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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 norms or *de facto* arrangements, the main focus of this study is on the formal arrangements (e.g., international agreements, conventions, policies, and programs) that govern the use and management of marine resources in selected Indo-West Pacific countries. The approach to capture the institutional networks draws from recent research on trans-boundary governance in the Coral Triangle region (Fidelman and Ekstrom, 2012). A database of 200 documents (e.g., treaties, conventions, policy declarations, action plans, and memoranda of understanding) pertaining to international environmental agreements involving two or more of the 13 countries of interest was developed (Table S2 presents examples of the documents used in the analysis). These documents were identified and gathered primarily from the ECOLEX database (http://www.ecolex.org) between May and June 2013. For each country a list of international environmental agreements to which that country was signatory was retrieved; those agreements pertaining to marine conservation and management were then selected. The documents were analyzed in MINOE v1.10, a software tool to analyze documents as they relate to the management of ecological systems (Ekstrom et al., 2010), drawing on the approach developed in Ekstrom and Young (2009) and employed in Fidelman and Ekstrom (2012). The analysis included counting the number of times key terms appeared in each of the documents within the database. This term frequency was then used as a proxy indicator of the extent to which the documents related to one or more ecological topics of interest (defined through the key terms). For this purpose, key terms were organized and aggregated into 'concepts' defining the key topics of interest, such as 'coral reefs', 'marine protected areas', 'fisheries management', etc. (Table S3) relating to marine management in the geographic region defined by the ecological networks, discussed above. This analysis resulted in two data matrices: (1) a document by term data matrix storing the term frequency per document and (2) a document by country data matrix indicating each country's participation in each arrangement represented by the documents. These two data matrices were aggregated to quantify the unique linkages among countries. Here, an individual institutional linkage between two countries was counted if there was at least one occurrence of a particular search concept within a document where these two countries were participants. As a result, each document can generate many linkages where multiple concepts are found and multiple countries are involved. An example of an institutional linkage could be if Australia (AUS) and Papua New Guinea (PNG) both signed onto the same International Agreement A that deals with coral reef conservation. In this case this co-signing constitutes a single coral reef-based institutional linkage. That same agreement may include another signatory country, such as Indonesia (IDN). With this third signatory, International Agreement A resulted in three institutional linkages connecting these countries: (1) PNG and AUS; (2) AUS and IDN; and (3) PNG and IDN.

The linkage data for the region were represented as institutional networks where the nodes consisted of individual countries and the links among them showed the strength of the connection (i.e., the number of linkages in common between a pair of countries) for each concept. Although 14 concepts in total were analyzed, we present results for the four that are most central to marine connectivity and conservation issues: Coral Reefs, Marine Protected Areas (MPAs), Fisheries, and a composite (MPAs + Fisheries) network. Institutional linkage strengths were reclassified based on the relative strengths defined by the quartiles across the entire network: strong institutional link (4th quartile), medium-strong institutional link (3rd quartile), medium-weak institutional link (2nd quartile), and no or weak institutional link (1st quartile).

In addition, to explore the non-spatial institutional alignment, we used a principal components analysis using a singular value decomposition of the document-by-country data matrix to visualizing the highly multivariate data. In this way, countries in the plot that appear closer together are more similar in terms of the documents they participate in, providing an alternative picture of the region's institutional landscape.

2.3. Network Analysis

The primary objective of this study was to access the different institutional and ecological networks as complimentary systems to evaluate their fit, expanding on the approaches developed by Ekstrom and Young (2009) and Bergsten et al. (2014). Ekstrom and Young (2009) developed a method to create and compare institutional and ecological networks against one another to measure varying degrees of functional fit and identify ecological linkages for which no arrangement covers. Here, we construct the networks differently. Rather than exploring linkages between components of an ecological system, the nodes are countries and the relationships between countries represent co-signatories of international agreements or ecological pathways, the former of which was done in Fidelman and Ekstrom (2012) and the latter done in Treml and Halpin (2012). Bergsten et al. (2014), similar to this study, compared networks of the same structure, but at the sub-national level and only for a single topic (i.e., wetlands). As a further development in analyzing fit, our study evaluated multiple topics of concern as a way to incorporate the notion of functional fit. Specifically, we sought to reveal cases in which two countries were linked ecologically and whether these same countries were also connected through shared participation in international agreements. Thus, we developed a typology of combined institutional and ecological linkages based on the union of the two networks (Table 1). This typology was developed to be consistent across all coupled ecological–institutional networks

