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

Chiara Piroddi a,b,*, Giovanni Bearzi b, Joan Gonzalvo b, Villy Christensen a

a Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada V6T1Z4
b Tethys Research Institute, Viale G.B. Gadio 2, 20121 Milano, Italy

ARTICLE INFO

Article history:
Received 29 November 2010
Received in revised form 22 June 2011
Accepted 5 July 2011
Available online 31 July 2011

Keywords:
Short-beaked common dolphin
Fisheries management
Food web
Ecosystem modelling
Ionian Sea
Marine biodiversity

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.

© 2011 Elsevier Ltd. All rights reserved.

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 fishery 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 over-exploitation 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.
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 km² 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/km²), consumption (/year), production (/year), and efficiency; furthermore, fishing activities are included by adding data on landings (t/km²), discards (t/km²), and by-catch (t/km²) 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
2.4. Ecosim simulations

To investigate the impact of fisheries on common dolphins and their prey (sardines and anchovies), we conducted a routine in Ecopath called ‘mixed trophic impact’ (MTI; Ulanowicz and Puccia, 1990) based on the following equation:

$$MTij = DCij - FCij \cdot I$$

(1)

where DCij is the diet composition term expressing how much j contributes to the diet of i, and FCij is a host composition term giving the proportion of the predation on j that is due to i as a predator. This procedure allows the quantification of the impacts that changes in the biomass of a group would have on the other groups of the ecosystem. In the present study, fisheries were treated as predators (Christensen et al., 2008). In particular, we compared the year 1964 (Ecopath baseline) with the year 2007.

2.5. Ecosystem indices

Ecosim uses a series of differential equations to calculate temporal biomass and catch changes for selected functional groups (Christensen and Walters, 2004; Christensen et al., 2008). It describes the interactions between predators and prey by attributing a vulnerability term for each of these interactions. This vulnerability parameter sets the maximum increase in predation mortality a given predator can cause on a given prey. Low values of vulnerability (close to 1) indicate that prey production determines the predation mortality (phenomenon also known as ‘bottom-up’ control), while high values of vulnerability (e.g., 100) indicate that predator biomass determines how much prey is consumed (top-down control); (Christensen and Walters, 2004). Here, we used Ecosim simulations to assess whether the decline in common dolphins was influenced by the increase in fishing pressure observed in the area over the last decades. With this aim, we incorporated into the model available estimates of biomass and by-catch of common dolphin as well as biomass and catches of sardine and anchovy.

Common dolphin biomass data obtained by combining mark recapture estimates (Bearzi et al., 2008) with mean body weight (Kastelein et al., 2000) were available annually from 1995 to 2007. Annual sardine and anchovy biomass and catch data were available for the years 1964–2003 (Tsikiras et al., 2007). Fishing effort and nutrient concentration time series were used to fit predicted to observed trends over time. In particular, time series of effort for all fleets, expressed as Horse Power (HP year\(^{-1}\)) was estimated using data from Kapadagakis et al. (2001) for the period 1996–2000, and from Stergiou et al. (2007b) for the period 1964–1995 and 2001–2003, while nutrient concentration was estimated by the model using a non-parametric routine (see Appendix for details). First, to fit the model to observed common dolphins, sardines and anchovies time series data, we applied the ‘fit to time series procedure’ of Ecosim, by searching for those predator–prey vulnerability values that would minimize the sum of squared deviation (SS) of observed data from model predictions. Then, we adjusted some of the default Ecosim parameters to further decrease the SS of certain functional groups. We increased the maximum relative feeding time and the feeding time adjustment rate for marine mammals considering that if prey becomes more scarce, marine mammals will spend more time looking for their food resources and they will be able to change their search feeding time as food availability varies (Christensen et al., 2008). In addition, we increased the default density-dependent catchability effect for sardines and anchovies since, being small pelagic schooling fish, their catchability may remain high even when their abundance decreases (Christensen et al., 2008). Finally, to evaluate the impact of environmental factors on sardines and anchovies we used an automated procedure in Ecosim to simulate a time series of nutrient loading within the ecosystem. The estimated changes in nutrient concentration in the water column in our case impacted directly the primary production biomass affecting therefore sardines and anchovies trends. It was not possible to compare this predicted nutrient loading trajectory with observations because of a lack of data from the study area. However, since previous studies have suggested changes in the thermohaline circulation of the Eastern Ionian Sea, we assessed whether simulated changes in nutrient concentration were affected by changes in temperature. To do so we correlated the simulated nutrient trend with sea surface temperature (°C) time series obtained from the NOAA sea surface temperature database (http://nomads.ncdc.noaa.gov), using the Spearman’s rank correlation test. The results of this analysis showed a positive correlation between the two variables with a rho = 0.36 and p-value = 0.010.

