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Community structure and trophic interactions in a coastal management and exploitation area for benthic resources in central Chile

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ABSTRACT

Management and Exploitation Areas for Benthic Resources (MEABR) is the most common type of coastal marine protected area in Chile, being used for managing inshore benthic resources since 1991. The structure of the biological community in MEARBs are poorly studied and it is though that a better understanding of this framework is key to sustainability. Here we present a food web model to characterize the benthic community and key functional groups in the MEABR of San Vicente Bay (36°44′S–73°09′W), using the Ecopath with Ecosim software (EwE). The Chilean albalone *Concholepas concholepas* is the main fishing resource in many MEABRs, including the MEABR of San Vicente Bay. The structuring role of main predators is assessed and compared using mixed trophic impacts (MTI) analysis and through calculate an interaction strength (IS) index.

The results show that the main flows of consumption in the benthic community of the MEABR of San Vicente Bay occur in lower trophic levels ($TL \leq 2$), while flows in higher trophic levels ($TL \leq 3$) are related mainly to *C. concholepas*. The MTI and IS analysis show that *C. concholepas* and crabs are the groups whose changes in biomass caused the greatest change in total system biomass in MEABR of San Vicente Bay and can be characterized as playing important ecological roles in that places. Exploitation resulted in direct and indirect trophic impacts that have the potential of affecting the sustainability of this and other MEABRs. Future research should also aim at advancing knowledge on basic ecological parameters of exploited benthic communities beyond target species.

1. Introduction

In Latin America, fisheries targeting benthic invertebrates have an important socio-economic impact as they represent a primary source of food, employment and income for fishermen that inhabit coastal areas (Castilla and Defeo, 2001). This is the case of the fishery based on the gastropod *Concholepas concholepas* in Chile (Muricidae, Bruguière, 1789), locally known as "loco" and internationally as "Chilean abalone". This fishery started in the 1960s, reaching maximum landings of 25 thousand tons in 1980. During this period, benthic fishing resources in Chile were in open access and a strong increase in their catches started due to a developing export market. As a consequence, the loco fishery was overexploited and closed in 1989.

The Chilean government promulgated in 1991 the Fisheries and Aquaculture Law No 18.992 (FAL), which incorporates territorial use rights in fisheries (TURFs) under the name of Management and Exploitation Areas for Benthic Resources (MEABR). MEABR is a type of marine protected area in which both use and management are exclusively for local unions of benthic artisanal fishermen. The aim was to provide incentives for sustainable resource exploitation (Orensanz and Parma, 2010; Aburto and Stotz, 2013; Aburto et al., 2013), by setting total allowable catches (TAC) calculated from the results of single-species stock assessment models. At the end of year 2015, 596 MEABRs were active covering a seabed area next to 74 thousand hectares (Subpesca, 2015).

Field studies conducted at the intertidal and subtidal Chilean coast in early 1980s analyzed how changes in the abundance of

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C. Concholepas, mainly related to decline in fishing effort, affected community structure and dynamics of intertidal communities (i.e., Castilla and Duran, 1985; Duran and Castilla, 1989). These studies determined that *C. concholepas* is a key predator exerting top-down control on barnacles, bivalves and limpets, among other important prey. However, the ecological role of other important predators such a starfish, crabs and small marine mammals in Chile as well as interactions in food webs are still poorly understood.

The concept of keystone species was established to describe those species with trophic impacts disproportionally larger than their abundance (Paine, 1980; Power and Mills, 1995; Power et al., 1996). Nevertheless, this concept does not consider an important aspect of the trophic ecology, namely, the degree of interaction between species (Shannon and Cury, 2004). A simple way to quantify interactions in food webs are the Mixed Trophic Impacts analysis (Ulanowicz and Puccia, 1990) and the interaction strength index (IS; Shannon and Cury, 2004). MTI quantifies the direct and indirect impacts of each group in the web, while IS quantifies how strong these interactions are by measuring the effect that a change in biomass of one group has on the combined biomass of other groups in a system.

