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Land use is a better predictor of tropical seagrass condition than marine protection

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ABSTRACT

Effective coastal conservation requires a better understanding of how human activities on land may directly and indirectly affect adjacent marine communities. However, the relationship between terrestrial and marine systems has rarely been considered in terrestrial and marine reserve design. Seagrasses are affected by land-based activities due to their proximity to terrestrial systems and sensitivity to fluxes of terrestrially-derived organic and inorganic material. Our study examines how land use patterns adjacent to seagrass meadows influence the ecological integrity of seagrass using a suite of seagrass condition metrics on a landscape level across the Philippine archipelago. Using canonical correlation analysis, we measured the association between environmental variables (land use and seagrass abiotic conditions) with biotic variables (seagrass species richness and abundance). Terrestrial protection adjacent to seagrass meadows, defined as the absence of various anthropogenic land use perturbations, had significant positive effects on seagrass condition. The watershed area, and area of farmland and human development, had the most negative effect on seagrass condition. Using analysis of covariance and regression, we examined how marine protected area (MPA) establishment, size, and age, affected seagrass biotic conditions while holding environmental conditions constant. The relationship between biological and environmental canonical factors did not vary as a function of an MPA. This study provides evidence that land use is more important than marine protection for tropical seagrass condition. Our results demonstrate the complementary connection between land and sea, justifying the ‘ridge-to-reef’ approach in coastal conservation. Proper management of seagrasses should account for stewardship of the adjacent watersheds.

1. Introduction

The accelerating loss of marine and terrestrial biodiversity and the ecosystem services it provides to people has been a growing concern globally (Turner et al., 2007; Waycott et al., 2009; Cardinale et al., 2012; Tittensor et al., 2014; McCauley et al., 2015). Habitat loss is the second most important driver of past extinctions and the current leading driver which endangers species on land (Tershy et al., 2015), and human impact has had the greatest effect on coastal biodiversity (Lotze et al., 2006). Globally, >US$21 billion is spent annually to prevent and mitigate this loss (Waldron et al., 2013). The creation of protected areas is a well-established tool to reduce this trend via reducing habitat loss and mortality from harvesting (Pimm et al., 2001). There are > 200,000 protected areas worldwide (Chape et al., 2005; Jenkins and Joppa, 2009; Juffe-Bignoli et al., 2014), and ~4400 of those are marine protected areas (MPAs) (Wood et al., 2008), totaling 3.4% of marine area (Juffe-Bignoli et al., 2014). However, up to 421.9 million people worldwide live near the borders of protected areas, resulting in over 83% of MPAs and 95% of terrestrial protected areas (TPAs) being highly impacted by humans (Mora and Sale, 2011).

Many coastal MPAs are at least potentially impacted by human activities on land such as human development and growing human populations (Mora and Sale, 2011), and these MPAs are not necessarily mitigated by marine protection (Valiela et al., 2001; Freeman et al., 2008; Packett et al., 2009). The coastal ecotone is an interconnected set of habitats made up of coastal, estuarine, wetland and freshwater systems that is high in organismal diversity and density (Sheaves, 2009), and important for ecosystem function and services (Beck et al., 2001). This ecotone is important in the transfer of organic and inorganic material between terrestrial and marine ecosystems (Cloern, 2007). However, it is also where 60% of the world's growing human population is located, resulting in direct habitat conversion for housing, transportation, energy, and agriculture, and in indirect conversion due to increased physical disturbance, eutrophication and sedimentation (Musters et al.,

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2000; Sala et al., 2000; Hughes et al., 2009). In developing countries, the daily subsistence of coastal inhabitants is largely derived from these transitional zones (Nordlund et al., 2010; De la Torre Castro et al., 2014; Cullen-Unsworth et al., 2014).

Seagrasses are shallow-water coastal marine plants that provide important ecosystem services such as carbon sequestration (Fourqurean et al., 2012), wave attenuation (Bradley & Houser 2009), and habitat and nursery area to a variety of commercially important fish and invertebrates (Hughes et al., 2009). Seagrasses are often used to assess the health of the nearshore marine environment (Martinez-Crego et al., 2008) with studies showing that siltation from suspended inorganic solids (Bach et al., 1998) and upstream watersheds (Freeman et al., 2008), sediment burial (Duarte et al., 1997), water pollution and sediment deposition (Van Katwijk et al., 2011) all impact seagrass condition. Seagrass species population declines are due both directly or indirectly to anthropogenic impacts (Waycott et al., 2009; Short et al., 2011), and there is a call to reduce watershed nutrient and sediment inputs to seagrasses to stem seagrass loss (Orth et al., 2006).

Consequently, there is growing interest in integrating terrestrial and marine conservation in the coastal zone (Cicin-Sain and Belfiore, 2005; Stoms et al., 2005; Richmond et al., 2007; Tallis et al., 2008; Beger et al., 2010; Klein et al., 2010; Alvarez-Romero et al., 2011). However, the establishment of marine and terrestrial protected areas has largely proceeded independently, without examination of the costs or benefits of co-locating marine and terrestrial protected areas (Stoms et al., 2005). While others have modeled different land-use scenarios on coral reef and seagrass response (Tulloch et al., 2016), this has not been empirically measured.