2.6. Fisheries management scenarios

After the fitting procedure, we examined different ecosystem indices to evaluate changes in structure and functioning of the Inner Ionian Sea Archipelago ecosystem (Christensen and Walters, 2004). In particular we selected: (1) the Kempton’s index of biodiversity that expresses biomass species diversity by considering those organisms with trophic levels 3.5 or higher (Kempton and Taylor, 1976; Ainsworth and Pitcher, 2006); (2) the ratio between common dolphin biomass versus total biomass; (3) the ratio between top predators biomass (those organisms with trophic levels 4 or higher) versus total biomass; (4) the ratio between total fish biomass (trophic levels between 2.8 and 3.5 or higher) versus total biomass; and (5) the ratio between total invertebrates biomass versus total biomass.

We used the outcomes of Ecosim dynamic simulations to evaluate different fishing management scenarios for the conservation of common dolphin and the restoration of sardine and anchovy stocks starting in the year 2011 up to 2030. Since periodic fishing closures already exist for purse seiners, beach seiners and trawlers, we decided to close them yearly for the entire time and evaluate the effect on the selected species. Population recovery was set relative to the first year of observed biomass data (year = 1995 for the common dolphin and year = 1964 for sardine and anchovy). Also, to take in consideration the changes in nutrients concentration in the area, estimated nutrient time series have been factored in to all four fishing closures scenarios. In the first scenario, we kept
current fishing effort constant for each fishing fleet present in the study area. In the second scenario, we hypothesized a closure of the purse seine fishery. In the third scenario, purse seiners, trawlers and beach seiners were not allowed to fish. In the fourth scenario, we closed the entire area to all fisheries (no-take zone).

3. Results

3.1. Ecosystem indices

Mixed trophic impact (MTI) analysis revealed an overall negative impact of local fisheries on the common dolphin population that increased from 1964 to 2007 (MTI index1964: −0.045; MTI index2007: −0.068; Fig. 2a). Of all fisheries, purse seiners had the greatest negative impact on common dolphins, followed by other pelagics, hake, purse seiners, and trammel netters. In 2007, common dolphin was almost absent from sardines MTI (MTI index2007: −0.0017) with purse seiners having the greatest negative impact. We observed a similar scenario for anchovy MTI with the exception that hake, and not purse seiners, had the highest impact in 2007. The reason why trophic interactions and not local fishing pressure had the most detrimental effect on anchovies was related to their low presence in the reported fisheries landings, likely due to low abundance of anchovies in recent years. The MTI analysis also revealed the importance of phytoplankton and zooplankton in the trophic dynamics of common dolphins, sardines and anchovies.

Ecosystem indices showed clear evidences of decline trough time of common dolphin, top predators, fish community but more generally of the marine biodiversity with increase in fishing effort. In contrast, total invertebrates biomass increased significantly, following a trend similar to that observed in fishing effort (Fig. 4).

3.2. Ecosim simulations and fisheries management scenarios

Our Ecosim model reproduced relatively well the relative biomass trends of sardines, anchovies and common dolphins (Fig. 3a). Model fitting allowed us to minimize sum of squares (SS) by adjusting vulnerabilities, prey-switching, prey-handling and foraging for all species (SSdefault = 1470; SSfitted best model = 699). Fishing pressure on common dolphin prey was found to explain the rapid decline of common dolphins. For sardine and anchovy biomass, fishing effort, in addition to changes in ocean productivity, were responsible for their observed decline. The overall best fit (effort plus productivity) is displayed in Fig. 3a. Predicted sardine landings and to a lesser extent anchovy landings showed higher trajectories compared to observed trends (Fig. 3b), probably due to the presence of few high observed values (for the sardine trend only one data point in 1993) in the catch time series.

