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Food Web Models and Data for Studying the Interactions between Marine Mammals and Fisheries

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ABSTRACT

We are developing ecosystem models to examine the trophic interactions between marine mammals and fisheries in (1) Northwest Africa, (2) the Caribbean, and (3) the tropical South Pacific. Food web models are being constructed using *Ecopath and Ecosim* (*EwE*, www.ecopath.org) to examine the potential impact of a reduction in the abundance of great whales on fishery yield. An extensive literature search is being conducted to synthesize available data about ecological parameters and trophic interactions for marine mammals, fish and invertebrates to parameterize models for our three study areas. Models will allow us to characterize the structure and function of these ecosystems in terms of biomass, mortalities, consumption rates, food habits and fisheries. Faced with sparse data for our study regions, we are explicitly accounting for uncertainty in input data, ecosystem structure, model accuracy, marine mammal feeding rates, abundance estimates, and consumption in breeding areas. In addition, we are conducting an extensive sensitivity analysis to examine the effects of model parameters and changes in model assumptions. The predictability of our models is validated with time series of biomass for important species of the system. We then use our model as a predictive framework for examining the ecosystem impacts of changes in the abundance of large whales, including changes in fishery yield.

In this paper we present preliminary results from our Northwest Africa model, which includes the Large Marine Ecosystem (LME) of the Canary Current, located on the eastern part of the Atlantic Ocean, and bounded by the coasts of Morocco, Mauritania, Senegal, Guinea-Bissau, the Canary Islands (Spain), Gambia, Cape Verde and Western Sahara. The model includes 10 marine mammal groups and 17 additional groups comprised of fish, seabirds, invertebrates, benthos, and plankton. Both local and foreign fleets are also included the model. Preliminary results indicate that: 1) The overlap between prey species consumed by marine mammal and species targeted in fisheries is low; and 2) Given a wide range of assumptions about whale abundances, diet composition and food consumption in breeding areas, we consistently found that: (a) Whale consumption is several orders of magnitude lower than total fishery catches; (b) Food intake of whales in our study area is two orders of magnitude lower than the amounts taken by other trophic groups (e.g. pelagic fishes); and (c) In preliminary simulations, reducing whale biomass does not influence the biomass of commercially important fish, nor any other species of the food web. While our results are preliminary, we expect that our modeling approach will begin to answer questions about the competition between whales and commercial fisheries in these regions, and will allow the identification of data gaps and additional research needs.

KEYWORDS: COMPETITION, *ECOPATH WITH ECOSIM*, FISHERIES, MARINE MAMMALS, PREDATION, TROPHIC IMPACTS, MARINE MAMMAL-FISHERIES INTERACTION, ECOSYSTEM MODELING

INTRODUCTION

In recent years, there has been much debate about the potential impacts of large whales on marine ecosystems (Tamura and Ohsumi, 2000; Anonymous, 2001; Struck, 2001; Mori ad Butterworth 2006; Holt, 2007; Jackson, 2007) and it has been proposed that whales are the culprits behind decreased fish stocks (e.g. Tamura and Ohsumi, 2000). According to Tamura and Ohsumi (2000), the total annual prey consumption by cetaceans in the world is estimated to be 249-436 million tons, representing three to six times the amount taken in marine fisheries. The implication of this estimate is that this biomass represents a surplus resource that would be directly available for human consumption if cetacean numbers were to be reduced. The rationale for such arguments is questionable in light of documented overfishing occurring on a global scale (Jackson *et al.*, 2001; Pauly *et al.*, 2002; Baum *et al.*, 2003; Myers and Worm 2003), the lack of scientific evidence for existing large-scale competition between marine mammals and fisheries (Kaschner, 2004; Morissette, 2007, *Alder et al.*, in press), and the unpredictable consequences of culling (Paine *et al.*, 1998; Scheffer *et al.*, 2001). Nonetheless, the "whales eat fish" issue has become a significant point of contention at recent International Whaling Commission (IWC) meetings.

Little is known about the ecological consequences of the removal of whales in terms of their past roles as consumers in food chains and as prey and carrion (Katona and Whitehead, 1988; Springer *et al.*, 2003). Evidence suggests that ocean ecosystems throughout the world have experienced a dramatic shift in ecosystem structure as a result of the removal of large whales as well as extensive fishing activities (see Estes *et al.*, 2007). To understand the impact of whales on commercial fisheries, it is necessary to analyze the situation in the context of ecosystems as there are a large number of indirect and direct interactions through which these two groups might influence each other (Bax, 1998; IWC, 2004; Morissette *et al.*, 2006). When complex trophic interactions are taken into consideration, culling of marine mammals does not always benefit the fish stocks (Punt and Butterworth, 1995; Plagányi and Butterworth, 2002; Morissette *in prep*.). By feeding on other species that could be competing with fisheries, marine mammals and other high-level predators may actually increase fisheries yield (Punt and Butterworth, 1995; Walters and Kitchell, 2001). Only by considering all possible direct and indirect trophic linkages can the effect of the partial or complete removal of large whales on current fisheries yields be reliably assessed.

