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Ecosystem health in coastal areas targeted by small-scale artisanal fisheries: Insights on monitoring and assessment

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ABSTRACT

The assessment of the status of marine ecosystems is still a major challenge, because in general we lack well-established ecosystem-based monitoring programs. The coast of central Chile is subjected to moderate but historic fishing pressure by small-scale fisheries. In spite of the increasing evidences of the impact of fishing beyond target species, there is a lack of systematic ecosystem-based assessments. We focused on this problem with the goal of identifying community components, based on a Biological Traits Analysis, that respond to fishing activities to ultimately define ecosystem health. We sampled a set of study sites subjected to benthic invertebrate gathering, and more recently to kelp harvesting. Sites included paired fishery restricted and open access areas where mobile invertebrates and sessile benthos were surveyed. In addition, kelp density and size structure were assessed in two sites subjected to kelp harvesting (also pairing restricted and open access areas). Target species exhibited higher densities in fishery-restricted areas. Fisheries restricted-areas also showed overall higher richness and redundancy of biological traits. Otherwise, we observed high variability in the structure of sessile benthos linked to small-scale heterogeneity of the seabed. The areas subjected to kelp harvesting exhibited variability in mobile invertebrates' composition between fishing access regimes, whereas no effects could be detected by only considering target species. Current monitoring efforts seem to be well-suited to address target species but fail to inform on ecosystem health in an area with increasing signs of community-wide effects from fishing. Therefore, we recommend future monitoring schemes targeting community components, beyond commercial species' densities, at different scales.

1. Introduction

Fisheries are amongst the most acute impacts that have historically altered marine ecosystems worldwide (Dayton et al., 1995). Improving fisheries management is a crucial task for the near-future, particularly recognizing that traditional approaches, largely based on single-species management, have failed in many fisheries resulting in the collapse and overexploitation of resources (Costello et al., 2012). New approaches to fisheries management have emerged acknowledging the need to explicitly include wider ecosystem components to achieve long-term sustainability (Leslie and McLeod, 2007). However, the implementation of ecosystem approaches faces many difficulties, in part because of our poor level of understanding of the structure and processes of ecosystems confronted with multiple and cumulative impacts (Steneck et al., 2013). In addition, different ecosystem responses, and recovery from human impact, will depend on the characteristics of the fisheries (Dayton et al., 1995), the productivity of the ecosystems and the role of exploited species on the ecosystem processes and functions (Worm et al., 2006). In this sense, the identification, assessment and monitoring of the variables that inform about the response of marine ecosystems to stressors such as fishing, is a critical step to improve management and conservation actions (Levin et al., 2009).

Ecosystem indicators aim to summarise copious, complex, scientific information in a simple, condensed, comprehensible way that can be very effective for communicating a system's condition to managers and policy makers (Levin et al., 2009; Muntadas et al., 2017). However, identifying measures that capture the complexity of marine systems is still a major challenge (Rombouts et al., 2013). Limited scientific knowledge may hamper the selection of metrics that are efficient for tracking ecosystem trends over time. Multivariate indicators based on species traits provide clear advantages as the replacement of sets of species with particular traits by othersets with different traits may

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indicate variability in ecosystem structure and functioning (Bremner et al., 2003; de Juan et al., 2007; Mouillot et al., 2013), and reflect ecosystem health in response to environmental changes (Vandewalle et al., 2010). In fact, univariate descriptors (like total abundance or diversity) show lower performance than methods that summarize community structure by considering ecological attributes of the species (Subida et al., 2012) across inconspicuous gradients of pressure. The multivariate Biological Trait Analysis (BTA) has proved to be a useful approach to assess the effects of human activities on biological communities (e.g., de Juan et al., 2007; Mouillot et al., 2013), but their use is biased towards highly polluted soft-sediment habitats (e.g., Bolam et al., 2016; Borja et al., 2009; van der Linden et al., 2016). The effectiveness of this approach on a variety of environmental scenarios, and under a wide range of human impacts, is still limited. We advanced in this direction, assessing the performance of BTA approaches on the highly productive rocky shore of central Chile, subjected to historic fishing pressure by small-scale fisheries.

Small-scale fisheries represent 90% of world fisheries, and are under high risk of overexploitation (Costello et al., 2012). In central Chile, the impact of artisanal fisheries is evident on the abundance of exploited invertebrates (Gelcich et al., 2012). But the removal of large volumes of target species, which in many cases are key-species in the ecosystem, might also have unpredictable consequences over associated communities (Lloret et al., 2016). The small-scale fisheries operating in central Chile targets only 23% of the 147 species described in the subtidal trophic coastal community (Pérez-Matus et al., 2017). However, some of the target species are keystone predators such as the Chilean abalone, *Concholepas concholepas* (Castilla and Duran, 1985), and habitat structuring species such as kelps (Pérez-Matus et al., 2017). Thus, a large influence of fishing on the whole community can be predicted since 88% of the exploited species have trophic interactions, and the removal of exploited species affect half of the species in the trophic web (Pérez-Matus et al., 2017). Additionally, the recent harvesting of the habitat structuring kelp *Lessonia trabeculata* may generate unpredictable consequences on the associated communities and, ultimately, on ecosystem health. Unfortunately, there is a lack of systematic assessments of biological communities and habitats sustaining artisanal fisheries in central Chile.