Table 1
Alignment/misalignment typology based on the union between the institutional linkage networks (columns) and the ecological network (rows) where each cell in the table represents a uniquely possible ecological–institutional linkage between two countries (see also Bergsten et al., 2014). White linkages (top row) representing no ecological connectivity are removed for visual clarity.

		INSTITUTIONAL LINKAGES (STRENGTHS)			
		No or weak institutional arrangements (Q1)	Medium-weak institutional arrangements (Q2)	Medium-strong institutional arrangements (Q3)	Strong institutional arrangements (Q4)
ECOLOGICAL LINKAGES	0 species	Appropriate fit	Ambiguous	Ambiguous	Ambiguous
	1-2 species	Medium level Misfit	Appropriate fit	Ambiguous	Ambiguous
	3-4 species	High level misfit	Medium level misfit	Appropriate fit	Ambiguous
	5 species	Very high level misfit	High level misfit	Medium level misfit	Appropriate fit

Very high level of misfit	Ecological connectivity exists for all species and institutional linkages are lacking or weak (represented by red linkages); i.e., a strong ecological connectivity is not paired with joint institutional arrangements (weak governance of critical ecological connectivity).
High level of misfit	There is a significant mismatch between the ecological connectivity and the strength of institutional arrangements (represented by orange linkages).
Medium level of misfit	There is a slight mismatch between the strength of ecological connectivity and the relative strength of institutional arrangements (represented by green linkages).
Appropriate fit or ambiguous	Some ecologically-significant connectivity exists and institutional linkages are relatively strong (represented by gray linkages), i.e., a strong ecological connectivity is paired with joint institutional arrangements (strong governance of ecological connectivity).

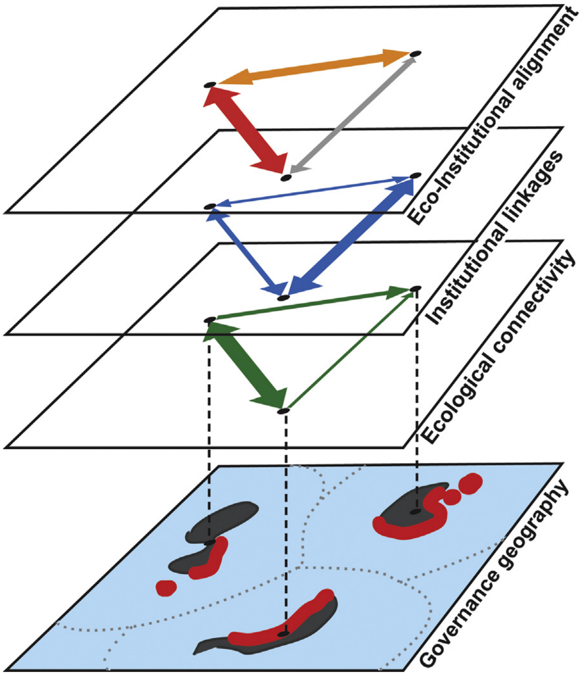

Fig. 1. Schematic of the ecological–institutional arrangement network overlay analysis. For a given seascape of interest where ecological processes cross jurisdictional boarders (dashed lines in Governance geography layer), ecological connectivity is quantified among countries (green arrows) and overlaid with the linkages defined by institutional arrangements (blue arrows). The union of the two networks allows the ecological–institutional misfit (or alignment) to be quantified and mapped. In the top panel, red arrows represent a very high level of misfit between the ecological and institutional networks, whereas orange represents a high level of misfit, and gray shows ambiguous fit (as in Table 1).

and be easily interpreted (Fig. 1). Three categories were of greatest interest: very high level of misfit, high level of misfit, and medium level of misfit as described in Table 1. For visual clarity, all linkages representing various institutional arrangements where no ecological connectivity exists have not been shown in the ecological–institutional networks.