Results from the different fisheries management scenarios are presented in Fig. 5. In the first scenario, with continued fishing effort as in the present days, common dolphins, sardines and anchovies are predicted to disappear from the ecosystem by 2030. Closure of the purse seine fishery (scenario 2) showed a positive effect on all the considered species although common dolphin biomass only increased slightly. The closure of the purse seine, trawl and beach seine fishery (scenario 3) predicted to restore by 2030 sardine and anchovy stocks to levels comparable to those in the 1960s. Common dolphin population recovery was more pronounced in this latter scenario. Closing all the study area to fishing activities (scenario 4) would bring common dolphins by 2030 to biomass levels similar to those observed in 2004 (approximately 50 individuals) while sardines and anchovies would keep the same trajectories as delineated in the previous scenario.

**Fig. 2.** Mixed trophic impacts for the years 1964 and 2007 showing the combined direct and indirect trophic impacts of functional groups as well as of fisheries on common dolphins, sardines and anchovies.

<table>
<thead>
<tr>
<th>Year</th>
<th>Common dolphin</th>
<th>Bottlenose dolphin</th>
<th>Monk seal</th>
<th>Sea bird</th>
<th>Tuna</th>
<th>Swordfish</th>
<th>Sardine</th>
<th>Anchovy</th>
<th>Other pelagic</th>
<th>Hake</th>
<th>Other demersal</th>
<th>Cephalopod</th>
<th>Crustacean</th>
<th>Zooplankton</th>
<th>Phytoplankton</th>
<th>Trammel netters</th>
<th>Beach seiners</th>
<th>Longliners</th>
</tr>
</thead>
</table>
4. Discussion

In recent years, as major fish stocks collapsed (Pauly et al., 2002, 2003) and human demand for seafood increased, competition between marine mammals and fisheries for same food resources has been cited as a source of concern (Plagányi and Butterworth, 2002; Kaschner and Pauly, 2005). While popular arguments point to marine mammals as a source of competition for marine fisheries in reducing valuable fish stocks (Jackson, 2007; Gerber et al., 2009), to our knowledge, our study is the first to show that overfishing is actually causing a decline in the supposed competition.

Some studies hypothesized the decline of several marine mammal species due to reduced prey availability (Demaster et al., 2001; Boyd et al., 2006; Bilgmann et al., 2008), but they failed to demonstrate it. For instance, in the western Gulf of Alaska, the Aleutian Islands, fishing pressure on Atka mackerel Pleurogrammus monopterygius has been considered a contributor for Steller sea lions Eumetopias jubatus decline (Guénette et al., 2006). Along the Black Sea coast, a mass mortality event of common dolphins showing evidence of emaciation has been associated to the concurrently rapid decline of the European anchovy Engraulis encrasicolus and European sprat Sprattus sprattus stocks, the main prey of Black Sea common dolphin (Birkun, 2002). In the Mediterranean Sea, increased overexploitation of small pelagic fish (sardines and anchovies) has been suggested to be one of the major reasons of the decline of common dolphins throughout the region (Bearzi et al., 2003, 2008; Cañadas and Hammond, 2008), but such link has been difficult to investigate. Behind the difficulty of assessing such interaction is the complexity of studying marine ecosystems and the difficulties to monitor and track changes and responses in complex systems (Trites et al., 2006). Ecosystem modelling approaches have been used increasingly to understand the trophic role of such animals and their dynamic interactions with other marine organisms, as well as fisheries (Guénette et al., 2006; Gerber et al., 2009; Morissette et al., 2010).

Here, our results showed how reduced prey availability caused by intensive fishing pressure on small pelagic stocks induced the sharp decline (from 150 to 15 animals) of the common dolphin population (Fig. 3a) (Bearzi et al., 2006, 2008). Even if by-catch in fishing gear is an important source of mortality for small cetaceans like common dolphins (Silvani et al., 1999; López et al., 2003; Tudela et al., 2005) particularly when fishing pressure increases, only few by-caught animals were observed and reported in the area across the entire 15 yr study (1993–2007) (Bearzi et al., 2008). Recent surveys conducted in the study area between 2008 and 2010 have recorded the sporadic presence of up to 40 individuals that have likely dispersed over a wider area,
moving into the Inner Ionian Sea Archipelago only for short periods of time (Dr. Giovanni Bearzi, Tethys Research Institute, unpublished data). This suggests that while lack of prey caused by overfishing resulted in a sharp decline in the numbers of dolphins regularly using the area, as well as in the dispersion of a formerly ‘resident’ community (Bearzi et al., 2005), common dolphins being still present in adjacent waters may re-colonize the study area and possibly increase in numbers if timely fisheries management action is taken.