Here, we examine the scientific evidence for the assertion that commercial fisheries are negatively impacted by whales in tropical waters. Our approach is to develop food web models using *Ecopath* and *Ecosim* (*EWE*, www.ecopath.org), which allows us to characterize the structure and function of these ecosystems in terms of biomass, mortalities, consumption rates, food habits, general ecosystem indicators and fisheries. Our analyses focus on three regions where the "whales eat fish" assertion has become a political and management issue. Our study includes three areas: (1) northwest Africa, (2) the Caribbean and (3) the tropical South Pacific. In this paper we present preliminary results from the northwest African model. While competition between marine mammals and fisheries might occur in areas that represent important marine mammal feeding grounds (NAMMCO, 1997; Tamura *et al.*, 1998; Folkow *et al.*, 2000; Sigurjónsson *et al.*, 2000; Kaschner, 2004), our focal areas are primarily breeding sites for baleen whales thus we do not expect that the great whales have the potential to significantly impact fisheries (Lockyer 1981). Nonetheless, to incorporate the possibility for unusual feeding events, we consider a range of scenarios for whale biomass, feeding rates as well as the trophic levels that are targeted by whales. While there is great uncertainty in many model parameters for our focal areas, we propose that models could be developed and refined as data become available (Walters *et al.*, 1997; Currie, 2007; Hammill and Stenson, 2007) rather than engaging in discussions about the interactions between whales and fish in the absence of data. Furthermore, models may be used to consider the range of plausible outcomes emerging from various assumptions about uncertainty in parameters. In this way our models provide useful starting points for understanding the interaction between whales and fisheries in tropical waters. In collaboration with Pew-Lenfest Ocean Program, we recently convened a regional workshop have been held in Northwest Africa to access local data resources and expertise and to gain feedback from scientists and other local stakeholders that will allow us to improve our models (Appendix 1). Similar workshops are planned for the other focal areas during summer and fall 2008. Here we describe our modelling approach and preliminary results for Northwest Africa.

MATERIAL AND METHODS

Our study area was selected because the "whales eat fish" conflict has become a management controversy in this region (Busby, 2004, Fig. 1). For instance, a recent symposium in northwest Africa concluded that:

> *"We, participants of African countries and members of the IWC, gathered in Rabat on 11 and 12 February 2008 for the symposium on the sustainable utilization of living marine resources in the African region...Considering the natural competition existing between the whale species and the inhabitants of developing countries in the use of living marine resources, notably the stocks of small pelagic species...invite the contracting parties to pay particular attention to scientific research and to give priority to objective decisions based on science"* (Symposium on the

Sustainable Utilization of Living Marine Resources of the African Region, Rabat, 11-12 February, 2008).

While it may seem intuitive that whales do not impact fisheries in tropical breeding areas, the 'whales eat fish issue' has become very relevant in the policy management context in these areas, including Northwest Africa.

Study area and cetacean species

Our study area is located off the coast of Africa, bounded by Morocco, Mauritania, Senegal, Guinea-Bissau, the Canary Islands (Spain), Gambia, Cape Verde and Western Sahara (Fig. 1). This area is defined by the United States National Oceanic and Atmospheric Administration (NOAA) as the Canary Current large marine ecosystem (LME), and is included in the Food and Agriculture Organization's (FAO's) Eastern Central Atlantic (Major Fishing Area 34), mainly covering subdivision 34.1 (Northern coastal), and part of subdivision 34.2 (Northern oceanic). The specific area of this model covers latitudes from 8.5 N to 35.97 N, and longitudes from 30W to 6.5W, for a total area of 3,561,028.537km^2 (Fig. 1). Our study area includes the continental shelf as well as the deeper offshore waters.

The northwest coast of Africa is characterised by the presence of the Canary Current, which flows along the African coast from north to south between 30°N and 10°N and offshore to 20°W (Fedoseev, 1970). As a consequence, one major characteristic of this ecosystem is that it represents a major upwelling zone and is also supported by other seasonal nutrient enrichments. Climate is the primary force driving the dynamics of this ecosystem, with intensive fishing as the secondary driving force (Bas, 1993).

The geographical and oceanographic characteristics of our study area represent unique environmental conditions, supporting significant biodiversity of both resident and migratory cetacean species (Brown and Lockyer 1984; Klinowska, 1991; Northridge, 1991; Jefferson *et al.,* 1993; Perry *et al.,* 1999; Perrin *et al.,* 2002). Baleen whales that occur in terms of significant biomass include sei (*Balaenoptera borealis*), Bryde's (*B. brydei*), humpback (*Megaptera novaeangliae*), minke *(Balaenoptera acutorostrata)* and fin (*B. physalus*) whales. Other baleen whales such as blue whales (*B. musculus*) are known to be present, but are likely to be less abundant (Kaschner, 2004). In terms of biomass, sperm whales (*Physeter macrocephalus*) are probably the most important toothed whale species. Other odontocete species include killer whales (*Orcinus orca*) and beaked whales (such as *Mesoplodon densirostris*, *M. europaeus*, and *Ziphius caviostris,*). Finally, there are also communities of small delphinids (Table 1).