3. Results

Of the 200 documents included in the database, 181 unique documents contained terms in the key concepts and lead to 878 institutional linkages. See Table S4 for document, concept, and compound concept statistics for the complete database. Below we present the results for (1) ecological networks linking countries based on their ecological connectivity; (2) patterns of the countries' participation in the international agreements; (3) networks of countries based on their involvement in the set of international agreements; and (4) the degree of fit and misfit between countries for how well the institutional networks reflect the ecological connectivity in the region.

3.1. Ecological Connectivity

The five modeled taxa and the composite multi-species networks showing the ecologically significant linkages among countries display strong geographic patterns (Fig. 2). The pattern of linkages within these networks illustrates the ecological linkages among countries following major ocean current corridors. Although directionality is preserved in the analysis, only the direction of the strongest connection between a pair of countries is shown in the figure, the thickness directly proportional to the strength of ecological connectivity. Within the multi-species network where the individual networks are added together, there are connections common to one or two species only (thin links), those common to three of four taxa (medium links), and connections common across all five taxa (heavy links); all these connections are independent of the direction of connectivity. This multi-species network shows that all countries across the Indo-West Pacific region are ecologically connected to at least one other country for several species. The geographic structure of the specific multi-taxa and trans-boundary dispersal linkages used in the country-level connectivity network

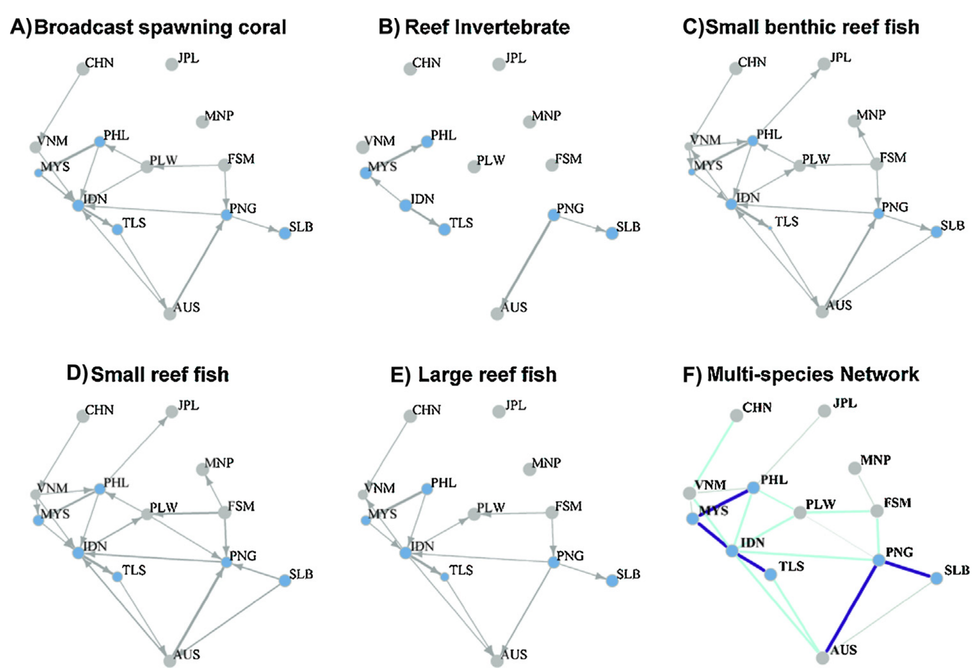

Fig. 2. Ecological networks. All connections shown in these networks are ecologically significant, the dark/heavy linkages are highly significant (i.e., strong ecological connectivity between countries), whereas light/thin lines represent significant, yet weak or intermittent ecological connectivity. The direction of the linkage is for the strongest connectivity between any two countries. In the multi-taxa network, F, only strong 'ecological' linkages (probability > 0.001) are shown with the dark/heavy connections representing those common in all five modeled taxa, the medium/light links are common to three or four taxa, and the thin lines are unique to two or less taxa. See Table S1 for country names.

