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Analyzing the (mis)fit between the institutional and ecological networks of the Indo-West Pacific

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ABSTRACT

Critical to improving environmental governance is understanding the fit (alignment) between institutional arrangements and key ecological processes. This is particularly true for biodiversity hotpots and ecologically sensitive areas that are subject to significant impacts from human activities. Here, we have developed an innovative approach to quantify ecological-institutional alignment across an environmentally and politically complex large-scale marine social-ecological system. We mapped the trans-boundary networks of marine population dispersal corridors, and intersected these with estimates of cross-country institutional linkages related to marine management and conservation. In integrating large-scale ecological-institutional networks, we identify geopolitical fit and misfit between a region's ecological processes and its governance. We have demonstrated this approach in the Indo-West Pacific region, a global marine biodiversity hotpot in the Indo-West Pacific. We present region-specific institutional and ecological networks, highlight current challenges, and suggest future directions to refine the proposed approach to quantify alignment between ecological processes and governance arrangements. Ultimately, our method has the potential to assist management efforts in prioritizing and strengthening governance to effectively safeguard ecological processes across multiple jurisdictions.

1. Introduction

Research on sustainability is increasingly focused on an integrative systems perspective that acknowledges complex social–ecological interdependencies (Berkes et al., 2003; Cumming et al., 2006; Kittinger et al., 2012). Arising from these interdependencies is the "problem of fit", one of the core constraints to effective governance in Social–Ecological Systems (SES). It is based on the idea that effective SES governance depends to some extent on how the characteristics of the governance system (e.g., institutional arrangements) align with the characteristics of the ecosystem it is trying to govern (Bodin et al., 2014; Brondizio et al., 2009; Brown, 2003; Crowder et al., 2006; Ekstrom and Young, 2009; Folke et al., 2007; Galaz et al., 2008; Young, 2002). "Poor" alignment (low degree of fit) may lead to ineffective SES governance, which implies that the likelihood for meeting long-term ecological and social benefits is severely reduced. Similarly, "good" fit may be necessary, but not sufficient, for effective SES governance and safeguarding ecological properties. An example of where better alignment has shown to be beneficial is the southern ocean fishery (Osterblom and Bodin, 2012; Osterblom and Sumaila, 2011). This fishery for Patagonian toothfish, *Dissostichus eleginoides*, involves many actors from different nation states and several non-governmental organizations with the fish population distributed over vast oceanic areas. Decades-long development of joint institutional arrangements, collaborations, and practices among the actors has led to new regional institutional linkages that are better aligned with the characteristics of the fishery. This qualitative increase of fit over time has likely contributed to increased governance effectiveness, and could therefore help explain the remarkable reduction of illegal, unreported, and unregulated fishing over the last two decades in this area (Osterblom and Bodin, 2012; Osterblom and Sumaila, 2011).

Despite the importance of the problem of fit, very few studies have quantitatively evaluated such a problem, and of those that have, struggled to incorporate the multiple functional, spatial, or temporal dimensions of fit (Cash et al., 2006; Young, 2002). This study develops a quantitative approach and evaluates two dimensions of fit, i.e., the level of spatially and functionally defined fit

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between key ecological processes and the governance structures (i.e., institutional arrangements) relating to the management of these processes. This was undertaken in the context of the geopolitically and ecologically complex region of the Indo-West Pacific where we focus on the coral reefs and the trans-boundary corridors (i.e. ecological links) utilized by marine taxa dispersing between these reefs as the ecological system. Ecological links are thus operationalized as the abilities of different marine species to disperse between different areas of coral reefs (Cowen et al., 2006; Treml et al., 2012). In our study and others (e.g., Fidelman and Ekstrom, 2012), an institutional linkage occurs when two countries take part in a common institutional arrangement (e.g., treaty, convention, agreement, or memorandum of understanding), addressing a given issue of concern that directly or indirectly relates to marine conservation or management. Using these conceptualizations of trans-boundary institutional and ecological links, this study investigates whether institutional arrangements connecting countries exist along ecological corridors.

Three main analyses were performed in order to evaluate the fit between institutional arrangements and the ecological system: (1) recast the structure of multi-species coral reef connectivity in terms of the potential ecological linkages among countries to define the regional ecological network, (2) develop and analyze a database comprising agreements, conventions, policies, and programs between countries pertaining to the governance of the region's coral reefs, thereby mapping the regional network of institutional linkages connecting countries, and (3) analyze the combined ecological–institutional networks to identify the degree of fit (key alignments and misalignments).

