will need to be shared that include maps to help explain the assessment results, rationale for a decision, and what the decision would be.

Relevant References

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Theme 3: Connectivity

Session Leads: Lew Gramer and Matt Kendall

Overview and Relevant Case Examples from Workshop Attendees

Connectivity can be broadly divided into two topics that occur at very different scales, both of which can influence reef resilience: landscape-scale and larval connectivity.

Landscape-scale connectivity occurs among adjacent or nearby habitats. This may include any of the following: daily movements of fish residing on one habitat type during the day and foraging on another at night (e.g. haemulidae on Caribbean reefs), seasonal migrations such as movement from inshore residence areas to shelf-edge spawning sites, or ontogenic shifts wherein fish move from settlement or juvenile habitat to habitats that better suit the adult phase. Telemetry and tag-recapture projects are ideally suited to addressing these types of questions. For example, Pittman et al. (2013) use telemetry data to describe cross-shelf movements of a diversity of reef fish taxa in the context of habitat distribution, spawning sites, and MPA boundaries. Within landscape-scale connectivity there is vertical connectivity, which is the transport of organisms and reproductive material from deeper reefs, for example in an offshore reef slope, to shallower reefs inshore. This form of connectivity can be strongest where local retention is strong, and can be most important when vertical connectivity exists and deep-water reefs serve as refugia (i.e., from thermal stress). Genetic studies have provided the primary information on vertical connectivity so far (Beger et al. 2014; Serrano et al. 2014); this is by far the least well-studied aspect of connectivity.

Larval connectivity includes interisland or inter-regional larval and egg transport for some fish, corals, and invertebrates. At this scale of connectivity eggs and larval forms are transported from spawning sources to settlement destinations primarily by ocean currents. Sufficient larval sources must be maintained for reefs to absorb and recover from disturbance. Larval connectivity may occur on a wide range of spatial scales, from basins (Cowen and Sponaugle 2009; Shulzitski et al. 2009) to inland seas (e.g., Muhling et al. 2013) to the scale of patch reefs and the surface wave field (Monismith 2004). The longer the larval duration and lower the swimming and sensory capabilities of the larvae, the greater the potential for longer-distance transport of larvae from sources to destinations.

Several approaches can be used to investigate larval connectivity. Drifter data can be used to track the ocean currents that move larvae. The micro-chemistry of otoliths or skeletal elements can be used to track larval pathways. Genetics can be used to measure gene flow and even parentage among locations. Lastly, transport models can be used to simulate the movements of virtual larvae among sources and destinations. These transport models can be as simple as wind- and tide-based estimates of cross-shelf transport, or as complicated as multi-scale hydrodynamic ocean models. In combination, these approaches can provide an understanding of: 1) which reefs in a region serve as important larval sources and destinations, and 2) where to focus management efforts to increase the resilience of sites and the system.

Workshop attendees have used the approaches described above recently. For example, Kendall et al. (2014) used satellite-tracked ocean-drifters to document the relative isolation of the Mariana archipelago as either a source or destination of larvae with a pelagic phase under ~30 days. Kendall et al. (2013) also recently used transport simulations to demonstrate the westward transport of larvae along the Samoan Archipelago and the reduced connectivity anticipated in the region in response to warmer waters and climate change. Gramer et al. (2009) and Gramer (2013) investigated the cross-shelf transport mechanisms, which provide the "last leg" in far-field larval connectivity with reefs, in particular those on continental as opposed to insular shelves.

Some connectivity information can be gleaned from freely available global-hydrodynamic models and drifter datasets that can be analyzed to provide a basic understanding of larger-scale transport direction and scale. While not appropriate for all regions, these datasets can be used to guide more efficient sampling for other techniques such as plankton tows, genetic analyses, and microchemistry studies. Other low-cost options include using proxies such as prevailing wind patterns and modeled tidal currents with knowledge of local geography and seafloor topography to evaluate local retention and landscape-scale connectivity. Guidance needs to be made available to managers so that these low-cost options are utilized and to help set standards for how this information is gathered and used.

