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Food-web structure of and fishing impacts on the Gulf of Cadiz ecosystem (South-western Spain)

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ABSTRACT

The Gulf of Cadiz (North-eastern Atlantic, Spain) is an exploited ecosystem characterized by high marine biodiversity and productivity. Over the last decade, the landings of fish stocks such as anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and hake (*Merluccius merluccius*) have been declining and currently remain low. A food-web model of the Gulf of Cadiz has been developed by means of a mass balance approach using the software EwE 6 to provide a snapshot of the ecosystem in 2009. The goals of this study were to: (1) characterize the food-web structure and functioning, (2) identify the main keystone groups of the ecosystem, (3) assess the impact of fishing to the Gulf of Cadiz compared to that in other essential marine ecosystems in the coastal area of Spain: Cantabrian Sea (North-eastern Atlantic) and Southern Catalan Sea (Mediterranean Sea), and (4) examine the limitations and weaknesses of the Gulf of Cadiz model for improvements and future research directions. The model consists of 43 functional groups, including the main trophic components of the system with emphasis target and non-target fish species. The main trophic flows are determined by the interaction between detritus, phytoplankton and micro- and mesozooplankton. Rose shrimp (*Parapenaeus longirostris*), cephalopods and dolphins present important overall effects as keystone species on the rest of the groups. The exploitation of fisheries composed mainly of trawlers, purse seiners and artisanal boats is intensive in the Gulf of Cadiz with all fleets exerting high impacts on most living groups of the ecosystem. The findings highlighted that the Gulf of Cadiz is a notably stressed ecosystem, displaying characteristics of a heavily exploited area. The comparative approach highlights that the three ecosystems display similarities with regard to structure and functioning such as the dominance of the pelagic fraction, a strong benthic-pelagic coupling, the important role of detritus, and the high impact of fishery exploitation.

1. Introduction

During the last decades, inefficient fisheries management together with illegal, unreported and unregulated (IUU) fishing practices in many marine ecosystems have caused the decline of fish stocks and therefore, major threats to marine biodiversity (e.g. Jackson et al., 2001; Agnew et al., 2009; Samhouri et al., 2009; Holt et al., 2011; Christensen and Walters, 2011). Consequently, fishing activities may alter the structure and functioning of marine food webs (Pauly et al., 1998a, 2002). This shows that fishery management based on single species is not sufficient and ongoing efforts to develop an ecosystem-based approach to fisheries (EAF) are urgently needed for integrating sustainable exploitation and marine ecosystems conservation (Garcia et al., 2003; Garcia and Cochrane, 2005; FAO, 2008). For the EAF, new methodological tools have been developed, such as ecological models (e.g. Christensen and Walters, 2004; Plagányi, 2007) and ecosystem indicators (e.g. Cury and Christensen, 2005; Shin and Shannon, 2010). These tools provide a framework for assessing the impacts of interactions between species and fisheries and their implications for marine fisheries management (Coll and Libralato, 2012).

The Ecopath with Ecosim (EwE) approach is currently one of the most used ecosystem modeling tools for building ecological models within the context of ecosystem-based approaches to marine resources management (Polovina, 1984; Christensen and Pauly, 1992; Pauly et al., 2000; Christensen and Walters, 2004, 2011). This ecological modeling tool contributes to the science of an

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ecosystem-based approach by integrating human activities within an ecosystem context and evaluating their impacts on marine food webs, including environmental factors (Coll and Libralato, 2012). Results of this type of modeling can provide important insights into ecosystem structure and functioning, adding to our understanding the control of energy flows transferred through the food web while informing the practitioner as to the most appropriate management policies. In addition, these studies have also gathered a significant amount of information at an ecosystem level based on network analysis and information theory (Ulanowicz, 1986; Christensen and Pauly, 1993; Heymans and Baird, 2000; Heymans et al., 2007, 2012).

The Gulf of Cadiz marine ecosystem (ICES IXa South) connects the Atlantic Ocean with the westernmost part of the Mediterranean Sea (Fig. 1). This area is an important fishing ground with a high diversity and high productivity of exploited species (Sobrino et al., 1994). The abundance of marine resources is related to the bathymetric characteristics of its continental shelf and slope, the existence of a warm-temperate climate, the presence of oceanographic processes, and the enrichment produced by the outflows of important rivers such as Guadalquivir and Guadiana (Vila et al., 2004; Ramos et al., 2012). In addition, the Gulf of Cadiz is considered a highly suitable habitat for the reproduction of some commercial species due to the combination of warm and nutrient-rich waters and wind regimes (Jiménez et al., 1998; Millán, 1999). Several authors have shown the importance of the Guadalquivir River estuary, or related areas, in attracting spawning or juvenile development of commercial species such as anchovy and sardine (e.g. Baldó and Drake, 2002; Sobrino et al., 2005; García-Isarch et al., 2006).

