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Mass balanced trophic models and short-term dynamical simulations for benthic ecological systems of Mejillones and Antofagasta bays (SE Pacific): Comparative network structure and assessment of human impacts

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ABSTRACT

Mass-balanced and dynamical multispecies trophic models were constructed for benthic systems of Mejillones and Antofagasta bays. We analysed data on biomass, *P*/*B* ratios, catches, food spectra, and the consumption and dynamics of commercial and non-commercial species or functional groups using the *Ecopath* with *Ecosim* framework. The biomass of the Rhodophyta group, which contributed 25.5% of the total system biomass, was the most abundant compartment in Mejillones bay, whilst the bivalve *Transenella pannosa* recorded the highest biomass (~39%) in Antofagasta bay. Amongst the carnivores, the commercial gastropod *Tais chocolata* (~2%) and the sea star *Luidia magallanica* (~4%) were the compartment containing the highest biomass in Mejillones Bay and Antofagasta Bay, respectively. Based on the magnitudes of *Pp*/*R*, *Relative Ascendency* (*A*/*C*), *Relative Overhead* (*Ov*/*C*), *Redundancy*, *Finn's cycling index* and the system recovery time (*SRT*), the benthic system of Antofagasta Bay was more developed or mature and, in turn, less resistant against perturbations compared to Mejillones Bay. The outcomes of the mixed trophic impacts (*MTI*) indicate that the small epifauna carnivore (*SEC*) and the phytoplankton propagate the highest magnitudes of direct and indirect effects on the remaining compartments in the Mejillones and Antofagasta bays, respectively. According to the *Ecosim* short-term simulations (increasing 10, 30 and 50% the mortality by fishing and/or toxic substances) the snail *Tegula* spp. had the highest impact on the other compartments in Mejillones Bay, whilst the bivalve *T. pannosa* exhibited the highest impacts in Antofagasta Bay. Based on our results, we suggest that environmental studies should not only aim to promote and ensure the quality of physical components of nature, but should also consider the ecosystem properties and dynamics that emerge from complex networks.

1. Introduction

In coastal northern Chile (SE Pacific coast), a notable geological structure called Mejillones Peninsula separates the two most important bay systems of this area: Mejillones Bay and Antofagasta Bay (Fig. 1). Both bays have been historically impacted by various human activities, principally those related to the mining industry (loading of mineral concentrates of Cu, Zn, Pb and Hg), thermoelectric plants, acid transfer plants, port operations, artisanal fisheries and the sewage treatment of human settlements, amongst others. It has been recently accepted that the port operations related to mineral transport have enriched the bottom sediments and seawater of both bays with Cu, Pb, and Zn (Valdés and Sifeddine, 2009). As a result, it has suggested that the current Chilean Environmental Legislation is not an efficient tool for the protection of these marine ecosystems (Valdés et al., 2010, 2011). However, we claim that this legislation is additionally biased because it only considers the chemical loading of the physical environment (seawater and

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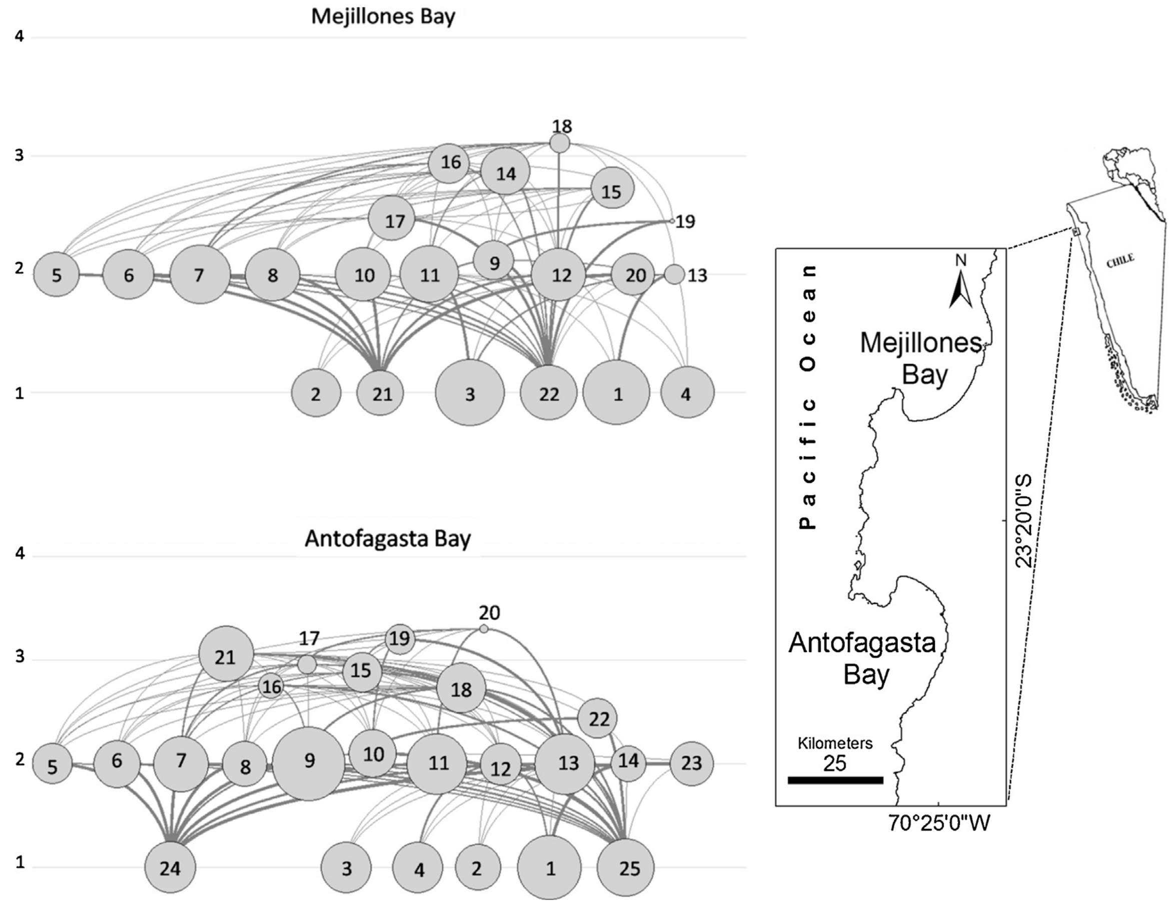

