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Delineating priority areas for marine biodiversity conservation in the Coral Triangle

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ABSTRACT

Identifying priority areas for biodiversity conservation requires systematic approaches and integrated ecological and biological information. Here, we applied a range of ecological criteria to assess areas of biodiversity importance in the Coral Triangle region, a priority region for marine biodiversity conservation because of its high species richness and endemicity. We used distribution data of three biogenic habitats to assess the criterion of sensitive habitat, modeled geographic distributions of 10,672 species ranges and occurrence records of 19,251 species to evaluate the criterion of species richness, distributions of 834 species of special conservation concern to examine the criterion of species of conservation concern, distributions of 373 reef fish species to assess the criterion of restricted-range species, and distribution of nesting sites and migratory route of six species of sea turtle to evaluate the criterion of areas of importance for particular life history stages. We identified areas of biodiversity importance by superimposing each of the different criterion. We performed two tiers of multi-criteria analysis: (1) a Coral Triangle regional level analysis to identify "clustered hotspots" (*i.e.*, groups of cells) of biodiversity significance, and (2) a site-based analysis to identify the specific sites (cells) of greatest biodiversity importance. We found that approximately 13% of the Coral Triangle was clustered into hotspots of high biodiversity importance. These areas occurred along the southern part of the Philippines, the north-eastern part of Malaysian Sabah, central to eastern reaches of Indonesia, the eastern part of Papua New Guinea and the Solomon Islands. By comparison, the site-based analysis identified seven sites of highest biodiversity importance in the Coral Triangle include: (1) the northern tip of Sulawesi Island, (2) Ambon Island, (3) Kei Islands, (4) Raja Ampat Archipelago of Indonesian Papua, (5) the Verde Island Passage, (6) the southern part of Negros Island, and (7) Cebu Island. This information is useful to inform participatory decision-making processes in the Coral Triangle region to identify priority areas for conservation and management.

1. Introduction

Protected areas have been widely advocated as an effective tool for conserving and managing biodiversity (Brooks, 2010; Venter et al., 2014). Marine protected areas (MPA) benefit conservation of species and habitat (Beger et al., 2003; Williams et al., 2009; Hart et al., 2013; Péron et al., 2013), fisheries management (*e.g.* increased abundance, species diversity and "spill over" effect) (Russ and Alcala, 2010; Hamilton et al., 2011; Edgar et al., 2014; Smith et al., 2014), and recreational and educational opportunities (Ballantine, 2014; Costello, 2014). Coral reef cover inside Indo-Pacific MPA has shown increases up to 2% per year (Selig and Bruno, 2010), while globally, biomass of large fishes was 35% greater inside compared to outside MPAs (Edgar et al., 2014). Currently, over 12 million km^2 of the world's ocean has been designated as MPAs (Juffe-Bignoli et al., 2014), with a growth of over 360-fold in the last ten years (Klein et al., 2015). However, the proportion of MPA that actually conserve biodiversity is questionable. Around 94% of MPA are 'take-MPA" that allow fishing within their boundaries and cannot protect all aspects of biodiversity (Costello and Ballantine, 2015). More than 83% of marine species have less than 10% of their home ranges protected within MPAs globally (Jenkins and Van Houtan, 2016). Thus, to support the MPA's objectives in conserving biodiversity requires additional designation of larger, more effective and fully protected areas through identification of important areas for biodiversity conservation (Ricketts et al., 2005; Butchart et al., 2015).

Previously, we synthesized a set of ecological and biological criteria

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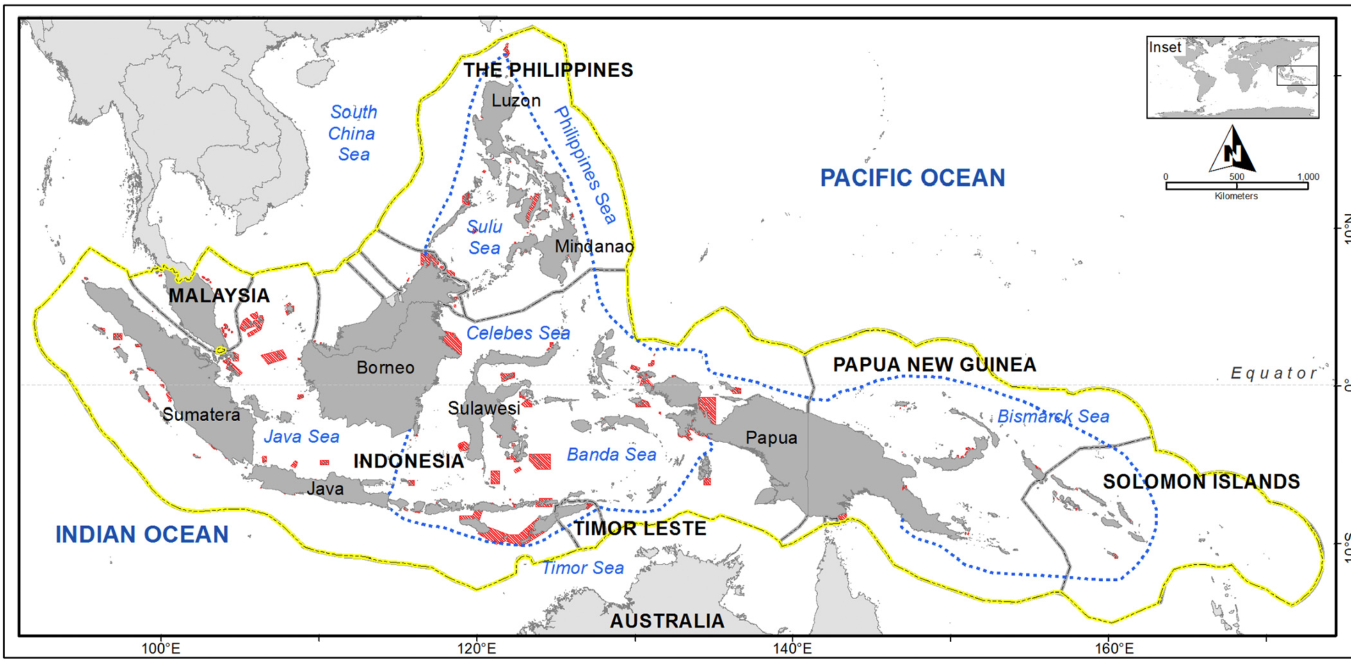