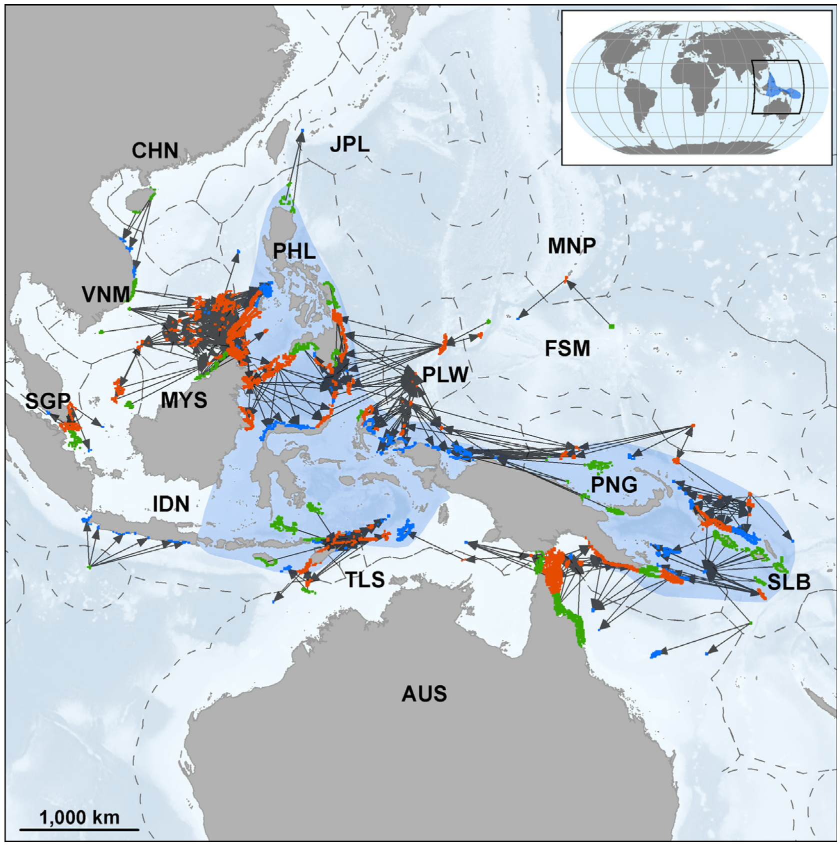

Fig. 3. Trans-boundary connectivity. The coral reef areas important in establishing upstream and/or downstream connections across jurisdictional boundaries are highlighted: Green reefs are those serving as sources to other countries, blue reefs are those benefiting from upstream sources in other countries, and red reefs are those acting as both sources and destinations for trans-boundary connectivity. Arrows depict those trans-boundary dispersal events that occur in at least one of the key marine taxa (each contributing to more than 1% of the receiving reef's settlers). Exclusive Economic Zone (EEZ) boundaries are shown in dashed lines. Map shown in a Mercator projection.

(Fig. 2F) were extracted and mapped for the entire region (Fig. 3). The fine geographic structure of trans-boundary source and destination reefs highlight the key seascapes responsible for facilitating ecological connectivity among countries.

3.2. Thematic Institutional Fit

While the examination of the documents defined by terms such as 'MPA' is informative for the ecological–institutional fit question, there is merit in analyzing the general relationship among the countries participating in any of the agreements embodied in the documents analyzed. The thematic institutional alignment among countries was revealed in the PCA analysis (Fig. 4). The arrows indicate the association strength that each country has for the documents (shown as ' + ') with the direction indicating the broad similarity in the participating patterns of the countries. For example, Australia, Papua New Guinea, and US-Northern Mariana Islands (AUS, PNG, MNP) tend to participate in the same institutional arrangements. In contrast, Malaysia, Indonesia, and Philippines (MYS, IDN, PHL) tend to participate in a different suite of arrangements compared to Palau, Micronesia, and Solomon Islands (PLW, FSM, SLB).

