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Trophic structure in the Gulf of Lions marine ecosystem (north-western Mediterranean Sea) and fishing impacts

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ABSTRACT

The Gulf of Lions ecosystem was described using the Ecopath mass-balance model to characterise its structure and functioning and to examine the effects of the multispecific fisheries operating in this area. The model is composed of 40 compartments, including 1 group of seabirds, 2 groups of cetaceans, 18 groups of fish, 12 groups of invertebrates, 5 groups of primary producers, detritus and discards. Input data were based on several recurrent scientific surveys, two alternative datasets for fishing data, stock assessment outputs, stomach content analyses and published information. Results showed that the functional groups were organised into five trophic levels with the highest one represented by dolphins, anglerfish, Atlantic bluefin tuna, European hake and European conger. European pilchard and European anchovy dominated in terms of fish biomass and catch. Other fish with high biomass such as Atlantic mackerel and blue whiting were highly important in the food web. Seabirds, dolphins and cuttlefish–squids represented keystone species. Important coupled pelagic–demersal–benthic interactions were described. The 7 different fisheries analysed were operating at mean trophic levels situated between 2.6 for small artisanal boats, and 4.1 for purse seines (>24 m) targeting large pelagic fish, indicating an intensively exploited ecosystem. Large trawlers (24–40 m) had the highest impact on most of the groups considered; while purse seines (12–24 m) targeting small pelagic fish had the lowest impact. Preliminary results highlighted the importance of data sources for further ecosystem and fisheries analyses and management scenarios.

1. Introduction

The Gulf of Lions is an important feeding area for fish, birds and mammals, for both resident and migratory species. It represents a highly productive system because of the Rhone River inputs, coastal upwelling activity, bottom morphology and water circulation (Agostini and Bakun, 2002; Hu et al., 2009; Lefevre et al., 1997; Petrenko et al., 2005). In this area many species of commercial interest have been intensively exploited on the continental shelf and upper slope for decades by the French and Spanish fleets using multispecific artisanal gear such as trawlers, purse seines, gillnets and other gear (Farrugio et al., 1993; Lleonart and Maynou, 2003; Sacchi, 2008). Throughout the Mediterranean Sea, marine resources have been exploited since ancient times (Margalef, 1985), although in the last decades the development of fishing technologies and the increasing demand for marine resources have generated a stronger and more amplified pressure on marine resources. Current analyses suggest that most demersal and pelagic stocks are fully exploited or overexploited (Aldebert and Recasens, 1996; Bas et al., 2003; FAO, 2009; Papaconstantinou and Farrugio, 2000; Sardà, 1998).

Fishing is known to be one of the major human disturbances in coastal marine ecosystems (Jackson et al., 2001; Jennings and Kaiser, 1998). It has various kinds of direct and indirect impact, in addition to those induced by oceanographic features and other anthropogenic and natural disturbances (Christensen et al., 2003; Hall, 1999). According to Food and Agriculture Organisation (FAO, 1995, 2002) "the achievement of real marine ecosystem-based management of fisheries implies the regulation of the use of the living resources based on the understanding of the structure and dynamics of the ecosystem of which the resource is a part". This requires an improvement in our understanding of the structure and functioning of exploited ecosystems and of the changes induced in them by human and environmental factors.

In the north-western Mediterranean Sea coupled physical and biogeochemical models were made (Baklouti et al., 2006). In these models the highest trophic level was represented by mesozooplankton (Eisenhauer et al., 2009).

This work is the first ecosystem modelling approach in the Gulf of Lions ecosystem, taking into account the entire food web from primary producers to top predators, and covering a large area from the

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coast up to 2500 m. The objective was to analyse the structure and the functioning of the food web and to estimate the relative impact of the different fishing gear. To do so, we used the Ecopath with Ecosim (EwE) software that has been widely used in many places over the world to quantitatively describe marine and aquatic ecosystems and to assess fishing impact (Christensen and Walters, 2004; Pauly et al., 2000). Ecosystem modelling has been proposed as a management tool for marine fisheries (Plagányi, 2007) and also in Mediterranean Sea (Cochrane and de Young, 2008), where EwE models were previously made in different areas (Coll and Libralato, 2011; Coll et al., 2006, 2007; Libralato et al., 2002; Pinnegar and Polunin, 2004; Tsagarakis et al., 2010).

2. Materials and methods

2.1. Study area

The Ecopath model represents an average annual situation over the last decade (2000–2009) of the Gulf of Lions ecosystem covering a total area of 20,400 km^2 and with a bathymetry between 0 and 2500 m. The Gulf of Lions is located in the north-western Mediterranean Sea (42°26.3′N, 3°9.9′E; 43°12.6′N, 5°27.5′E) (Fig. 1). The continental slope constitutes a long open boundary to the southeast of the Gulf. Along this boundary, the main mesoscale circulation feature is a strong geostrophic current, the Northern Current, which generally flows along the continental slope of the Gulf of Lions (Millot, 1999). The dominant forcing drivers in the area are the strong north-western (tramontane) and northern (mistral) winds which induce strong coastal upwelling activity (Agostini and Bakun, 2002; Millot, 1999), the western Mediterranean mesoscale circulation, and the fresh water input from the Rhone River (Petrenko et al., 2005). These drivers generate important primary and secondary production and the Rhone River is an important source of dissolved and particulate organic matter in this system (Gaudy et al., 2003; Harmelin-Vivien et al., 2008; Lefevre et al., 1997). The Gulf of Lions shows a decreasing trend in nutrient concentration and production from east to west and from the continental shelf to deeper waters. The substrate is characterised by muddy and sandy bottoms. The area presents a high diversity of organisms and many aspects of their ecology and biology have been investigated over the past decades (Beaubrun, 1995; Hermand et al., 2008; Labrune et al., 2007; Mellon-Duval et al., 2009).