More resource-intensive approaches can greatly improve our understanding of connectivity. As examples, fine-scale hydrodynamic models are needed to resolve nearshore current processes that may promote or hinder larval retention, and promote or hinder connectivity with other reefs and reef systems. Genetic sampling can provide similar information and costs for testing continue to decrease. However, gathering samples within systems comprised of remote islands poses logistical challenges and can have high costs.

At reefs and in reef systems everywhere, all of the following have to be measured or estimated to assess connectivity at any scale with confidence: spawning population size and fecundity, navigational and swimming capabilities of larvae, larval mortality rates in response to environmental conditions, and the extent and quality of settlement habitat for larvae from diverse taxa.

Key Next Steps

Next steps presented in italics are high priorities and are also presented in the workshop summary.

1. *Define simple and inexpensive ways to establish a basic understanding of larval retention and connectivity potential and develop guidance for these approaches.*

2. *Seek to define "how much connectivity is enough" to maintain genetic versus demographic connectivity. Defining such values for various scales should ultimately replace present studies that only describe relative connectivity strength among locations.*

3. **Refine regionally specific guidance (based on 1 and 2) on spatial density and size for area based management initiatives where intensive circulation modeling/studies or genetic connectivity data are not available. This goes beyond traditional efforts to show linkages between MPAs by expanding the analysis to include linkages between all types of place based management, including but not limited to: priority watersheds, restricted areas, LMMAs, MPAs, high use and high enforcement areas, etc.*

4. *Develop case studies that describe: 1) how to include connectivity information to expand/enhance field-based assessments of ecological resilience, and 2) the actions managers can take once connectivity at any or all scales is better understood.*

5. Additional information is needed to enhance realism in the transport simulations now commonly used to estimate and depict larval connectivity. Proper parameterization of variables such as spawning population size, growth and survival dynamics during transport at sea, sensory and swimming capabilities of larvae near reefs, and suitability of settlement habitat are all needed. Basic research on these processes is needed everywhere resource-intensive approaches to understanding connectivity are planned. We need to better link experts developing models with those that have been working to parameterize input variables.

6. Develop a report on the significance of mesophotic reef connectivity for both field-based assessments of coral reef ecosystem resilience as well as resilience-based management more broadly. Effort will include a review of how we can better identify potential mesophotic reef areas using remote sensing and mapping technologies and characterize areas once ground-truthed. Review will also examine the implications of assuming that the relative resilience potential of shallow reefs in an area is representative of adjacent deep reefs.

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Theme 4: Land-based Sources of Pollution

Session Leads: Dr. Simon Pittman and Dr. Kirsten Oleson

Overview and Case Examples from Workshop Attendees

Land-based sources of pollution (LBSP), entering the marine environment from runoff, discharges and spillages, are widely acknowledged to have a detrimental impact on the condition of coral reefs. LBSP typically involves the addition of nutrients, sediments, toxins, bacteria and viruses to coastal waters that can impair coral health. Corals and associated organisms will respond differently to stressors, with different thresholds, depending on their physiological and anatomical adaptations to environmental conditions. Stressors from LBSP also interact with other stressors such as thermal stress and disease, contributing to cumulative impacts. LBSP can reduce the quality of non-reef environments too such as seagrasses, mangroves and unvegetated sediments which are known to function synergistically to form interconnected coral reef ecosystems. For example, where seagrass-reef connectivity is important, changes such as loss, gain or fragmentation of seagrasses due to freshwater exposure, nutrification or burial can impact the resilience of coral reefs. More directly, LBSP can introduce toxins to the marine environment which may persist, accumulate and transform in sediments and in the tissues of plants and animals creating disease in corals and a potential threat to human health where reef organisms are consumed.

All of the following pose challenges to our understanding of the impact of LBSP on reef resilience: the exposure is geographically widespread, the history of exposure is usually not well documented, the fate of pollutants when dispersed in marine waters is often unknown, and there is insufficient numerical knowledge of biological tolerance to pollutants to allow managers to set meaningful exceedance thresholds.