3.3. Institutional Linkages

The institutional linkage networks including link-weight histograms are shown (Fig. 5) for the four key topic-based networks: Coral Reefs, MPAs, Fisheries, and MPAs + Fisheries compound linkages (see Fig. S1 for all other the remaining networks). All four topic-based networks have some similarities: universally weak connections with Timor Leste (TLS as small node with a star-burst of weak red linkages), some weak ties with Malaysia (MYS), and some weak or variable linkages with Micronesia (FSM) and Vietnam (VNM). In addition, the frequency

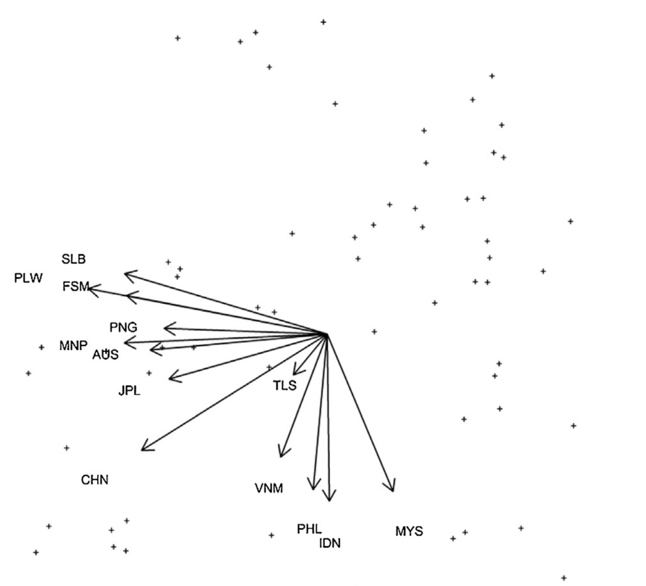

Fig. 4. Trends in country-level institutional arrangements. The principal component plot shows the thematic institutional alignment among countries with respect to the documents each is involved in. Plus symbols (+) refer to the 181 unique documents used in the analysis.

