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Comprehensive Assessment of Risk to Ecosystems (CARE): A cumulative ecosystem risk assessment tool

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ABSTRACT

Unassessed marine ecosystems are often unmanaged marine ecosystems. Several risk assessment methods exist that can provide a scientific basis for siting interventions and guiding management actions, but these methods focus mainly on single species and evaluate only the impacts of fishing in detail. We present a new ecosystem risk assessment model, the Comprehensive Assessment of Risk to Ecosystems (CARE), which allows analysts to consider the cumulative impact of multiple threats, interactions among threats that may result in synergistic or antagonistic impacts, and the impacts of a suite of threats on whole-ecosystem productivity and functioning, as well as on ecosystem services. CARE can be completed very rapidly, and uses local and expert knowledge where data are lacking. It can be applied to virtually any system, and can be modified as knowledge is gained or to better match different site characteristics. Two case studies are provided to illustrate how CARE can be applied. These CARE analyses suggest that in Karimunjawa, Indonesia activities other than fishing should be addressed to ensure that a fisheries intervention will achieve desired outcomes. Conversely in Cantilan, Philippines a well-designed and implemented fishery intervention could address all of the most important system threats.

1. Introduction

1.1. Ecosystem risk assessment—existing tools, uses, and challenges

Failure to assess the impacts of human activities on ocean ecosystems can impair the capacity of these systems to produce the goods and services people value. Understanding risks is also important for siting management interventions when capacity and resources are limited: for example, improving fisheries management will not result in higher yields or better fishing revenues if other impacts are limiting the production of fish biomass. Without an accurate assessment of the full suite of risks facing a system, managers may spend valuable time and resources attempting to control the wrong drivers of system change. For instance, after four decades of concerted efforts to protect and restore the Great Barrier Reef, recent research suggests that a failure to accurately assess and prioritize the different factors impacting this system has been a main reason for its continued decline (Kearney and Farebrother, 2014). Furthermore, recent research suggests that the potential impact of various risks on the achievement of project objectives has not been given sufficient attention by most conservation organizations (Game et al., 2013).

A variety of methods have been developed to assess the status of fisheries and the ecosystems on which they depend, and to model the predicted impacts of various stressors that affect those systems. Recently, methods to assess risks to marine ecosystems, even when data are limited, have been developed (Hobday et al., 2011; Miriam et al., 2015; Patrick et al., 2009; Samhouri and Levin, 2012; Sharp et al., 2014). Data-limited fisheries are those that lack sufficient scientific data to conduct the complex assessments traditionally used to inform fisheries management decisions (Honey et al., 2010). Data-limited fisheries present a variety of challenges for sustainable management, and it is often necessary to use novel or specialized methods to assess stock and ecosystem health and functioning before implementing management changes (Fujita et al., 2013).

Ecological Risk Assessment (ERA) is a process that involves scoring the impacts of various stressors on a set of system characteristics. For example, the Ecological Risk Assessment for the Effects of Fishing (ERAEF) developed by Australia's Commonwealth Scientific and Industrial Research Organisation in 2007 is a seminal example that uses a hierarchical process to estimate the risk to a species, habitat, or community from fishing activities (Hobday et al.,

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2011, 2007). ERAEF starts with a largely qualitative scoping exercise conducted to collect information on known attributes of the species, habitat or communities, followed by a qualitative assessment of the scale and intensity of threats along with the likely consequences for the species or system, and a semi-quantitative Productivity Susceptibility Analysis that uses scores on attributes associated with productivity and susceptibility to fishing to estimate overall vulnerability of the species, habitat, or community to a given fishery. Finally, a fully quantitative system model is recommended when sufficient data become available (Hobday et al., 2011). Other authors and organizations have since built on this method, and modified it for application to a variety of settings. For example, the National Oceanic and Atmospheric Administration (NOAA) developed a PSA tool to estimate stock vulnerability (NOAA Fisheries Toolbox: Productivity and Susceptibility Analysis (PSA), 2010; Patrick et al., 2009). The Natural Capital Project has developed a Habitat Risk Assessment model as part of their InVEST suite of modeling tools (Sharp et al., 2014). Samhouri and Levin (2012) developed an assessment of ecosystem risk from land- and sea- based impacts, which mirrors the PSA process, but compares the exposure of a population to any activity, and the sensitivity of the population to that activity, given a particular level of exposure.