Research is conducted either through controlled laboratory experiments to examine lethal doses to organisms, and some reef specific *in-situ* observational or controlled studies to examine reef-specific organismal and/or community response, or at broader spatial scales with modeling and mapping of potential threats using information on the physical characteristics of watersheds. Here, we focused on the application of spatial models as a rapid and cost-effective approach to identify and prioritize areas for management concern at the scales of both individual watersheds and whole islands or continents. The majority of models require spatial data, but the data requirements vary widely.

The Landscape Development Intensity Index (LDI) (Brown & Vivas 2005) uses only land cover data, which is widely available from satellite imagery. There are more sophisticated models that incorporate dynamic hydrological processes and surface geology, such as INVEST, N-SPECT and Summit to Sea. For the island of St. Croix, in the U.S. Caribbean, LDI has been applied by a NOAA-led team to assist marine protected area managers in identifying areas of concern (http://coastalscience.noaa.gov/projects/detail?key=164). The study (Pittman et al. 2014) defined a near-shore zone, referred to as the Watershed Impact Zone (WIZ), where in-water biological surveys had been conducted and used to evaluate the relative threat to vulnerable coral species from LBSP. The LDI was subsequently used in a reef resilience assessment for St. Croix by The Nature Conservancy (Maynard et al. 2014) with a weighted distance to LDI factor. An earlier LDI approach was conducted by a team from the US-EPA, which found that the highest LDI (i.e., most urbanized watersheds) was associated with reefs of lowest coral cover (Oliver et al. 2011). The US-EPA is currently developing a database of species sensitivity and tolerance to LBSP stressors for the Biological Condition Gradient framework to help implement the Clean Water Act of 1972 in the U.S. Caribbean. A comparison of watershed health and reef health indices in Hawaiʻi found a positive relationship especially in south-facing shores (Rodgers et al 2012).

The InVEST tool was applied to estimate sediment runoff from watersheds in Hawaiʻi. InVEST uses the universal soil loss equation to estimate sediment loss due to sheet erosion. However, in some areas of Hawaiʻi this may not be the dominant process driving sediment loads. Channel erosion and mass wasting events may be significant contributors. Other more complex models may be better at capturing these processes, and handling the flashy, heterogeneous nature of Hawaiian watersheds. Moreover, stressors other than sediment, such as urban pollution, on-site disposal systems, legacy chemicals from agriculture, and wastewater injection, inevitably play important roles, necessitating tools that can weight and combine stressors. However, little is known about the relative importance of these stressors in Hawaiʻi and elsewhere.

Key next steps

Next steps presented in italics are high priorities and are also presented in the workshop summary.

1. *Compile a list of evidence-based water quality standards with exceedance threshold values for key stressors that are relevant to coral reefs (e.g., toxins, sediment, bacteria, salinity, total max daily loadings) through a literature review. This list needs to be made publicly accessible and a group or groups needs to be accountable for keeping the list updated.*

2. *Consistent and coordinated reporting on water quality status and trends for parameters that are meaningful to coral reef health (see above) are required.*

3. *Write a review of the tools and approaches for spatial modeling of land-based sources of pollution to produce a concise guide with estimates of resource requirements, case studies and links to required software.*

4. *Regional and global studies are needed to examine the linkage between 1) historical changes in land cover; 2) ocean color/water quality; and 3) coral reef condition. This will inform 'what if' scenarios to help communicate the consequences of land cover change for coral reef health.*

5. *More evidence is needed to assess the effectiveness of spatial proxies in representing the distribution of threats from watershed to marine water quality and coral reef condition. For example, direct measurements of water quality and benthic communities are needed*

(water samples and ocean color data, dispersal models) to link the landscape models such as LDI to coral condition (see Maina et al. 2012).

6. A detailed region-by-region cumulative impacts model is required to support resilience assessments. Global cumulative impact models such as Reefs at Risk Revisited (Burke et al. 2011) and Halpern et al. (2008) models need to be refined and updated to be locally applicable.

