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Effects of small-scale and recreational fisheries on the Gran Canaria ecosystem

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ABSTRACT

A mass-balance trophic model was built in order to describe the impact of the different fleets that operate in the Gran Canaria marine ecosystem between 2005 and 2010. This is the first food-web model developed in the Canary Islands, and results were presented and compared with other ecosystems that have been modeled in Atlantic and Mediterranean coastal areas. Thirty-four functional groups were defined, corresponding to benthic, demersal, and pelagic domains, also including the deep scattering layer (DSL) and detritus. Keystone index and mixed trophic impacts matrix showed a bottom-up control in the benthic-demersal area while in the pelagic zone intermediate predators such as cephalopods, are more relevant to the ecosystem. Primary production required to sustain the fishery was higher when taking into account the detritus and the primary producers, suggesting the importance of detritivorous organisms such as crustaceans, DSL, molluscs, and other benthic species in the catches. Recreational fishermen exert high impacts on most groups of the ecosystem, especially in breams and epidemersal fishes. Benthic sharks, groupers, breams, parrotfishes, leatherjacket fishes, and common pandora showed high exploitation rates, suggesting that these species are overexploited.

1. Introduction

Fishing pressure on marine resources has increased in the last decades (Watson et al., 2013), and this, together with the degradation of marine habitats, and climate and environmental changes, have ecological impacts on ecosystems such as trophic cascades or imbalances in ecosystem control, regardless of whether the systems exhibit bottom-up, top-down or wasp-waist control (Cury et al., 2000; Chassot et al., 2007; Baum and Worm, 2009; Ferretti et al., 2010). This has generated a growing interest in the modeling of marine ecosystems and their associated fisheries, which has served to identify the structure and functioning of the communities. Consequently, new methodologies have been developed to manage marine resources from an ecosystem-based approach to fisheries (EAF) (Garcia et al., 2003). Overfishing and increasing fishing effort make it necessary to implement new management models, which not only ensure the sustainability of the fisheries but also the integrity of marine ecosystems (Pauly et al., 2000; Walters et al., 2005; Coll et al., 2006, 2007; FAO, 2008; Torres, 2013). These approaches allow the study of energy flows in the food web, as well as variations in the biomass of the species and the impact of external shocks on organisms (Plagányi, 2007).

The mass-balance model Ecopath with Ecosim (EwE) (Polovina, 1984; Christensen and Pauly, 1992) is the most commonly used model for analysis of food-webs. The software that implements the approach has been widely used in many countries to assess the impact of fishing on the ecosystem, management and implementation of marine protected areas, to explore possible management policies or to estimate ecological indicators, among others.

The Canarian Archipelago is a group of oceanic volcanic islands independent from the African continent and separated from it by depths close to 2000 m (Carracedo, 1984). The island of Gran Canaria is geologically independent from the other islands of the archipelago, with depths reaching nearly 3000 m in the channel that separates the island of Tenerife, and above 2000 m in its separation from the island of Fuerteventura.

The discontinuity of the shelf between the islands and the African continent has important implications for species distributions and their biological characteristics, and therefore must be considered in the fisheries management policies for each island (Castro et al., 2002). The great depths surrounding the island of Gran Canaria can act as a physical barrier to many marine species, such as fishes, crustaceans and molluscs; therefore, it can be assumed that the distribution of these organisms is geographically isolated

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to the waters that surround the island. This also applies to the other islands of the archipelago.

The Deep Scattering Layer (DSL) is a sound-reflecting layer in ocean waters, consisting of a stratified and dense concentration of mesopelagic organisms and it is one of the most important biological resources in the Canary Islands (Caldentey et al., 2011). These organisms play an important role in the marine ecosystem, by contributing to transport of matter and energy between the different trophic levels.

In the Canary Islands, numerous studies have collected biological and ecological data such as growth and mortality, diets as well as information about fishing activities and their impact on the ecosystem. However, it has not been possible to integrate all this information from a multidisciplinary point of view, as has occurred in many neighboring areas, including the Mediterranean, North Atlantic and Cantabrian Sea (Sánchez and Olaso, 2004; Coll et al., 2006, 2007; Araújo et al., 2008; Morato et al., 2009; Tsagarakis et al., 2010; Valls et al., 2012; Torres et al., 2013). There are two main reasons for this: in contrast to these areas, there is little information in Gran Canaria about the actual state of fish stocks, and only a few oceanographic surveys have been conducted in the area; furthermore there were no accurate landing statistics of the artisanal fisheries until 2005.

