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From common to rare: The case of the Mediterranean common dolphin

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ABSTRACT

Although overfishing has been recognized as responsible for the decline of major fish stocks, it has been less easy to demonstrate its indirect and detrimental effects on marine mammals, particularly dolphins. Competition with fisheries for the same food resources has been hypothesized to have led to the decline of several species of dolphins, including the endangered Mediterranean short-beaked common dolphin. Based on an ecosystem model for the Inner Ionian Sea Archipelago, a former hotspot for common dolphins in the Mediterranean Sea, we investigated the effect of increasing fishing effort on common dolphins, its prey and on marine biodiversity and we evaluated the outcomes of different fisheries closures (1 – closure of the purse seine fishery, 2 – closure of purse seine, trawl and beach seine fisheries, 3 – entire area closed to fisheries) ran between the years 2011 and 2030. Our results showed that local fisheries have negatively impacted the marine biodiversity of the ecosystem causing sharp declines of common dolphins and major fish stocks and weakening the robustness of the marine food web. The implementation of fisheries closures would gradually recover fish stocks, while common dolphins would increase more pronouncedly only if the study area was to be closed to all fisheries. As shown in this study, common dolphins have reflected ecosystem changes and degradation over time. Ensuring the survival of dolphin populations is thereby essential to enhance marine ecosystems and ensure sustainable fishing.

1. Introduction

Global fisheries have caused profound and significant ecological changes to the structure and the functioning of marine ecosystems by removing target and non-target species and by deteriorating marine habitats (Pauly et al., 1998; Jackson et al., 2001; Worm et al., 2006). While fisheries regulations have been used to manage the direct effects of fisheries on target species, it has been more difficult to reduce indirect effects of fishing on the other components of the ecosystem (Crowder et al., 2008). Particularly, little effort has been made to understand the consequences of fishing on species that are important prey to marine mammals (Read, 2008). Worldwide, several marine mammal populations have declined rapidly and overfishing has been suggested as key to their collapse (Crowder et al., 2008; Heithaus et al., 2008; Read, 2008).

In the Mediterranean Sea, overfishing is well documented (Stergiou and Koulouris, 2000; Coll et al., 2008a; Heithaus et al., 2008; Piroddi et al., 2010) and has had negative effects on prey availability for marine mammals, especially for small cetaceans (Bearzi et al., 2008; Cañadas and Hammond, 2008; Piroddi et al., 2010). One of the cetacean species that competes the most with fisheries for fish resources is the short-beaked common dolphin *Delphinus delphis* (hereafter 'common dolphin' (Bearzi et al., 2003)). Although it used to be one of the most common cetacean in the Mediterranean Sea, it has suffered drastic declines since the 1960s and now it regularly occurs only in few delimited areas of the region (Fig. 1) (Bearzi et al., 2003; Cañadas and Hammond, 2008). In the Inner Ionian Sea Archipelago, the focus of our study, one suggested reason for the decline has been the increased overexploitation of epipelagic fish (sardines and anchovies), the main prey of common dolphins (Bearzi et al., 2006), caused by local fishing fleets, particularly purse seiners (Bearzi et al., 2008; Piroddi et al., 2010). In 2003, the Mediterranean population of the common dolphin was classified as 'Endangered' in the *International Union for Conservation of Nature* (IUCN) Red List of Threatened Animals (Bearzi et al., 2003, 2008). In 2005, it was also listed in the Appendices I and II of the Convention on the Conservation of Migratory Species (Bonn Convention, CMS).

Ecosystem-based approaches explore the dynamic linkages between marine organisms and human pressure (Mace, 2001; Pauly and Christensen, 2002; Pauly et al., 2002; Smith et al., 2007; Crowder et al., 2008; Heithaus et al., 2008). In particular, ecosystem models such as the freely available software *Ecopath* with *Ecosim* (www.ecopath.org) have been suggested to be the most suitable tool to assess direct and indirect effects of fisheries on marine mammals and to evaluate possible ecological consequences

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Fig. 1. Relative distribution of the Mediterranean short-beaked common dolphin based on Bearzi et al. (2003) and Cañadas and Hammond (2008). The numbers indicate the sites where the species remains still regularly present. The area #3 indicates the study area with bathymetric contour lines.

of their decline (Plagányi and Butterworth, 2004; Morissette et al., 2010). Focusing on the Inner Ionian Sea Archipelago, we investigated (1) the direct and indirect trophic impact of common dolphin and its prey, (2) ecosystem indices to evaluate changes in structure and functioning of the marine ecosystem; (3) the temporal impacts of local fisheries on common dolphin and its prey; and (4) several fishing management scenarios to preserve the common dolphin population and to sustain important target fish stocks.

2. Methods

2.1. Study area

The Inner Ionian Sea Archipelago, situated in western Greece (area #3 in Fig. 1), covers approximately 1020 km^2 and is extremely oligotrophic (Casotti et al., 2003) with values of chlorophyll *a*, nutrients, and particulate organic carbon among the lowest in all Mediterranean coastal waters (Pitta et al., 1998). The Greek Ministry of the Environment Physical Planning and Public Works included this area in the Natura 2000 network as a 'Site of Community Importance' under the 9243 EEC 'Habitats' Directive. The network aims to ensure the long-term survival of Europe's most valuable and threatened species and habitats, as well as the sustainable use of marine resources, through the progressive implementation of an ecosystem-based approach for the management of human activities.

The fishing fleet in the study area includes 9 bottom trawlers, 12 purse seiners, 24 beach seiners, 49 longliners and 213 boats trammel netters (Bearzi et al., 2008). Periodic fishing closures are in force for purse seiners (December–February), beach seiners (April–September) and trawlers (June–September) but the issuance of multiple gear permits (i.e. beach seiners continued fishing through summer as trammel netters) allow them to skirt closures and operate year round (Gonzalvo et al., 2010).

2.2. The model

Ecopath with *Ecosim* is the most utilized ecosystem modelling approach worldwide with the number of publications detailing results of the software's use having increased in the last decade (Watson et al., 2000; Christensen et al., 2008). *Ecopath* is a mass-balance model that provides a static description of an ecosystem at a given time period (Christensen et al., 2008). It can describe all the principal autotrophic and heterotrophic species individually or by aggregating them into functional groups (species with similar trophic role) and incorporate data on biomass (t/km^2), consumption (/year), production (/year), and efficiency; furthermore, fishing activities are included by adding data on landings (t/km^2), discards (t/km^2), and by-catch (t/km^2) as well as bioeconomic parameters (e.g., ex-vessel value and cost). *Ecosim* is the tropho-dynamic simulation model that has the capability to conduct multispecies simulations to explore ecosystem structure and functioning, the impact of fishing and policy exploration (Christensen and Walters, 2004; Christensen et al., 2008). A detailed explanation on how *Ecopath* and *Ecosim* function can be found in Appendix S1.

Our *Ecopath* model consisted of 19 functional groups: three marine mammal species (common dolphin, common bottlenose dolphin *Tursiops truncatus*, and monk seal *Monachus monachus*), one sea turtle species (loggerhead turtle *Caretta caretta*), one seabird, seven fish, four invertebrate, one primary producer groups and two detritus groups and included data on biomass, production, consumption, diet and catch. This food web model was based on the previous work by Piroddi et al. (2010), which examined temporal dynamics of marine organisms from 1964 to present days using fishing pressure and changes in nutrient concentration as main drivers (Tables 1 and 2). In addition, in order to be able to compare the direct and indirect trophic impacts of common dolphin and its preys in this past ecosystem with a current one, we built a 2007 *Ecopath* model including recent reliable estimates of common