In this study, we focus on this problem by exploring indices related to the multivariate structure of coastal benthic communities subjected to traditional artisanal fishing, and more recently, to kelp extraction. Paired sites open and with restrictions to fishing activities were sampled to obtain data on the benthic communities. Based on previous studies, we predict changes in these communities driven by the selective extraction of benthic invertebrates. Invertebrate extraction is higher in open access areas (OAA) even in the case of resources that cannot be legally fished in these areas (Andreu-Cazenave et al., 2017). Furthermore, the eventual negative effects of the controlled extraction of target species in the areas with restricted fishing activities seem to be buffered by the add-on conservation benefits of the fisheries management operating in areas with restricted fishing activities (Gelcich et al., 2008, 2012). From the above, we predict a lower abundance of target species, particularly of the larger sizes, and a higher abundance of species with k-strategy reproductive traits in OAA (except perhaps in the case of the resource loco, which experiences a permanent and national ban outside management areas). The remaining species co-existing with target resources in the same community might be also indirectly affected by fisheries through changes in the patterns of interspecific interaction (Gelcich et al. 2008). Thus, the diversity and composition of traits, particularly of trophic traits, might also be affected through reductions of the trait richness and redundancy. In open access areas recently subjected to kelp extraction, we expect lower densities of kelp than in restricted fishing zones, with a decreased size of the harvestable fraction. Also, we might be able to observe a decrease in the number and density of the invertebrate species living on kelps, with an increase in the abundance of grazers, which might lower the richness and redundancy or traits. The sessile component is also expected to change towards an assemblage dominated by turf or bed forming species, that benefit from the free substrate, and a decrease in suspension feeders due to reductions in the turbidity generated by the kelp holdfast extraction. Since traditional monitoring schemes in the study area are centered on target species, and it is broadly acknowledged that this frequently fails to inform on all potential ecosystem changes (Soulé et al., 2003), the ultimate aim of this work is to explore our predictions and identify indices of community structure that can be used to assess and monitor ecosystem health.

2. Materials and methods

2.1. Study sites

Sampling was conducted in the shallow subtidal zones in nine sites that span through *ca.* 150 km of the coastline in central Chile. The study sites have been historically subjected to small-scale fishing activities that principally target benthic invertebrates, and more recently to kelp harvesting in some of the sites. The small-scale fisheries include divers and coastal gatherers that harvest benthic invertebrates and reef fish principally from rocky reefs, often in habitats dominated by kelp forests. This fishery is subjected to two management regimes: (a) Management Areas for the Exploitation of Benthic Resources (hereafter management areas, MA) and (b) open access areas. This system was primarily developed to manage the Chilean abalone, known as “loco” (*C. concholepas*), whose exploitation is banned outside the management areas, but nowadays includes the management of a set of benthic invertebrates, including key-hole limpets (*Fissurella spp.*) and red sea urchin (*Loxechinus albus*) among others. Outside the management areas there is an open access regime for all benthic resources, except loco. Other regulations besides entry access, such as minimum legal sizes or reproductive bans, operate on both systems. Regular monitoring is only conducted on the fraction of the stocks distributed within management areas, in order to determine annual exploitation quotas. Therefore, most of the exploited areas remain largely unassessed.

2.1.1. Sites with different fishing access regimes

We sampled seven sites, where historically benthic fisheries have operated, during the austral Spring-Summer 2012, El Quisco and Laguna Verde, and 2013, Los Molles, Maitencillo, Montemar, Quintay, and Las Cruces (Fig. 1). In all these study sites, we considered two access regimes, (a) restricted access areas (RAA, including MAs and Marine Protected Areas) and (b) open access (OA), positioned in nearby locations with similar environmental conditions. Among RAA, we sampled two small no-take Marine Protected Areas (MPAs; Las Cruces and Montemar), established more than 30 years ago, and five Management Areas (established more than 15 years ago). The MA surface ranges between 95 and 186 ha, while MPAs have a surface of *ca.* 15 ha. The average distance among the study sites was *ca.* 25 km and all the areas were characterized by bare rocky bottoms alternating with patches of the kelp *Lessonia trabeculata*. The only exception being the Montemar MPA, where kelp patches are absent.

The benthic communities were surveyed along four 50-m transects in each area, positioned perpendicular to the coastline from a randomly selected starting point. The transects were divided in five equidistant stations, and the average depth in each station was estimated (depth ranged between 3 and 15 m). Mobile benthic macro-invertebrates, larger than 3 cm, were visually identified and counted within a 2-m wide band along the transect. The species identified included three invertebrates targeted by the fishery (the gastropods *C. concholepas* and *Fissurella spp*. and the sea-urchin *L. albus*), and five other species belonging to the taxonomic Classes Polyplacophora (*Acanthopleura echinata*), Asteroidea *(Heliaster helianthus* and *Meyenaster gelatinosus*) and Echinoidea (*Tetrapygus niger*). This group of species includes key herbivores and carnivores in the system. To sample the sessile benthos,