2.2. The Ecopath model

The Ecopath and Ecosim (EwE) modelling approach version 6 (Christensen and Walters, 2004; Christensen et al., 2008; Link, 2009; www.ecopath.org) was used to ensure the energy balance of the model of the Gulf of Lions' marine system. Ecopath has been widely used for constructing, parameterisation and analysis of food web models of aquatic and terrestrial ecosystems. It led to generalisations on the structure and functioning of many marine ecosystems and has been used in fisheries assessments.

EwE divides the production (P) of each component or functional group (i) of the ecosystem into: (1) predation mortality ($M2_{ij}$) caused by the biomass of the predators (B_j), (2) exports from the system both from fishing activity (Y_i) and (3) other exports (E_i), (4) biomass accumulation in the ecosystem (BA_i) and (5) baseline mortality or other mortality ($1-EE_i$), where EE is the ecotrophic efficiency of the group within the system, or the proportion of the production of (i) that is exported out of the ecosystem (i.e. by fishing activity) and consumed by predators within it.

$$P_i = \Sigma B_j * M2_{ij} + Y_i + E_i + BA_i + P_i * (1-EE_i)$$

This equation can be re-expressed as:

$$B * (P/B)_i = \Sigma B_j * (Q/B)_j * DC_{ij} + Y_i + E_i + BA_i + B_i * (P/B)_i * (1-EE_i)$$

where $(P/B)_i$ indicates the production of (i) per unit of biomass and is equivalent to total mortality, or Z, under steady-state conditions

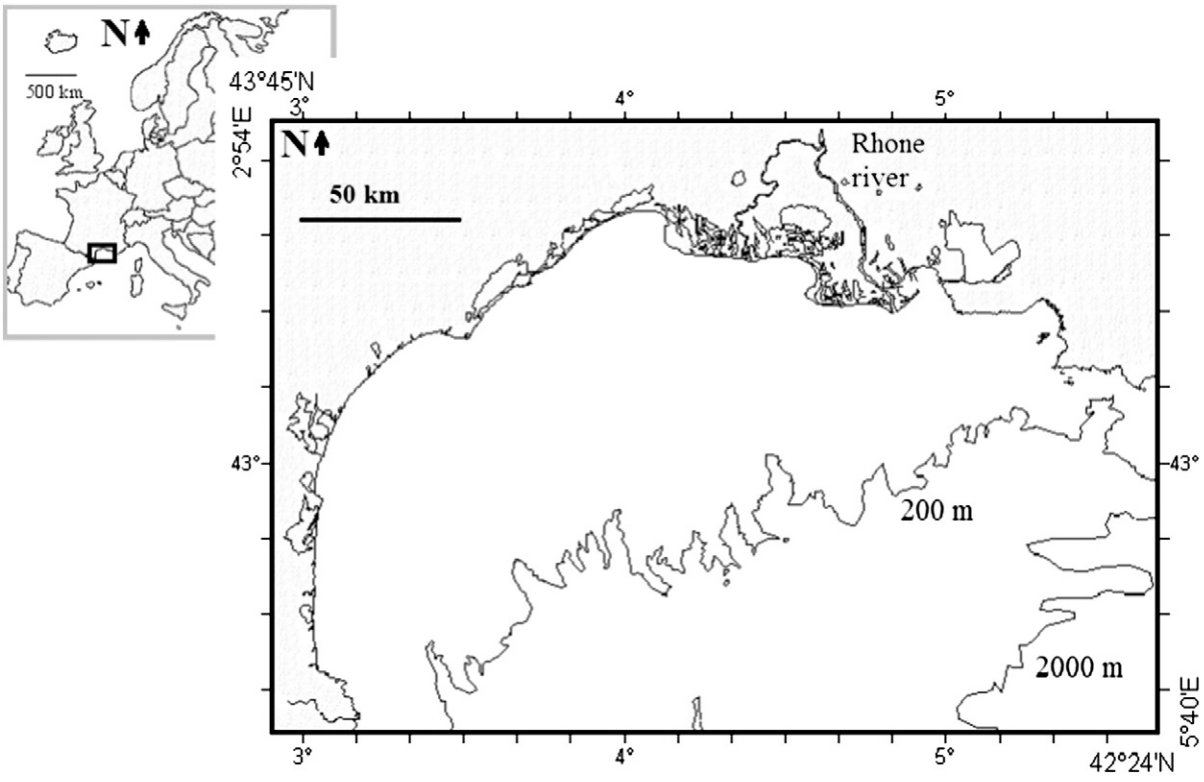

Fig. 1. Study area situated in the Gulf of Lions (north-western Mediterranean Sea).