Tools to aid coral reef managers in French Polynesia and other reef regions to build resilience to climate change into management and conservation planning ('ReefManagerTools')

Researchers: Dr. Jeffrey Maynard (fellow) and Dr. Serge Planes (LABEX CORAIL and CRIOBE Director).

Background and Objectives - In the vulnerability model adopted by the IPCC the vulnerability of a habitat, or ecosystem, or even an industry or community is determined by exposure, sensitivity, and adaptive capacity (see recent review in Marshall et al. 2013). Exposure and sensitivity combine to produce a potential impact – these terms capture what happens to the system, and how the system reacts. The adaptive capacity of the system determines whether those potential impacts have a short or long-lasting legacy. Assessing and reducing vulnerability to climate change is now the hallmark of many conservation programs and is critical to ensuring coral reefs can persist. From the perspective of a coral reef manager, reducing vulnerability equates to reducing sensitivity and supporting the adaptive capacity of coral reefs (Mumby et al. 2013). This involves supporting the natural resilience of coral reef systems – their ability to resist and recover from disturbances and continue to maintain essential functions and processes (Walker et al. 2004). Limiting exposure to disturbances caused by global climate change, like coral bleaching, is well out of the scope of all local coral reef managers (Anthony et al. in revision). Thus, managing to support the resilience of reefs (and reduce vulnerability) requires reducing stress caused by human activities (Anthony and Maynard, 2011).

Marine protected areas (MPAs) zoned for multiple use have become the most popular tool used by coral reef managers to support reef resilience while managing for sustainable use (Edgar et al. 2007). The Nature Conservancy developed a model to frame the concept of resilience in a way that is easy for managers to understand (Obura and Grimsditch 2009). The model has four components: representation and replication, critical areas, connectivity, and effective management. In the first, ensuring that all habitat types are well represented and replicated decreases the risk a catastrophic event will destroy the whole reef system. Critical areas enhance replenishment and recovery of reefs by providing secure sources of larvae. These could include fish spawning aggregation sites, as well as refugia – locations that are far less exposed to disturbances than other sites due to local conditions. Critical areas could also be areas where the coral communities are especially resistant to bleaching or have been shown to recover quickly. Preserving connectivity can enhance recovery by ensuring coral communities can be replenished after disturbances. Lastly, effective management has to ensure threats caused by human activities are actually mitigated or reduced at protected sites (TNC resilience model description - http://www.reefresilience.org/Intro_to_Resilience.html).

The focus of this proposal is the identification of critical areas - part 2 of the TNC resilience model. Ensuring critical areas are well represented and replicated (part 1) within MPAs that are effectively managed (part 4) and preserve connectivity (part 3) *requires that these areas can be identified.* Finding fish spawning aggregation sites (SAGS) can be difficult but in many locations these are well known to the fishing community (Sadovy and Domeier 2005) and SAGS were not the focus here. In contrast, identifying sites in an area that have been especially resilient in the past and identifying refugia is more challenging.

The research we undertook during the MC-IIF had three phases related to identifying critical areas in French Polynesia and aiding others to do the same everywhere coral reefs occur. The objective of each phase is described just below.

Objectives

1. **Bleaching and cyclones at long-term monitoring sites in French Polynesia.** Identify especially resilient sites that have experienced thermal stress and waves from cyclone winds and either suffered less mortality than expected or recovered quickly.
2. **Exposure mapping for French Polynesia.** Map spatial patterns in exposure of coral reefs in French Polynesia to thermal stress and waves from cyclone winds, and possible exposure to crown-of-thorns starfish outbreaks to identify possible refugia.
3. **Global interactive tools for the coral reef community.** Develop tools that make data on exposure to thermal stress and strong waves from cyclones (1982-2011) publicly accessible through a user-friendly interface.

Results – The fellow and collaborators produced 14 peer-reviewed publications during the project period as well as an e-book and major international workshop report. These papers were published in leading academic journals, including: Nature Climate Change, Global Change Biology, Nature Communications, Conservation Letters, and Biological Conservation. The three key tools developed for the international coral reef community (scientists and managers) are described below.