7. Spatially explicit techniques such as dynamic exposure mapping (Maynard et al. in review), as demonstrated for the Great Barrier Reef, should be integrated with LBSP models and applied more widely around the world. A greater understanding of the impact to reef resilience from multiple interacting stressors is urgently required. Existing studies suggest that sedimentation and nutrification decrease reef resilience to climate change impacts (Carilli et al. 2009; Melbourne-Thomas et al. 2011).

8. LBSP assessments need to be framed in a holistic interdisciplinary framework. A more complete understanding of the bigger picture of LBSP and reef resilience requires a holistic systems science approach capable of modeling spatial dynamics, feedback loops and interactive effects. This systems science approach has to be inclusive of expertise from hydrological and hydrodynamic modeling, biogeochemical analyses, physiology and toxicology, ecology and socio-economics. The DPSIR (Driver-Pressures-State-Impact-Response) model (Bricker et al. 2003) has potential as a broad causal framework where linkages can be examined from point of stress (e.g. coral mortality) to drivers such as State policy (e.g. agricultural policy/ urban planning). The DPSIR framework may need to be evolved from a static reporting framework to a dynamic modeling environment capable of integrating information from a coupled socio-ecological system (see, e.g., Kelble 2013 as a good first step).

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Theme 5: Managers Use of Resilience Information and Reporting

Session leads: Roger Beeden and Britt Parker

Overview and Relevant Case Examples from Workshop Attendees

Coral reefs are among the most sensitive ecosystems to climate change and ocean acidification. Managing coral reefs at a time when changing sea temperatures, levels and chemistry are already negatively affecting the capacity of hard corals to settle, grow, calcify and persist, presents a unique set of challenges. In many reef areas, increasingly frequent environmental disturbances combined with anthropogenic stressors are challenging the natural resilience of reef systems. Adaptively managing coral reefs to support their resilience requires a dynamic understanding of their current condition and the pressures that affect their future health.

Far from replacing current approaches, resilience-based management and resilience assessments simply provide a way of optimizing established ecosystem-based management practices to address current and future pressures. Resilience-based management (RBM) is akin to the use of Global Positioning Systems (GPS) that allow users to successfully navigate complex routes and adapt to changing conditions to reach a target destination. In combination with long-term trend monitoring to validate and refine ecosystem models and current, up-to-date estimates of pressures and ecosystem status (the starting conditions for resilience assessments), resilience-based decision-making enables managers to identify, recommend and credibly defend short-term tactical and long-term strategic actions into the future. Building on the GPS simile, from a management perspective, trend monitoring is similar to a *car's rear view mirror,* providing understanding of where we have come from. Assessment of pressures and ecosystem status is like the *car windscreen* that drivers respond to in real time in order to stay on course. Resilience assessments provide the data that the GPS unit (RBM) uses to recommend one or more courses of action to achieve an outcome. Importantly resilience-based management is not a panacea, and its use will undoubtedly highlight winners and losers among the ecological, social and economic values that are currently provided by coral reefs.

Iterative improvement of management actions based upon evaluation is essential to the successful integration and use of resilience theory in conservation management. Given how busy most reef managers are, the commitment to monitoring, evaluation and improvement is only likely to happen if the process is simple and managers are convinced of its merit. Therefore, it is important to: 1) show how a resilience-based approach can result in outcomes that could not be achieved without it and 2) identify priorities/actions that would not have been apparent without the application of RBM.

Most current marine protected areas (MPAs) were not set up for systems management or with resilience in mind, with the notable exception of the Bahamas, which explicitly used resilience theory in its design. The TNC R2 toolkit has been used in a number of areas for MPA design. Broader application of resilience approaches in MPA and MPA network establishment and management is needed. Using a resilience based approach can also strengthen the application of existing frameworks towards EBM, such as marine spatial planning, as well as some sectoral planning processes. Current use of resilience thinking in coastal zone management, such as adjusting plans for anticipated sea level rise, provides valuable precedents.

To aid understanding and build support for resilience approaches we will need a good readily understood definition for RBM and analogies or case studies (e.g. GPS, healthcare and immune system, fire management etc.; see Appendix 3).

Key Next Steps

Next steps presented in italics are high priorities and are also presented in the workshop summary.