The objectives of this paper are to describe the structure of mass/energy flows in a characteristic MEABR in Chile, to assess the main flows of consumption in each trophic level, and to identify the functional group(s) whose changes in biomass generate the greatest impacts in the biomass of other groups in benthic exploited communities. For this, we build a model the trophic web of the MEABR of San Vicente Bay in year 2003 using the Ecopath and Ecosim software (Walters et al., 1997). The MEABR of San Vicente Bay is located in central-south Chile and it is one of the oldest MEARB in Chile. The first assessment of the benthic resources there in was carried out in year 2003, indicating that this MEARB is one of the most productive and active MEABRs in central Chile. The yield reached 45,000 individuals of *C. concholepas* and 2983 individuals of keyhole limpet (*Fissurella* spp.) per year, generating $US 82,500. In addition, the exploitation of *C. concholepas* in the MEABR at San Vicente Bay contributes to support the livelihood of 43 fishermen and their families, impacting the economy of both this fishing community and other MEABRs throughout the Chilean coast. Because there are ecological and socioeconomic reasons to study sustainability practices in MEABRs dominated by *C. concholepas* the MEABR of San Vicente Bay is a good candidate for a case study.

2. Materials and methods

2.1. Study area

The Management and Exploitation Area for Benthic Resources of San Vicente Bay (MEABR of San Vicente Bay) (Fig. 1), is located in the vicinity of San Vicente Bay (36°42′S–73°09′W) in central-south Chile. In 2003, the benthic resources in this area were directly evaluated through scientific divers establishing a baseline in terms of abundance and coverage, therefore we selected this year for our model.

The study area is characterized by marked changes in oceanographic features, resulting from the intense upwelling occurring in spring/summer (Cáceres and Arcos, 1991; Figueroa and Moffat, 2000). The MEABR of San Vicente Bay has a seabed extension of 91,66 ha (Subpesca, 2011), constituted by 40% hard substratum (massive rock boulders), 40% soft substrate (medium to thick sand type) and 20% mixed substrate (sand and rocks). The area varies in depth between 0 and 35 m (Céspedes and León, 2003).

2.2. Modeling the food web at the MEABR of San Vicente Bay

A trophic mass-balance model was built to represent community structure and trophic relationships of 19 functional groups in the study area (Table 1). Functional groups were selected because they exhibit direct or indirect trophic interactions with the main target species and ecological information was available. In addition, these 19 functional groups allows a good representation of all trophic levels of the food web. We selected the Ecopath with Ecosim (EwE) software version 6.1 (Walters et al., 1997) as model platform. EwE parameterizes food web models based on two master equations describing steady-state and mass-balance conditions for each functional group. The production for each group is calculated using the following equation:

$$P_i = Y_i + M2_i \times B_i + E_i + BA_i + M0_i \times B_i \quad (1)$$

where P_i is the total production rate of each group i, Y_i is the total catch of each group, $M2_i$ is the instantaneous predation rate for group i, E_i is the net migration rate (emigration − immigration), BA_i is the biomass accumulation rate (under steady-state conditions BA_i and E_i are considered to be equal to 0), while $M0_i$ is the ‘other mortality’ rate for group i, B_i is the biomass of the group i.

The mass-balance of each component of the system is given by:

$$Q = P + R + U \quad (2)$$

where Q is the consumption of prey within the system as well as the allochthonous prey, P is production, R is respiration, U is unassimilated food by consumers.

Data source used to parameterize the model are detailed in Table 2. Once the input parameters required to run the model were completed, the balance for each group i was verified by checking the values of the ecotrophic efficiency (EE) and the gross food conversion efficiency (GE). According to Christensen and Pauly (1992), the following ranges for these parameters are acceptable: $0 < EE < 1$ and $0.05 < GE < 0.3$.

2.3. Mixed trophic impacts

Once the model was balanced, the mixed trophic impacts (MTI) routine in EwE was run to calculate direct and indirect trophic impacts that any one compartment (predator) can have on any other in the flow network (Ulanowicz and Puccia, 1990). The MTIs are calculated from the predator–prey matrix with dimensions n × n, where the elements 1 i and j represent the interactions between the impacting group i and the impacted group j. The mathematical expression of each MTI is as follows:

$$MTI = DC_{ij} - FC_{ij} \quad (3)$$

where DC_{ij} is the proportion (in weight) of prey j in the diet composition of predator i, FC_{ji} is the impact of the predator i on its prey j and corresponds to the proportion of the predation caused by i in the total predation mortality on predation on j (Christensen and Walters, 2004).

2.4. Time dynamic simulation (Ecosim)

Once the trophic model constructed in Ecopath has been balanced, the use of Ecosim allows modeling the biomass dynamics of each functional group in the food web model, using a series of coupled differential equations developed by Walters et al. (1997). These equations are derived from the Ecopath master equation (Eq. (1)), and take the following form