Fig. 1. Study area of Mejillones and Antofagasta bays (SE Pacific coast), northern Chile. Trophic model for the benthic ecological system of Mejillones and Antofagasta bays. Vertical position approximates trophic level. The circle size is proportional to the compartment (populations and/or functional groups) biomass (g wet weight m^{-2}). The number in circle corresponds to the species or functional groups (for details see Table 1).

sediments), without considering the living components, and supposes the ecosystems as homogenous and replicable units. This reductionist view is also shared by numerous fisheries studies, which are based solely on population analysis for simulating and predicting the responses of exploited species (Walters et al., 1999; Scotti et al., 2007; Ortiz, 2010; Ortiz and Levins, 2011; Ortiz et al., 2013a). Additionally, it is important to mention that several species that inhabit the shallow benthic habitats of Mejillones and Antofagasta bays are exploited for human consumption.

Alternatively, a more holistic view is needed for the study of Mejillones and Antofagasta bays. However, this view implies a consideration of the links amongst the chemical and physical compartments with the organisms present, which, in turn, directly modify their immediate environments through their structures and activities (Levins and Lewontin, 1985) and also actively participate (by predation) in the flow of energy and/or matter through their trophic networks (Odum, 1969; Ulanowicz, 1986). Therefore, the impacts of natural or anthropogenic disturbances can be propagated through these trophic networks, buffered along some pathways or amplified along others. Meanwhile, human interventions are often not constant over time; that is, humans act on the system but also respond to it. Hence, human interventions are co-variables with the variables of the natural systems, and they introduce uncertainties (Ortiz and Levins, 2011).

Despite the numerous studies conducted in Mejillones and Antofagasta bays, most notably, studies examining oceanographic conditions (Escribano and Hidalgo, 2001; Escribano et al., 2004; Dávila et al., 2014), primary production (Escribano and McLaren, 1999; Escribano et al., 2004), heavy metal contents in coastal waters and sediments (Valdés and Sifeddine, 2009; Valdés et al., 2010, 2011), benthic communities (Laudien et al., 2007, Pacheco et al., 2012), and local benthic modelling (Ortiz et al., 2010), to date, few efforts have focused on ecologically integrating the benthic species that inhabit these two bays. For this reason, it is necessary to apply other complementary theoretical frameworks that allow the integration of a finite set of "core" variables that represent and describe the dynamics and structures of ecosystems to which they belong (Robinson and Frid, 2003; Hawkins, 2004; Francis et al., 2007). The application of network analyses based on multispecies or ecosystem models provides complementary strategies to the classic isolated-reductionist models for those cases in which the goals are to analyse the emergent properties (macrodescriptors) of ecosystems (Ulanowicz, 1986, 1997), the overall health (Costanza and Mageau, 1999) and to assess the propagation of direct and indirect effects within complex ecological systems (Levins, 1974, 1998a; Hawkins, 2004).

Multispecies trophic models based on *Ecopath* II (Christensen and Pauly, 1992) and *Ecosim* (Walters et al., 1997) have been widely employed for describing trophic webs and predicting the effects produced by the application of different exploitation scenarios in different marine ecosystems (Christensen and Pauly, 1992; Ortiz and Wolff, 2002; Ortiz, 2008a, 2010; Ortiz et al., 2009, 2010; Preikshot et al., 2013; Pinkerton and Bradford-Grieve, 2014). The main objective of this work was to build trophic models that represent the interspecific relationships (prey–predator) in the benthic systems of the Mejillones and Antofagasta bays, including the putative effects produced by the artisanal fisheries and industrial activities on the mortality rates of the benthic species, using