1. *Define 'resilience-based management' in the context of ecosystem-based management/coral reef management and communicate why it will enable managers and policy makers to deliver conservation and ecosystem service outcomes in a changing climate.*

Develop a succinct definition/description of resilience-based management, founded on the available literature and management needs and in the context of management approaches and principles commonly in use. Develop a communications piece that builds on the definition, and explains why resilience matters, how it compliments current management and planning arrangements and what managers need to do to integrate the concept into their business.

2. *Develop a case study driven evidence base to support the use of resilience assessments and resilience-based management actions.*

To be effective RBM requires future focused actions based on models as well as past trends. Gather and provide case studies and examples from conservation and other sectors to support the use of resilience assessments and RBM (e.g. how has this influenced planning, management, government budget allocations etc.) Highlight that developing and using projections is challenging but useful and a normal part of many corporate business practices. Collate and share examples of validation based improvement of predictive models to aid the understanding and acceptance of their use among stakeholders. Where possible, gather and publicize examples of how well resilience assessments have 'predicted' outcomes (see Appendix 3 for case study ideas).

3. *Develop guidelines for operationalizing resilience-based management.*

    a. Building on the definition and rationale for RBM adoption, provide guidance on how resilience thinking and assessments can be built into current planning and management processes, with examples from different organizations and jurisdictions with varying resource bases.
    b. Use the case studies provided by the group to illustrate the guidelines to demonstrate 'where resilience plugs in'.
    c. Highlight the value of taking a hierarchical approach (e.g. to resilience assessment/monitoring) that also utilizes citizen science to improve spatial and temporal

coverage while building community support.

d. Define the types of outputs (products) and outcomes (what does success look like?) that users can expect from implementing the guidelines.
e. Develop a template for a communication strategy to support the adoption and implementation of RBM – provide examples from the GBR and other locations (i.e., CRED: In-Brief version, Full report, Papers + buzz feeds, web based outputs?, Institute of Development Studies.)

This effort will build on other work to better understand how managers can implement resilience-based management. In July 2012, a workshop entitled "Operationalising resilience for management of coral reefs" was held following the 12th International Coral Reef Symposium. The workshop was co-funded by the Great Barrier Reef Marine Park Authority (GBRMPA), the Australian Institute of Marine Science (AIMS), the United Nations Environmental Programme (UNEP), the International Union for the Conservation of Nature (IUCN) and the NOAA CRCP. The primary outcome from this workshop was the development of an operational Adaptive Resilience-Based Management framework for identifying effective management options to enhance ecological and socio-economic resilience and support management decisions that reduce reef vulnerability (Anthony et al., 2014). In addition, Mumby et al. (2013) published "Operationalizing the Resilience of Coral Reefs in an Era of Climate Change" which will serve as another resource to this process.

4. Describe how integrated monitoring and evaluation is a requirement for effective resilience-based management and how managers can adapt their current monitoring programs to inform resilience-based management.

Package available RBM information for managers and highlight what communication and reporting options are available to inform decision-making. 'Outlook reports' and maps for reefs that summarize trend (past), status (current) and future (resilience) condition of values. Include examples of what RBM actions actually look like e.g. adapted zoning (Bahamas) and COTS control to support recovery (GBR).

5. Work with GCRMN to integrate resilience and future outlook in GCRMN reporting at regional and global level. This may include providing input towards the development of guidance for preparation of GCRMN regional reports (1st half 2015), as well as collaboration on the next Global GCRMN report.

***Potential output**: GCRMN "Status and Outlook for Reefs of the World"; incorporating trends, status and resilience-based outlook.*

a. Report on trend (past), status (current) and future (resilience)
b. Generate predictive maps based upon past and current exposure and IPCC based forecasts plus other relevant / available variables
c. Use the Landscape Development Intensity index to link catchments to marine systems.
d. Develop conceptual models to identify critical indicators (reconcile DPSIR with vulnerability / resilience).

e. *Develop a template for spatial RBM plans that can be user customized to inform decisions and maximize outcome.*

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