The results from the Mixed Trophic Impact analysis also suggest that the trophic role of common dolphins has decreased through time and has been replaced by another significant impactor, i.e., fisheries. These analyses confirmed the increasing negative impact of local fisheries, particularly purse seiners, on dolphins and their prey. The purse seine fishery, which includes only nine fishing boats representing 3% of the total fishing industry, had the greatest negative impact in 2007. In essence, it replaced the trophic role of this cetacean in the dynamics of the food web, to the point that common dolphins no longer play a role in the ecosystem (Fonseca and Ganade, 2001; Duffy, 2003). Ecosystem indices have confirmed the overall degradation of the marine ecosystem from species level (e.g., common dolphin), to functional groups (top predators) and also to biodiversity level, pointing out as well the domination of low trophic level organisms not commercially exploited (e.g., invertebrates).

The biomass of sardines and anchovies showed a remarkable decline since the late 1960s. Both MTI analyses and temporal simulations (Figs. 2 and 3) suggested that these stocks collapsed due to intensive and increasing fishing effort and to changes in primary production. These trajectories are consistent with other studies for the Mediterranean region, that demonstrated how in the last decades industrial fisheries—mainly purse seiners—have considerably reduced the local pelagic fish stocks (European Commission, 2004; Stergiou et al., 2007a; Bearzi et al., 2008; Piroddi et al., 2010). Fishing pressure on small pelagic fish in the region has intensified in the last decades not only for human consumption, but also for an increase demand of sardines and anchovies as fish meal to farm higher-trophic level species (Stergiou et al., 2009).

Fig. 4. Ecosystem indices calculated from Ecosim model for the period 1964–2007. In particular, common dolphin, top predators, fish stocks and invertebrates biomasses are plotted against the total biomass of the ecosystem (TB). The total fishing effort is plotted in the secondary axis.
Environmental changes, particularly changes in primary production, played an important role in the trajectories of these pelagic species (Stergiou et al., 1997; Theocharis et al., 1999), contributing to their decline. Several Mediterranean ecosystem models have highlighted the importance of primary production in the dynamic of the pelagic food web (Coll et al., 2008b, 2009; Piroddi et al., 2010). However, when the combinations of overfishing and environmental changes occur in an oligotrophic ecosystem, such as the one studied here, the effects on the pelagic compartment are even more acute and severe. Productivity is indeed crucial for the stability and dynamics of a food web. Despite considerable fishing pressure, highly productive ecosystems such as the Alborán Sea (area #1 in Fig. 1), still have high records of species richness (Coll et al., 2010), as well as hosting an important common dolphins population (Cañadas and Hammond, 2008).

Our model was unable to replicate the trends of observed sardine and anchovy catches. On average, predicted trends were 64% and 28% higher for sardines and anchovies, respectively. Underestimation and/or misreporting of local catch data are possible culprits. Different studies have pointed out that landing data from Greece—and more broadly from the Mediterranean—are generally incomplete and unreliable (Stergiou et al., 1997, 1998; Briand, 2000) and that fishers may deliberately misreport their catches to avoid stricter regulations or higher taxation (Bearzi et al., 2006).

When evaluating the impact of four different fisheries management scenarios, different outcomes have been observed. Keeping the fishing pressure at the same level as in 2007 threatened the survival of common dolphins in the area. The high fishing pressure on sardines and anchovies prevented the recovery of common dolphins as well as of sardine and anchovy stocks. Closing the area to purse seine fishery, (3) purse seiners, trawlers and beach seiners are not allowed to fish, (4) the entire area is closed to all fisheries. The dotted line corresponds to the first year of observed data (year = 1995 for the common dolphin and year = 1964 for sardine and anchovy). The continuous line corresponds to the last year of observed data (year = 2007).

Environmental changes, particularly changes in primary production, played an important role in the trajectories of these pelagic species (Stergiou et al., 1997; Theocharis et al., 1999), contributing to their decline. Several Mediterranean ecosystem models have highlighted the importance of primary production in the dynamic of the pelagic food web (Coll et al., 2008b, 2009; Piroddi et al., 2010). However, when the combinations of overfishing and environmental changes occur in an oligotrophic ecosystem, such as the one studied here, the effects on the pelagic compartment are even more acute and severe. Productivity is indeed crucial for the stability and dynamics of a food web. Despite considerable fishing pressure, highly productive ecosystems such as the Alborán Sea (area #1 in Fig. 1), still have high records of species richness (Coll et al., 2010), as well as hosting an important common dolphins population (Cañadas and Hammond, 2008).