This study measures the relative importance of marine protection vs. land use to the integrity of tropical seagrass communities on a landscape level at 54 sites across 35 islands throughout the Philippine archipelago. Here, we examine the impact of all MPAs regardless of management practices and levels of compliance compared to the impacts of land use. Specifically, we examined the independent and synergistic effects of marine protection vs. land use, the environmental conditions of the seagrass ecosystem, and the resulting effects on an array of abiotic and biotic indices of seagrass condition.

2. Methods

Our goal was to determine whether seagrass condition varied as a function of environmental attributes, marine protection, and land use. To address this goal, we sampled 54 seagrass meadows adjacent to 35 islands ranging in area from small islands of <1 km^2 (Agutaya) to large islands of over 100,000 km^2 (Luzon) (Fig. 1). We surveyed approximately 50% of the latitudinal range of the Philippine archipelago from the northernmost site in the Pangasinan province to the southernmost in the Negros Oriental province.

We selected sites based on geographic representation of marine protected areas and a variety of land uses across the archipelago, and accessibility for conducting fieldwork. Each island exhibited a combination of different land uses ranging from minimal human impact (de facto protected or TPAs) to highly impacted islands (multiple combinations of land uses), while the marine areas were categorized as protected (MPAs) or unprotected.

2.1. Definition of marine protection

Forty-two percent of the sites were located inside MPAs, and included both formal ($n = 16$) and de-facto ($n = 7$) MPAs. Formal MPAs were established as fisheries management tools through either the National Integrated Protected Areas System Act of the Philippines (NIPAS) or the Local Government Code of 1991 and the Fisheries Code of 1998, which gave local governments the authority to manage their nearshore marine waters in cooperation with the national government (Russ and Alcala, 1999). De facto MPAs were those managed by private island owners who prevented fishing around their islands. MPAs ranged from complete to incomplete protection; some included no-take zones ($n = 15$), while others had some level of fishing controls ($n = 9$). We collected data on the size of each MPA and the year each was established [Appendix 1]. Other studies have found that MPA age and size are among key features that optimize marine biodiversity protection (Claudet et al., 2008; Vandeperre et al., 2011; Edgar et al., 2014). In the Philippines, MPAs in practice have a spectrum of management schemes and compliance to those schemes. Here, we did not attempt to examine the impact of different management schemes, we did not rate the efficacy of MPAs, or assess levels of compliance, but rather we attempted to understand the impacts of MPAs of all types compared to the impacts of TPAs.

While positive effects of an MPA have been demonstrated within 5 years of establishment, previous studies used age >10 years as a threshold for an old MPA and <5 years as a new MPA (Claudet et al., 2008; Molloy et al., 2009; Babcock et al., 2010; Vandeperre et al., 2011; Edgar et al., 2014). Edgar et al. (2014) considered an area >100 km^2 as a large MPA, and an area <1 km^2 as a small MPA. Based on these criteria, we categorized an MPA of <5 years as new and older than 5 years as old, and an MPA <1 km^2 as small, and an MPA larger than 1 km^2 a large MPA. Globally, almost half of all MPAs are small 1 km^2 and are new (Wood et al., 2008). In our suite of samples, 65% were old/large, 17% were old/small, 9% were new/large, and 9% were new/small.

2.2. Definition of terrestrial protection

Since there is a lack of officially designated coastal terrestrial protected areas in the Philippines, we developed a proxy for terrestrial protection based upon level of human land use in two zones: (1) the watershed, or catchment that drained into the seagrass meadow, and (2) a 50-m wide coastal strip on the island adjacent to each seagrass meadow. Using ArcMap, we obtained Basemap satellite imagery (World Imagery) of the islands from ArcGIS online (ESRI, 2011). Using ArcCatalog, we created a geodatabase for each island. Using ArcMap, we created a new layer and shapefile for each island outline. With the polygon tool, we heads-down digitized islands by manually tracing each island outline. We digitized whole islands if they were smaller than 5 km^2, while for the 3 larger islands (Luzon, Negros, Mindoro), we only digitized the affected watershed.

To delineate the watershed that affected each seagrass bed, we overlayed ArcGIS Online's Topographic and World Shaded Relief layers with low resolution (15 m imagery). We adjusted the transparency of the layers using the effects toolbar (50% transparency) and toggled between the two layers. Using ArcCatalog, we created a shapefile for each watershed, and using the draw, trace function and point drawing tools in ArcGIS, we manually traced the watershed that drained into each of the seagrass meadows based on the changes in elevation (ESRI, 2011). To calculate the area of each island and the total area of each watershed, we opened the attribute table for each shape file, added a field for area, then calculated the geometry in square kilometers.

We classified land use in the following categories: human development (houses, commercial development, roads), vegetation (forests, scattered trees), bare ground (exposed soil, fallow farmland), farmland, and aquaculture. We considered areas containing native vegetation as protected (Klein et al., 2010). Unlike marine protection, which was a binary code, terrestrial protection ran along a gradient of different forms of land uses and vegetation in each watershed or coastal trip.

We created a feature class for each land use category, visually assessed the type of land use, and used the polygon and the edit vertices tool to trace out land use types for each island or watershed. We kept each land use category in separate feature classes. Our layers had resolutions that varied from low resolution (15 m imagery, Landsat 5; https://landsat.usgs.gov/) to high resolution (60 cm imagery,