More recently, the Department of Fisheries and Oceans of Canada commissioned the development of an ERA tool (called the Ecological Risk Assessment Framework or ERAF) to analyze risks facing their system of Marine Protected Areas (MPAs) (Department of Fisheries and Oceans, 2012; Miriam et al., 2015). This model follows the ERAEF framework and builds on other existing tools, examining the risk to a system from multiple threats, related to both fishing and non-fishing activities. However, rather than using the standard PSA approach, which calculates risk in terms of Euclidean distances from the origin of a graph for which species productivity and susceptibility represent the X and Y axes (Hobday et al., 2011; Patrick et al., 2009), the ERAF calculates risk as the product of the exposure to a threat, and the likely response to that exposure (Miriam et al., 2015). Because of this change, the resulting risk scores more accurately represent the potential impact of a given threat on a system, making them more appropriate for comparison with risk scores from other threats, or at other sites (Miriam et al., 2015).

These ERA tools represent remarkable progress in ecosystem risk assessment. However they all have certain limitations that will be important to overcome to fully characterize risk and thus provide good guidance for risk management. Specifically:

- most of these tools model only the impacts of fishing without quantitatively considering other threats that may face a marine system;
- none of these tools assess the synergistic or antagonistic effects that different threats acting on a system may have on each other;
- ecosystem productivity and functioning are substantially simplified to just a handful of representative factors, such as key population abundance or spatial habitat extent, and do not incorporate new findings on attributes of ecosystems associated with recovery or resilience;
- there are currently no tools designed to evaluate risk in relation to differential ecosystem service provision in data-limited systems, which will be especially important when considering siting of spatial management measures such as exclusive fishing territories and marine protected areas;
- all existing ecosystem risk assessment tools require significant time (several days) and capacity (expert knowledge and access to primary literature) to complete, limiting their feasibility where capacity is low.

1.2. Comprehensive Assessment of Risk to Ecosystems (CARE)

We developed the Comprehensive Assessment of Risk to Ecosystems (CARE) method to address these issues. This tool can be used to rapidly rank the threats facing a system or a species to aid in the selection of sites for fishery reform interventions and guide threat reduction strategies in data-limited systems. The CARE model draws from other ERA methods, and from recent research on cumulative impact assessment, ecosystem resilience, and ecosystem service assessment (Barbier et al., 2011; Halpern et al., 2008; Keith et al., 2013; Link, 2005) to add value to the existing ecosystem risk assessment tools in a number of important ways. First, CARE can be used to assess risk from any number of threats to a given ecosystem. Second, CARE allows the analyst to assess the *interactions* (synergistic or antagonistic) of multiple threats with each other. Third, CARE assesses risk to the entire ecosystem through use of a more comprehensive suite of attributes that characterize system health and functioning as described by intrinsic system recovery potential (e.g., "regeneration time" and "connectivity") and resistance to impact (e.g., "removability of system components" and "functional redundancy and diversity"). Fourth, CARE includes a module designed to quantify risk to the production of ecosystem services in both data-rich and data-limited settings. Finally, CARE can be implemented in the field, relying largely on local and expert knowledge when data are limited, and completion of a CARE analysis by system experts can take as little as 1–2 h. CARE generates risk values for each threat as it impacts each "target" (valued components of the system selected for analysis), ecosystem service production, and the ecosystem as a whole.

CARE can be used to evaluate risks facing a single site, to compare multiple sites for the suitability or necessity of different management options, or to evaluate the effects of a proposed management action aimed at reducing one or more risks. This method can help users identify which threats are the most important at a given site and for a given target, and therefore where limited management resources should be targeted. It can also help to identify where different management approaches might be most appropriate. For example, if a site is particularly at risk from fishing, but proves to be more resilient to the impacts of non-fishing threats such as coastal development or nearby aquaculture, a well designed and implemented fishery improvement project would be expected to result in significant improvements in fishery outcomes. Alternatively, if a site is at risk from a larger variety of non-fishing threats, policies aimed at reducing the most important threats might be a more appropriate approach. Furthermore, because CARE also results in scores for various ecosystem services at a site, it can be helpful for planning uses that are consistent with optimizing the value of ecosystem services. CARE can be applied to any spatially-explicit system, and can be adapted to better fit individual system characteristics.

We have applied CARE to sites in a variety of countries around the world to inform management strategy decisions. Here we briefly present our methods in designing CARE, along with example applications and results from two case study sites: Cantilan, the Philippines and Karimunjawa, Indonesia. Supplementary Appendix B provides greater detail on the design of the CARE model.

2. Methods

CARE, consistent with other ERA methods, guides users through evaluation of the potential impact of all natural and anthropogenic "threat" activities present in a system on a selection of "targets" (ecosystems and/or species) that are valued by the user. To maximize its usefulness in the field, and minimize time requirements for analysis, the complete CARE analysis of a given target is completed