Downscaled projections of bleaching conditions: Increasingly frequent severe coral bleaching is among the greatest threats to coral reefs posed by climate change. Global climate models (GCMs) project great spatial variation in the timing of annual severe bleaching (ASB) conditions; a point at which reefs are certain to change and recovery will be limited. However, previous model-resolution projections (~1x1°) are too coarse to inform conservation planning. To meet the need for higher-resolution projections, we generated statistically downscaled projections (4-km resolution) for all coral reefs; these projections reveal high local-scale variation in ASB. Timing of ASB varies >10 years in 71 of the 87 countries and territories with $\geq$500km^2 of reef area. Emissions scenario RCP4.5 represents lower emissions mid-century than will eventuate if pledges made following the 2015 Paris Climate Change Conference (COP21) become reality. These pledges do little to provide reefs with more time to adapt and acclimate prior to severe bleaching conditions occurring annually. RCP4.5 adds ~15 years to the global average ASB timing when compared to RCP8.5; however, >75% of reefs still experience ASB before 2070 under RCP4.5. Coral reef futures clearly vary greatly among and within countries, indicating the projections warrant consideration in most reef areas during conservation and management planning. The projections are publicly accessible at: http://coralreefwatch.noaa.gov/climate/projections/downscaled_bleaching_4km/index.php

Predicting coral disease: Rising sea temperatures are likely to increase the frequency of epizootic diseases affecting reef-building corals through impacts on coral hosts and pathogens. We present and compare climate model projections of temperature conditions that will increase 1) coral susceptibility to disease, 2) pathogen abundance, and 3) pathogen virulence, under moderate (RCP 4.5) and fossil fuel aggressive (RCP 8.5) emissions scenarios. We also compare projections for the onset of disease-conducive conditions and severe annual coral bleaching, and produce a disease risk summary that combines climate and anthropogenic stress. There is great spatial variation within and among reef regions in the projected timing of conditions facilitating disease development, with thresholds already surpassed in some locations. Under both RCP scenarios, >95% of reef locations are projected to experience at least 2 of the 3 temperature conditions favoring disease development in the next 20 years. Notably, these thresholds are exceeded before annual severe bleaching conditions occur. At ~22% of these locations, high or very high anthropogenic stress will further enhance disease likelihood. Our results indicate disease is as likely to cause coral mortality as bleaching in the coming decades. These projections identify priority locations to reduce anthropogenic stress and test management interventions to reduce disease impacts. The projections are accessible at: http://www.nature.com/nclimate/journal/v5/n7/full/nclimate2625.html

Assessing ecological resilience potential: Ecological resilience assessments are an important part of resilience-based management (RBM) and can help prioritize and target management actions. Use of such assessments has been limited due to a lack of clear guidance on the assessment process. This study builds on the latest scientific advances in RBM to provide that guidance from a resilience assessment undertaken in the Commonwealth of the Northern Mariana Islands (CNMI). We assessed spatial variation in ecological resilience potential at 78 forereef sites near the populated islands of the CNMI: Saipan, Tinian/Aguijan, and Rota. The assessments are based on measuring indicators of resilience processes and are combined with information on anthropogenic stress and larval connectivity. We find great spatial variation in relative resilience potential with many high resilience sites near Saipan (5 of 7) and low resilience sites near Rota (7 of 9). Criteria were developed to identify priority sites for six types of management actions (e.g., conservation, land-based sources of pollution reduction, and fishery management and enforcement) and 51 of the 78 sites met at least one of the sets of criteria. The connectivity simulations developed indicate Tinian/Aguijan are each roughly 10x the larvae source that Rota is and twice as frequent a destination. These results may explain the lower relative resilience potential of Rota reefs and indicates actions in Saipan and Tinian/Aguijan will be important to maintaining supply of larvae. The process we describe for undertaking resilience assessments can be tailored for use in coral reef areas globally and applied to other ecosystems. This guidance on assessing ecological resilience in reef areas is available at: http://www.sciencedirect.com/science/article/pii/S0006320715300926

The tools described above inform the development of management plans that often involve actions requiring community support. Increasing community support for management actions that enhance reef resilience requires fostering stewardship. For that reason, we developed a *Reef Manager's Guide to Fostering Community Stewardship*, an e-book in a new Reef Manager's Guide series we have started. The e-book is available at: http://www.iucn.org/news/reef-manager%E2%80%99s-guide-stewardship

The tools/data layers and publications developed during this fellowship are being used by coral reef scientists and managers worldwide. For example, the climate model projections we developed for coral bleaching conditions have already been viewed by 2,500 people from 80 different countries. The tools are positively influencing how MPAs in reef areas are planned and managed. Our completed research will inspire follow-on research, tool/application development, and communications efforts that will continually improve reef management and coral reef prospects under climate change.