1.1. The Indo-West Pacific

The Indo-West Pacific, containing the Coral Triangle (CT) region (Veron et al., 2009) is a global center of marine biodiversity (Roberts et al., 2002), and supports the livelihoods of more than 130 million people. However, it is under immediate pressure with an estimated 85% of the reefs currently threatened by human activities and local stressors (Burke et al., 2012). An important factor in determining how coral reefs withstand or recover from these pressures is the degree of population connectivity. Connectivity, or the ecological linkages among neighboring populations created by the dispersal of larvae (e.g., young fish, corals), largely determines population persistence and their recovery rates (Hastings and Botsford, 2006). As a result, coral reefs and their connectivity in the region have become an international priority for conservation and management under regional efforts, such as the Coral Triangle Initiative for Coral Reefs, Fisheries and Food Security (CTI-CFF) (CTI-Secretariat, 2009). The CTI-CFF is an example of the many international agreements that apply to marine conservation and management in Indo-West Pacific. It developed a Regional Plan of Action for improving the health of the marine environment and wellbeing of the local communities, prescribing a hierarchical management strategy and identifying long-term goals in which marine protected areas (MPAs) may be used in balancing the objectives of biodiversity protection with resource use (Fidelman et al., 2012; Halpern et al., 2012; Walton et al., 2014). However, although there has been some recent progress in the region with respect to MPA designations (White et al., 2014), broadly implementing the CTI-CFF and other international agreements of similar nature may prove a challenging task due to the complex social, political, and ecological structures, and the enormous geographic extent of the Indo-Pacific region (Fidelman et al., 2012). Accomplishing such ecological defined goals, such as those in the CTI-CFF, will require regional institutional arrangements that are, as much as possible, well aligned ('fitted') with the ecosystem processes (Folke et al., 2007; Young, 2002).

Like other large-scale SES, particular challenges arise from the structure of marine governance in the Indo-Pacific region, which is complex, fragmented, and characterized by jurisdictional overlaps (Fidelman and Ekstrom, 2012; Fidelman et al., 2012). Further, the multidimensional governance architecture of the region reveals significant variability in institutional arrangements among countries and policy sectors (e.g., fisheries, threatened species, marine protected areas, etc.). Improving governance in the region will require higher levels of coordination between institutional arrangements (Fidelman and Ekstrom, 2012; Walton et al., 2014) and, importantly, better fit between these arrangements and ecological processes (Fidelman and Ekstrom, 2012; Folke et al., 2007).

2. Methodology

The geographic focus of this study is the Indo-West Pacific Ocean, encompassing the six Coral Triangle countries (CT6) and seven of their neighbors (Table S1). To assess the degree of fit between the ecological connectivity and the relevant institutional arrangements, we developed, analyzed, and compared two types of networks: ecological connectivity and institutional linkages. The institutional linkage networks were based on several key topics (e.g. fisheries, marine protected areas, etc.), and were used to test how well the resulting institution networks fit with the multi-species ecological network. These ecological and institutional networks are described below, followed by a description of the alignment analysis used to identify the ecological–institutional (mis)fit.

2.1. Ecological Networks

The ecological network represents the demographically significant dispersal linkages, or connectivity, between individual coral reefs of the region. Connectivity is defined as the likelihood that, for a particular modeled species, larvae originating at a source coral reef are capable of dispersing and reaching downstream reef habitat. We modeled this ecological connectivity for five different coral reef functional groups, or dispersal strategies, to capture a range in species' dispersal potential. This was important as the spatial and temporal structure of ecological connectivity can be sensitive to individual biological parameters such as behavior, mortality, spawning time, and the time spent dispersing (Paris et al., 2007; Treml et al., 2012). For this reason, and for computational tractability, we define the region's ecological connectivity based on five generalized marine taxa: a monthly broadcast spawning coral, a seasonal spawning reef invertebrate (e.g., sea cucumber), a lunar spawning benthic reef fish, a continuously spawning pelagic fish, and a seasonally spawning large predatory fish (e.g., coral trout). For each taxon, dispersal was modeled (Treml et al., 2012) and the ecological connectivity among reefs was quantified as the probability of dispersal over two generations. These reef-based connectivity matrices were summarized at the country level (Treml and Halpin, 2012) and simplified to show where ecologically significant connectivity (probability greater than 0.001) exists between countries (link = 1) and where no ecological connectivity exists (link = 0). The networks for the five taxa were combined resulting in a final multi-species ecological network among countries where connection values were defined as: one (connectivity in one or two taxa), two (connectivity in three or four taxa), and three (ecological connectivity for all modeled taxa). This multi-species network was used throughout to represent the region's ecologically relevant coral reef connectivity.

2.2. Institutional Networks

In this study, institutions or institutional arrangements refer to the rules and norms that mediate human–environment interactions (Ostrom, 2005). Although institutions include informal