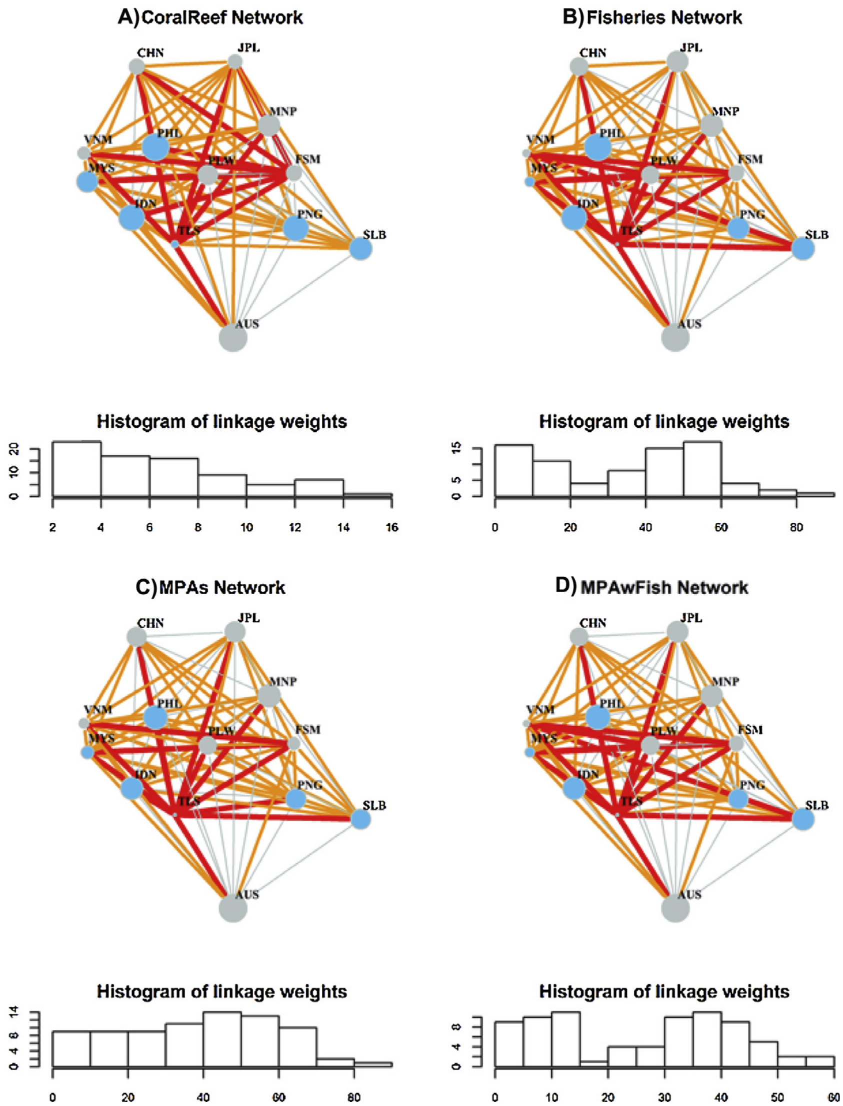

Fig. 5. Institutional networks. In all networks, the strength of policy linkages is depicted using: thin lines to represent the upper quartile (i.e., very strong linkages), medium/orange to represent the middle quartiles (Q2 and Q3), and heavy red lines show the lower quartile (Q1, weak linkages). The size of country nodes is in proportion to the relative number of linkages each country is involved in. The position of all nodes is tied to the relative geographic location of the countries.

and spatial coverage of gray and orange linkages (strong and moderate, respectively) clearly show some regional cohesiveness in institutional linkages across these concept areas.

3.4. Ecological–Institutional (Mis)fit

In combining the multi-species ecological network with the institutional linkage networks (Fig. 6), the ecological–institutional linkages can be easily identified across the entire alignment-to-misalignment spectrum (as in Table 1). Focusing on the high/very high level of misalignment (heavy red and orange linkages), the greatest degree of misalignment occurs between Indonesia (IDN) and Timor Leste (TLS), followed by connections with Australia (AUS), Malaysia (MYS), and the Philippines (PHL). Nonetheless, beyond these core areas of misalignment, there appears to be a good level of agreement or fit between the ecological connectivity and the strength of institutional linkages.

4. Discussion

Here we have proposed a flexible, transparent, and quantitative approach for evaluating the relative alignment or fit between important ecological processes (i.e., marine population connectivity) and applicable formal institutional arrangements. Our spatially explicit representation of the institutional and ecological networks and their misfit allows one to efficiently identify and prioritize key ecological features (e.g., Fig. 3) and strategic geopolitical alignments. Although we have demonstrated the utility of this new approach in the complex seascape of the Indo-West Pacific Ocean and the marine management concerns outlined in the CTI-CFF, this approach could be applied in other geographies, at other scales (e.g., local or provincial), and to other management issues.

In general, the CT countries appear to have a relatively high level of alignment in terms of institutional arrangements across the marine management topics explored. However, the analysis reveals instances where the ecological–institutional alignment appears to be somewhat misaligned, i.e., where pairs of countries are strongly ecologically connected yet do not share equally strong institutional linkages. An example of this misalignment occurs between Indonesia (IDN) and Timor Leste (TLS), followed by connections with Malaysia (MYS) and the Philippines (PHL), and to some neighboring countries. One probable explanation for this and other instances of misfit highlighted in this study is that international environmental agreement are not necessarily devel-