Fig. 1. Map of the Coral Triangle. The CT countries EEZ outer (yellow-dashed line) (representing the Coral Triangle Initiatives implementation area) and internal boundaries (grey-dashed line), and the CT scientific boundary (proposed by Veron et al., 2009) (blue dashed line) are indicated. Nearly 2000 MPAs occur in the area (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to aid systematic selection of areas for biodiversity conservation (Asaad et al., 2016). Based on the review of 15 international initiatives, we identified eight ecological and biological criteria required to identify suitable locations for biodiversity conservation. Four criteria identified areas that contain (1) unique and rare habitats; (2) fragile and sensitive habitats; (3) habitats important for ecological integrity; and (4) a network that is representative of all habitats. Another four criteria were based on species-specific attributes, including (5) the presence of species of conservation concern; (6) the occurrence of restricted-range species; (7) areas containing high species richness; and (8) areas important for life-history stages of particular species. Here, we explored the application of these synthesized ecological criteria in performing an assessment of important areas for marine biodiversity conservation in the Coral Triangle region.

The Coral Triangle (CT) Region is situated along the equator between the Indian and Pacific Oceans. This region includes the Exclusive Economic Zone of six countries (Indonesia, Malaysia, The Philippines, Papua New Guinea, Timor-Leste, and Solomon Islands) (Fig. 1). It is a global hotspot of marine biodiversity, and contains > 76% of the world's shallow-water reef-building coral species (Veron et al., 2009), 37% of the world's reef fishes (Allen, 2008), 50% of razor clams (Saeedi et al., 2016), six out of seven of the world's sea turtles and the largest mangrove forest in the world (Polidoro et al., 2010; Walton et al., 2014). In the socio-economic context, the marine ecosystems in this region have a gross domestic product worth $1.2 trillion per year (Asian Development Bank, 2014), and > 120 million people benefit directly from its ecosystem goods and services (Foale et al., 2013). However, the resources within this region are being threatened by anthropogenic activities and climate change induced impacts (Hoegh-Guldberg et al., 2009; Burke et al., 2012; McLeod et al., 2012). In response, in 2007 the Coral Triangle countries declared their commitment to working collaboratively to conserve and sustainably manage their coastal and marine resources through a multilateral partnership called the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) (CTI-CFF, 2009, 2013). One of the objectives of this initiative is to establish effective networks of MPAs, by protecting a representative range of biodiversity features (Weeks et al., 2014), encompassing the temporal and spatial scale of ecological systems (Laffoley et al., 2008) and facilitating ecological linkages between protected sites (Green et al., 2014). Currently, there are almost 2000 MPAs within this region, covering an area of 200,881 km^2 (White et al., 2014), which is < 4% of the marine area in this region. Moreover, under-representation of ecological and biodiversity coverage, and lack of management effectiveness (Weeks et al., 2014; White et al., 2014) are among factors that prevent MPAs within this region from achieving their goals (White et al., 2014). There is thus great interest to overcome the current limitations of MPA coverage and to develop conservation priorities for the protection of biodiversity and ecosystem services in the region (Green et al., 2014; Beger et al., 2015).

Previous biodiversity conservation studies in the Coral Triangle provided insights on MPA development (Green et al., 2009; Green et al., 2014), biodiversity patterns (Hoeksema, 2007; Allen, 2008) and conservation priorities (Ambal et al., 2012; Huffard et al., 2012; Beger et al., 2015) (Table 1). However, those studies were limited to specific taxonomic groups, had restricted geographic scope, and/or were based on limited datasets. The framework to design MPAs proposed by Green et al. (2014) was applied at a region-wide scale but has not been used to identify MPAs at national or local scales (Walton et al., 2014). The prioritization analysis developed by Beger et al. (2015) was successful in identifying areas of high conservation value but included only limited information on species connectivity models and insufficient data on threatened species. In other studies, conservation priorities were exclusively applied at national scales, such as the identification of key biodiversity areas in the Philippines (Ambal et al., 2012), and geographic priorities for biodiversity conservation in Indonesia (Huffard et al., 2012). Here, we identify areas of importance for biodiversity conservation at the regional scale for the Coral Triangle, based on a comprehensive measurement of biodiversity, encompassing a wide-variety of taxonomic groups, and pre-defined systematic ecological criteria.

We examined the applicability of the ecological criteria recommended in Asaad et al. (2016) to delineate areas of biodiversity importance. We applied biodiversity informatics to retrieve and analyze data on habitat and species diversity, and species distributions of