The commercial fisheries of the Gulf of Cadiz use mainly mixed-species low selectivity trawlers, purse seiners, and artisanal boats (Millán, 1992; Sobrino et al., 1994; Silva et al., 2002; Jiménez et al., 2004). In 2009, the highest landings were provided by purse seiners, accounting for 54% of the total landings, and followed by trawlers (33%) and artisanal boats (13%) (Instituto Español de Oceanografía (IEO) Fishery Database). The main commercial species caught by the trawl fleet were rose shrimp (*Parapenaeus longirostris*), hake (*Merluccius merluccius*), common octopus (*Octopus vulgaris*), cuttlefish (*Sepia officinalis*), and horse mackerel (*Trachurus* spp.). For purse seiners, the main catches were sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*). Both pelagic resources accounted for almost 80% of the total reported purse seine landings, though mackerel (*Scomber* spp.) landings were also important in this fleet. Artisanal boats targeted cephalopods, sparids and flatfishes (Silva et al., 2002).

The Gulf of Cadiz marine ecosystem has a great socio-economic importance. In 2012, fishing activities generated landed value of approximately €100 millions. Additionally, these activities are a source of employment in the area, reaching 5000 and indirectly 30,000. Most jobs opportunities are associated to coastal towns, such as Isla Cristina, Punta Umbría, Sanlúcar, Chipiona, Conil, Barbate and Tarifa (JA, 2013).

On a spatial scale, the diverse nature of the substrata over the Gulf of Cadiz shelf leads to the coexistence of different fisheries. Consequently, the rocky bottoms in the eastern area (Cadiz coast) favor the artisanal fisheries targeting sea breams (mainly *Pagrus* spp., *Dentex* spp. and *Pagellus* spp.). Sand, mud and gravel bottoms in the western area (Huelva coast) are exploited mainly by trawl and gillnet fisheries which capture hake (*Merluccius merluccius*), wedge sole (*Dicologlossa cuneata*), crustaceans and cephalopods, among others (Ramos et al., 1996). Seasonal abundance of several commercial species determines the sequential development of different demersal and pelagic fisheries (Jiménez, 2002; Silva et al., 2002). Species catches vary largely in space and time in association with the highly diverse environmental traits encountered in the shelf as well as the species life cycles (Sobrino et al., 1994; Ramos et al., 1996). In addition, anchovy and sardine biomass undergo large inter-annual fluctuations due to environmental changes (Sobrino et al., 2002).

In the Gulf of Cadiz, numerous studies have been undertaken mainly focusing on different fishing, biological, and ecological aspects (e.g. Jiménez et al., 2004; Torres et al., 2007; Gil et al., 2008; Vila et al., 2010; Silva et al., 2011). However, none have integrated all the available information to quantify fishing impacts in an ecosystem-based perspective despite the decline of the main stocks in the area (IEO Fishery Database). In addition, a recent study describing different features of the Gulf of Cadiz ecosystem required for the Marine Strategy Framework Directive has revealed that there are no studies about the food-web structure and trophic relationships of this marine exploited area (Ramos et al., 2012). Therefore, ecosystem modeling could be appropriate to fill this research gap, integrating all the available information on the Gulf of Cadiz marine ecosystem.

Hence, taking advantage of previous modeling work in surrounding areas, this study presents the development of the first food-web model of the Gulf of Cadiz (ICES IXa South) with the goals to: (1) characterize the food-web structure and functioning, (2) identify the main keystone groups of the ecosystem, (3) assess the impact of fishing to the Gulf of Cadiz compared to that in other essential marine ecosystems in the coastal area of Spain: Cantabrian Sea (North-eastern Atlantic) and Southern Catalan Sea (Mediterranean Sea), and (4) examine the limitations and weaknesses of the Gulf of Cadiz model for improvements and future research directions.

2. Material and methods

2.1. Area description and study period

The Gulf of Cadiz is located at the Southwestern end of the Iberian Peninsula and covers a large marine area of Spain, Portugal and Morocco. The Spanish area from the mouth of the Guadiana River, which borders Portugal in Ayamonte (Huelva), to the Cape of Tarifa (Cadiz) spans 303 km of coast (Sobrino et al., 1994). The modeled area is encompassed in ICES Subdivision IXa (South) and it covers 7224 km^2 with depths from 15 to 800 m (Fig. 1). The coastal area was excluded from the analyses because legal trawling fishing areas are only deeper than 15 m and since there is a lack of information necessary to parameterize the model. The food-web model developed in this study represents an annual average situation of the Gulf of Cadiz ecosystem in 2009 because this is the year when the best data were available, and most of the diet composition data for predators representing the marine food web were collected during this year (Torres, 2013).

2.2. The food-web model

The food-web model of the Gulf of Cadiz was constructed using the Ecopath with Ecosim (EwE) software version 6 (Christensen et al., 2008). In particular, we used the static Ecopath model that allows getting a snapshot representation of the resources in the ecosystem and their interactions in a specific period, namely the year 2009. The resources are represented by trophically linked biomass 'pools' in the form of functional groups (i). They consist of a single species or species groups representing ecological guilds (Christensen et al., 2008).

The model is parameterized based on two master equations. The first one describes how the production term for each functional group (i) of the model can be split into the following components: catches + predation mortality + net migration + biomass