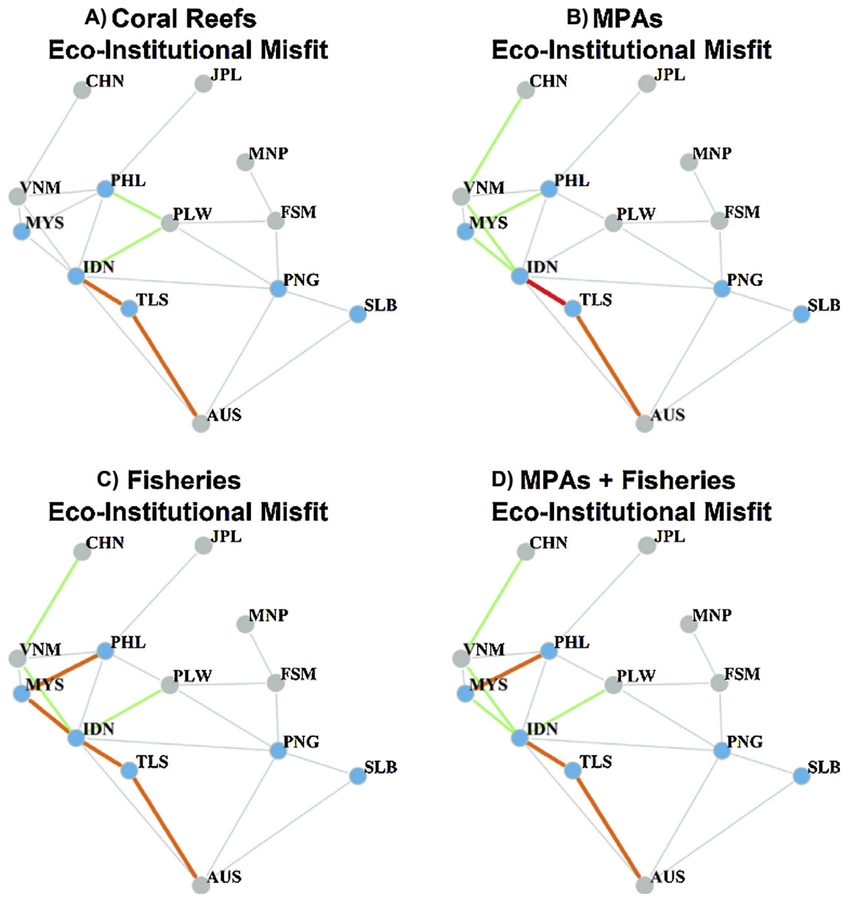

Fig. 6. Ecological–institutional fit/misfit networks. The linkages in the ecological–institutional networks showing the alignment and misalignment as: red representing very high ecological–institutional misalignment (high ecological connectivity and weak or no institutional arrangements), orange connections for high level of misalignment, green as medium level of misalignment, and gray linkages illustrate where ecological connectivity occurs yet the strength of institutional arrangements are higher than the relative level of ecological connectivity (see Table 1 for additional typology details). All institutional linkages where ecological connectivity is absent have been removed for clarity.

oped taking ecological connectivity into account. In addition, many factors—e.g., type of agreement, military interests, equitable distribution of the costs associated with an agreement, power distribution, governmental type of a state, and vulnerability to an environmental problem—and complex processes of international relations and politics may explain why countries choose to engage in an international environmental agreement (DeGarmo, 2005; Levin et al., 2013; Young, 1989).

Our analysis draws attention to instances of misalignments along important trans-boundary ecological corridors where strengthening institutional ties may improve protection and maintenance of these ecological systems (Fig. 6). However, any attempts to strengthen interactions between countries may require a better understanding of the apparent misalignments identified in this study, including the factors influencing the engagement (or lack of) of countries in relevant international agreements. Further, as discussed below, our analysis did not necessarily capture *de facto* arrangements (i.e., "rules-in-use"), or the activities resulting from the arrangements analyzed. These arrangements and activities, very often involving non-state actors (e.g., non-government organizations), may prove important in strengthening interactions between countries (Miclat et al., 2006; Walton et al., 2014).

Here, we suggest that efforts to reduce the level of misfit could target specific regions and countries that are strongly ecologically connected without the need to use limited governing resources to broadly increase institutional linkages in general. We also maintain that institutional development needs to explicitly and directly focus on the challenge of managing ecological connectivity through the maintenance of dispersal corridors across jurisdictional boundaries. However, it is important to note that improved ecological–institutional alignment alone is not a sufficient condition for resolving environmental problems (Galaz et al., 2008; Young, 2002); yet, together with other factors (e.g., management of institutional overlaps), it is an essential step to improve governance performance (Ekstrom and Young, 2009). Finally, we acknowledge that our method requires further development to better capture the complex nature of SES, such as that of the Coral Triangle. Below, we discuss how this method could be refined as a diagnostic tool for analyzing the fit between ecological processes and institutional arrangements.