Our model was unable to replicate the trends of observed sardine and anchovy catches. On average, predicted trends were 64% and 28% higher for sardines and anchovies, respectively. Underestimation and/or misreporting of local catch data are possible culprits. Different studies have pointed out that landing data from Greece—and more broadly from the Mediterranean—are generally incomplete and unreliable (Stergiou et al., 1997, 1998; Briand, 2000) and that fishers may deliberately misreport their catches to avoid stricter regulations or higher taxation (Bearzi et al., 2006).

When evaluating the impact of four different fisheries management scenarios, different outcomes have been observed. Keeping the fishing pressure at the same level as in 2007 threatened the survival of common dolphins in the area. The high fishing pressure on sardines and anchovies prevented the recovery of common dolphins as well as of sardine and anchovy stocks. Closing the area to purse seine fishery, (3) purse seiners, trawlers and beach seiners are not allowed to fish, (4) the entire area is closed to all fisheries. The dotted line corresponds to the first year of observed data (year = 1995 for the common dolphin and year = 1964 for sardine and anchovy). The continuous line corresponds to the last year of observed data (year = 2007).

Still, there is one limitation in the ecosystem model used that might prevent or slow down the recovery of common dolphins. The model is not capable to capture marine mammal’s social structure. As discussed by Bearzi et al. (2005), common dolphins in the Inner Ionian Sea Archipelago have been observed to progressively distribute themselves in smaller and more dispersed groups. Generally, this occurs when prey availability is scarce (Norris and Dohl, 1980; Chapman and Chapman, 2000). Chapman and Reiss (1999)
have also pointed out how in populations with lack of food resources these social and therefore reproductive constraints become major factors controlling animal population size. This could be particularly significant in common dolphins, whose highly promiscuous mating makes living in large groups important as to ensure reproductive success (Murphy et al., 2005). For instance, the few common dolphins surviving the nearby Gulf of Corinth (area #4 in Fig. 1), are found exclusively within large groups of striped dolphins Stenella coeruleoalba, and hybridization likely occurs (Frantzi and Herzing, 2002; Bearzi et al., 2010b). Living in mixed groups may be a consequence of the impossibility of common dolphins to find enough conspecifics to form large single-species groups (Frantzi and Herzing, 2002; Bearzi et al., 2010b), such as those observed where common dolphins thrive (Stockin et al., 2008).

Overall, our findings highlight a negative impact of fisheries on the biodiversity of the Inner Ionian Sea Archipelago, causing sharp declines of common dolphins and major fish stocks and weakening the marine food web. These results are valuable considering the poor understanding of the Mediterranean Sea food web dynamics, and the acute lack of data to investigate such dynamics (Briand, 2000; Coll et al., 2010).

5. Conclusions

Despite a lack in historical data, it is increasingly recognized that the Mediterranean biodiversity—particularly on top of the food web—has severely declined in the last decades due to anthropogenic pressure, mainly unsustainable harvest (Briand, 2000; Bearzi et al., 2008; Coll et al., 2008b, 2009; Lotze et al., 2011). As a consequence of such loss and depletion of large predators, marine biodiversity has been impoverished with effects on the complexity and connectivity of food webs and robustness against further species loss (Jackson et al., 2001; Myers and Worm, 2003; Heithaus et al., 2008; Lotze et al., 2011). As shown in this study, common dolphins reflect ecosystem changes and degradation over time. Ensuring the survival of healthy populations would lead to ways of enhancing marine ecosystems and ensure sustainable fishing (Trites et al., 2006). Charismatic megafauna can also help raise public awareness of ecosystem status and stimulate education and outreach on marine environmental issues, to support ecosystem-based management goals (Wells et al., 2004; Bossart, 2006; Moore, 2008).

Acknowledgments


Appendix A. Supplementary material


References


Guénette, S., Heymans, S., Christensen, V., Trites, A., 2006. Ecosystem models show combined effects of fishing, predation, competition, and ocean productivity on Steller sea lions (Eumetopias jubatus) in Alaska. Canadian Journal of Fisheries and Aquatic Sciences 63, 2495–2517.


Jackson, J.B.C., 2007. When ecological pyramids were upside down. Whales, Whaling, and Ocean Ecosystems. 27–37.