The fishing fleet that operates in Gran Canaria can be divided into three subfleets: artisanal, recreational and industrial. Of these, the industrial fleet operates near the African coast, so it has not a direct impact on the Canarian marine ecosystem. Artisanal fishing is conditioned by the seasonal arrival of tuna species, reducing the pressure on benthic-demersal fishes between spring and fall (Hernández-García et al., 1998). There is little information about recreational fishery in the Canary Islands, but recent data shows that the number of active licenses is excessive, and far exceeds the number of professional fishermen. During the period 2005–2013 the number of recreational licenses increased from about 5680 to 31,945, representing a considerable change in the fishing effort. Recreational fishermen are not required to report catches, despite the fact that they are higher than those obtained by artisanal fishermen. Since, in the Canary Islands, the recreational fishers catch the same target species as artisanal fishermen, it is necessary to include this type of fishing in future studies because it probably has a strong impact on marine ecosystems and the species that live there.

This work is the first attempt to define the Gran Canaria's marine ecosystem using a mass-balanced model, in order to obtain a detailed description of the ecosystem. This will allow us to analyze in detail the trophic interactions of the different communities through biomass flows and energy transfers as well as evaluating the impact caused by small-scale fisheries (artisanal and recreational) in order to propose new strategies that allow sustainable fishing.

2. Materials and methods

2.1. Study area

The model constructed in this study describes the coastal areas of the Gran Canaria Island in the Canarian Archipelago (Fig. 1). It includes the area where artisanal fleet operates, covering an area of about 2146 km^2 from the surface to 1000 m. The Canary Current and its trade winds generate variability in the oceanic and atmospheric flows, generating mesoscalar processes such as eddies or warm wakes (Arístegui et al., 1997; Barton et al., 2000; Pelegrí et al., 2005). Furthermore, the Canary Islands are located in a transition zone between the cold waters, rich in nutrients, from the African coast, and the oligotrophic waters of the open ocean (Barton et al., 1998). These phenomena generate variations in primary production in the area, which affect the entire food web.

Artisanal fishing is carried out in coastal waters of the island, with a large number of techniques and gears (see Bas et al., 1995). Fishery resources are mainly composed of demersal, coastal pelagic, and oceanic pelagic species (particularly tunas). The year 2005 was chosen to develop the Gran Canaria ecosystem model, because the governmental fishing data recording system was implemented this year for the whole island. For migratory species, such as tunas, we considered that only a proportion of the population was present in the area.

2.2. The model

The modelling approach used in this study was Ecopath with Ecosim software version 6 (Christensen et al., 2008). The parameterization of the model is based on satisfying two master equations. The first one describes how the production term for each functional group can be divided into terms: catch (i) + predation (i) + net migration (i) + biomass accumulation (i) + other mortalities (i)

Or:

$$\left(\frac{P}{B}\right)_i \cdot B_i = Y_i + \sum_{j=1}^{n} B_j \cdot \left(\frac{Q}{B}\right)_j \cdot \mathrm{DC}_{ji} + \mathrm{BA}_i + E_i + \left(\frac{P}{B}\right)_i \cdot B_i(1 - \mathrm{EE}_i) \quad (1)$$

where P_i is the production of group (i); B_i is the biomass of group (i); Y_i is the total catch rate for group (i); $(Q/B)_i$ is the consumption of (i) per unit of biomass; DC_{ji} indicates the proportion of (i) that is in the diet of predator (j); BA_i is the bioaccumulation rate for group (i); E_i is the net migration rate for group (i) (emigration–immigration); and EE_i is the ecotrophic efficiency of (i).

The second equation describes the energy balance of each group and is based in the principle of conservation of matter within a group, given by the form:

$$\text{Consumption}(Q_i) = \text{production}(P_i) + \text{respiration}(R_i) + \text{unassimilated food}(U_i) \quad (2)$$

Each functional group is represented by one balanced equation and four input parameters: B_i, $(P/B)_\mathrm{i}$, $(Q/B)_\mathrm{i}$ and EE_i Three of these four parameters, B_i, $(P/B)_\mathrm{i}$, $(Q/B)_i$ and EE_i have to be entered for each group (i). In addition, catches (Y_i) and diet composition (DC_{ji}) must be entered for all groups. The linear equations are then solved and the unknown parameters are estimated.

2.3. Input parameters

In all cases that were possible, input parameters were estimated from information obtained for the study area. For functional groups comprised of multiple species, the average P/B and Q/B ratios were obtained by the percentage of biomass contributed by each species within the group. For groups with no information provided from the area, values were assumed to be similar to those in other models including similar species and similar habitats. Input data is listed in Table 1, and references by all functional groups and estimation methods are included in Table A1.

2.3.1. Functional groups

The marine species in the Gran Canaria ecosystem model were pooled into functional groups based on habitat, feeding preferences, and other taxonomic similarities. Best-known commercial species are generally represented in a single group. The model was constructed based on thirty-four functional groups in total, including: two marine mammal groups (whales and dolphins), two