5. Limitations and Future Directions

Throughout we have made a number of explicit and implicit assumptions, several others should be mentioned thereby highlighting limitations and important areas for future work. First, simplification of the complex ecological process of multi-species marine population connectivity (Cowen and Sponaugle, 2009) was required in quantifying the ecological network in the region. An individual's ability to traverse the seascape is largely dependent on both physical factors such as ocean currents and temperature, and biological attributes such as the timing of reproduction, fecundity, and survival (e.g., Treml et al., 2012;

Wolanski and Kingsford, 2014). In addition, these attributes may be directly and indirectly impacted by climate change resulting in reduced or uncertain population connectivity outcomes (Gerber et al., 2014). Although exploring the impact of including other taxa (e.g., tuna) and the potential influence of climate change on the ecological networks would be of interest, this was well beyond the scope of the current work.

Second, our interpretation assumes that the institutional linkage database is a representative sample of the diversity of international environmental arrangements in the Indo-West Pacific region. Across the 200 documents included in this analysis ranging from 1945 to 2010, an average of 46 documents was related to each concept (see Table S4) supporting this assumption. Clearly, this database could be expanded in the future, particularly considering the significant momentum building through the CTI-CFF (Walton et al., 2014; White et al., 2014).

Third, we have not captured sub-national arrangements, such as, for example, agreements between Australia's Northern Territory and Timor Leste, or domestic-only agreements lacking an international component. Despite this exclusion and focusing on international agreements we do not imply that trans-boundary marine issues are addressed at the international level only. A myriad of formal and informal institutional arrangements at national, provincial, and local levels are integral to the region's governance. For example, many of the CT countries (e.g., Indonesia and Philippines) adopt a decentralized approach to marine management with a focus on local-level implementation (Fidelman et al., 2012). A more hierarchical and in-depth analysis in the future could uncover these local-scale arrangements. In this context, we also do not imply that the international agreements necessarily reflect national and subnational policies of the signatory countries. In fact, the decision to join a given agreement can be explained by reasons other than alignment of domestic policies or conservation concerns (in the context of the CTI-CFF, see Rosen and Olsson, 2013).

Fourth, we do not capture interactions that are not part of formal international agreements, e.g., *de facto* arrangements or "rules-in-use", or the activities resulting from the arrangements analyzed (on the implementation of the CTI-CFF and its challenges see e.g., Fidelman et al., 2014; Von Heland et al., 2014; White et al., 2014). Incorporating these other informal arrangements and activities in future studies, although involving significant operational challenges, would be beneficial in explaining interactions between countries.

Finally, by focusing on the notion of fit we do not imply that the effectiveness of international institutional arrangements is likely to be achieved by institutional fit alone. Effectiveness depends on a number of determinants (e.g., distribution of power, the effects of decision rules, the depth and density of regime rules, and the extent of knowledge of the relevant problem) that usually operate in conjunction (see e.g., Breitmeier et al., 2011). Although an explicit empirical assessment of the presumed link between good fit and governance effectiveness was beyond the scope of this paper, future research on ecological–institutional alignments should strive to incorporate a stage to evaluate the effectiveness of arrangements and, perhaps, the capacity of the signatories to comply with them.

Despite the limitations and challenges discussed above, the quantitative approach developed provides an important step forward in analyzing how well-aligned existing governance is with key ecological processes, such as population connectivity. Conservation managers and the broader management community could use this approach, particularly when paired with complementary qualitative studies of fit (Young, 2002), to help prioritize and strengthen management strategically to effectively and efficiently safeguard ecological processes across jurisdictions. Our analysis helps shed light on the problem of alignment between governance and the ecological systems they aim to manage, and is applicable to terrestrial and aquatic resources in additional to marine seascapes as presented here.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2015.01.012. These data include Google maps of the most important areas described in this article.

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