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Trophic network properties of coral ecosystems in three marine protected areas along the Mexican Pacific Coast: Assessment of systemic structure and health

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ABSTRACT

Trophic models were constructed to assess the systemic structure, organisation and health of coral ecosystems in three marine protected areas (MPAs) along the Mexican tropical Pacific Coast. Likewise, the degree of resistance of the model-systems and the compartments most sensitive after perturbations were also evaluated. The biomass of the Rhodophyta group was the most abundant compartment in Isla Isabel National Park (IINP) and Islas Marietas National Park (IMNP), whilst the Phytoplankton group had the highest biomass in Sanctuary of Islands and Islets of Bahía Chamela (SIIBC). Based on the magnitudes of *Total System Throughput* (TST), *Ascendency* (A), *Overhead* (Ov), *Capacity* (C), *Average Mutual Information* (AMI), *Finn's Cycling Index* (FCI) and the *Total Biomass/Total System Throughput* (TB/TST) ratio, IINP was more mature, organised, developed and healthy than IMNP and SIIBC. Phytoplankton, Detritus and Zooplankton contributed >60% of the total *Ascendency*, whereas Jacks and *Octopus* sp. accounted for the complexity of the three MPA model systems. The outcomes of the propagated impacts, using *Mixed Trophic Impacts* (MTI) and short-term *Ecosim* simulations (under three levels of mortality: 10%, 30% and 50%), showed that the Groupers (i.e., exploited fish), Omnivorous Fish, Rhodophyta, Large Epifauna and Phytoplankton produced the highest impacts on the remaining compartments of the three model systems. The average *System Recovery Time* (SRT) suggested that SIIBC was less resilient to disturbances compared with IINP and IMNP. Based on the outcomes, we suggest that the marine zones adjacent to IINP should be included in the Mexican Management Program to create a buffer zone for these coral ecosystems. Likewise, IMNP and SIIBC should be candidates for a putative monitoring programme to assess the trajectory of the systemic health of coral ecosystems. Finally, the trajectories of exploited species should be monitored because they constitute compartments that have relevant roles in the structure and trophic functioning of the three MPAs.

1. Introduction

Marine protected areas (MPAs) have become one of the foremost administrative tools for maintaining and managing fisheries in a responsible way. Simultaneously, MPAs help in the conservation of biodiversity, to maintain ecosystem function and structure and in providing economic benefits to human populations living in or near those areas (Halpern, 2003; Palumbi, 2003). Coastal marine ecosystems as coral ecosystems provide important ecological and economic services to humans; however, coral ecosystems are subject to several anthropogenic and natural disturbances (Jackson et al., 2001; Lotze et al., 2006), including an increase in pollution and degradation and the deterioration of the species that inhabit these ecological systems (Jackson et al., 2001; Halpern et al., 2008). Our study focused on three MPAs established along the Mexican tropical Pacific Coast: Isla Isabel National Park (IINP), Islas Marietas National Park (IMNP) and Sanctuary

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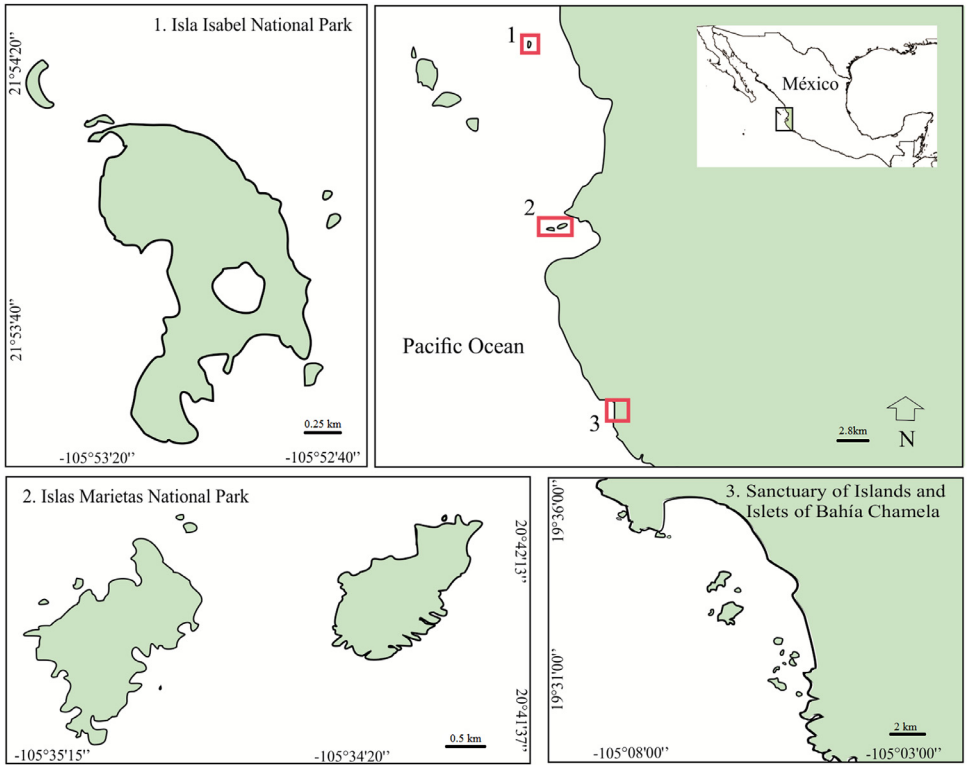

Fig. 1. Locations of study areas in the Mexican tropical Pacific Coast: Isla Isabel National Park, Islas Marietas National Park and Sanctuary of Islands and Islets of Bahía Chamela.

of Islands and Islets of Bahía Chamela (SIIBC). IINP and IMNP are considered to play an important role in the dispersal connectivity between zones of the eastern tropical Pacific because they are located in a transition zone between the California Current, the North Equatorial Current and the Gulf of California (Badan, 1997; Filonov et al., 2000). SIIBC is important as the first marine sanctuary established in this category in Mexico showing remarkable features of biodiversity, which have been important for scientific research (Ríos-Jara et al., 2013). These MPAs are facing different natural and anthropogenic threats, such as El Niño-Southern Oscillation (ENSO) climate change, extreme weather phenomena, fisheries, tourism and coastal development, which are associated with changes in the structure, organisation and performance of ecosystems (Pauly et al., 1998; Ray et al., 2000; Petersen et al., 2008; González et al., 2016). Additionally, the marine adjacent zone to IINP is not included in the Mexican Management Program, intensifying the possible threats and disturbances to ecosystem properties.

The rapid deterioration of ecosystems has motivated the development of multispecies trophic models and the assessment of macroscopic indices (emergent properties) that complement and/or provide an alternative to conventional population and community studies. Based on these model systems, the structure, health and dynamics of ecosystems can be evaluated (Constanza, 1992; Monaco and Ulanowicz, 1997; Arias-González, 1998; Almunia et al., 1999; Costanza and Mageau, 1999; Ray et al., 2000; Christensen and Pauly, 2004; Scotti et al., 2007; Ortiz, 2008a,b, 2010). In this sense, two theoretical frameworks, those of Odum (1969) and Ulanowicz (1986, 1997), would allow the emergent features to be quantified and the focus to be on the level of development or maturity, organisation and health of the ecosystem. Development or maturity describes the maximum biomass (information content) and optimal energy utilisation in the ecosystem. Organisation would represent the number and diversity of interactions among components (Ulanowicz, 1986, 1997). A healthy ecosystem may be viewed as the ability to maintain its organisation and function over time (Constanza and Mageau 1999). These macroscopic indices have been used in practical circumstances, for example, quantifying the status of an ecosystem (Baird and Ulanowicz, 1989; Halfon et al., 1996; Wolff et al., 1996; Heymans and Baird, 2000; Ray et al., 2000; Fetahi and Mengistou, 2007; Ortiz et al., 2015; Rodriguez-Zaragoza et al., 2016), measuring the effects of perturbations on an ecosystem (Baird and Heymans, 1996; Almunia et al., 1999; Cáceres et al., 2015; González et al., 2016), assessing ecosystem health and integrity (Constanza, 1992), and in comparisons of ecosystems (Baird and Ulanowicz, 1989; Heymans and Baird, 1995; Baird et al., 1991; Monaco and Ulanowicz, 1997; Patricio et al., 2004; Ortiz et al., 2013b).

Several multispecies trophic models have been developed for the Mexican tropical Pacific Coast (e.g., Arreguín-Sánchez et al., 2002; Morales-Zarate et al., 2004; Diaz-Uribe et al., 2007; Morales-Zárate et al., 2011; Cruz-Escalona et al., 2013); however, this type of study has not been conducted for the coral ecosystems in these three MPAs (IINP, IMNP and SIIBC). Therefore, this work represents the first attempt to quantitatively model and simulate the trophic interactions of these coral ecosystems. The findings will improve current conservation and management strategies, providing information on the ecological systems that should be monitored to assess the trajectories of the systemic health and also the species that constitute compartments with relevant roles in the structure and trophic functioning of the three MPAs studied. For this reason, the aim of this study was to assess the systemic structure and health in three Marine Protected Areas along the Mexican tropical Pacific Coast using trophic models that represent the ecological relationships (prey-predator/resource-consumer) among the most abundant species in the benthic-pelagic coral ecosystems. Based on this network analysis, the following ecological attributes were evaluated: (1) the emergent properties of the benthic-pelagic ecological systems related to the structure, organisation and ecosystem health based on the theoretical frameworks of Odum (1969) and Ulanowicz (1986, 1997); (2) the degree of resistance to disturbances and the resistance of the ecosystems in response to perturbation scenarios; and (3) the