Northwest African waters represent a tropical breeding environment for most baleen whales (Brodie, 1975; Sergeant, 1977; Brown & Lockyer, 1984; Corkeron & Connor, 1999; Perry *et al.*, 1999, Clapham, 2002; Jann *et al.*, 2003). Indeed, except for the Bryde's whale which is known to occur in these areas year round, minke, blue, fin, sei and humpback whales spend their feeding season in the subpolar and polar waters of the Northern or Southern Hemisphere. It should also be noted that for species such as minke, fin and possibly sei whales the low latitudes of our focal area likely represent the extreme limits of their equator-bound breeding migrations. In general, most baleen whales only spend about a third of the year in their breeding grounds, where they are known to either fast or eat at a considerably reduce rate (Chittleborough, 1965; Sergeant, 1977; Best, 1982; Brown and Lockyer, 1984; Horwood, 1990, Kenney *et al.*, 1995; Perry *et al.*, 1999; Clapham, 2002; Perrin, 2002; Mohammed, 2003) (Lockyer, 1981). Consequently, average amounts consumed in breeding areas have been estimated to amount to about 10% or less of that in the feeding ground (Lockyer, 1981). Sperm whales are also known to be migratory; adult males in particular undertake vast journeys to their summer feeding grounds in polar waters of both hemispheres. However, unlike the baleen whales, this toothed whale is not known to alter its feeding behaviour in tropical waters (Whitehead, 2002). Although some of the other toothed whale species might undertake small migrations or seasonal inshore-offshore movements, these are not known to be associated with changes in feeding patterns.

Whaling is known to occur in Northwest African waters (Reeves, 2002), but to our knowledge no official data on current actual harvests are available. The only record available documents aboriginal subsistence whaling in Equatorial Guinea, where Indigenous Africans principally target Humpback whales (and mainly calves). No estimate is available on the annual take, but Aguilar (1985) guessed that it was approximately three humpback whales annually. These whales are assumed to be part of a Southern Hemisphere population of humpback whales (Reeves, 2002).

In terms of fisheries, the area off the coast of Northwest Africa is generally thought to be overexploited for most coastal demersal species (Samb and Mendy, 2004). As a result, fishing effort has shifted to small pelagics, such as sardinellas. Despite the fact that acoustic surveys show a relatively stable abundance for this species, Samb and Mendy (2004) suggest that this shift in target species needs further investigation because sardinellas have an important role in maintaining the structure of the food web. The Northwest African ecosystem supports both local and foreign fleets, representing an average of 2 million tons of fish caught annually in the system (Sea Around Us, 2008). From 1987 to 2004, local fleets generally caught the majority of this biomass, but the proportion of local *vs.* foreign catches varied from a minimum of 53.1% taken by local fleets in 1990 to a maximum of 81.7% taken in 1994. Demersal fisheries have increased substantially over the last few decades (Gascuel *et al.,* 2007), but few studies describe catches and fishing effort (Gascuel *et al.,* 2007).

Ecosystem models

Ecopath is a widely used software program that provides a dynamic capability for exploring past and future impacts of fishing and environmental disturbances as well as for exploring optimal fishing policies. While there are a number of modeling approaches available (Morissette, 2007; Plagányi, 2007), we use *Ecopath* for our study given the good representation of predator-prey interactions and the inclusion of different routines to take account of the estimation uncertainty associated with model inputs (Plagányi and Butterworth, 2004). The model's simplicity and its ability to accurately identify ecological relationships is also appropriate for our questions relating to the interaction between whales and fisheries.

Using this model, each trophic group in the model is represented by one balanced equation and requires six input parameters: biomass (B_i), production to biomass ratio (P_i/B_i), consumption to biomass ratio (Q_i/B_i), ecotrophic efficiency (EE_i), diet composition (ΣDC_{ij}) and catch by the fisheries. Algorithms included in the model also allow for the estimation of one missing parameter in each group (B_i, Q_i/B_i, P_i/B_i, or EE_i; Christensen and Pauly 1992). Ecopath models are based on mass balance principles, assuming that production of a given prey group (*i*) is equal to the biomass lost to fishing or export, predation, and natural mortality other than predation (other mortality). This mass balance can be expressed as:

$$\text{Consumption} = \text{production} + \text{respiration} + \text{unassimilated food} \tag{1}$$

and

$$\text{Production} = \text{predation} + \text{fishing mortality} + \text{other mortality} \tag{2}$$

where consumption is composed of consumption within the system and consumption of imports (i.e., consumption "outside the system"), and production may be consumed by predators, be exported from the system or contribute to the detritus (Jarre-Teichmann, 1998). The terms of these equations may be replaced by:

$$\text{Production by i} = B_i * P_i/B_i, \tag{3}$$

$$\text{Predatory losses of i} = \sum_j (B_j * Q_i / B_i * DC_{ij}), \text{ and} \tag{4}$$

$$\text{Other losses of i} = (1\text{-}EE_i) * B_i * P_i/B_i \tag{5}$$

For any species or group of species of the system, this leads to the linear equation:

$$B_i * P_i/B_i * EE_i – (\Sigma B_j * Q_j/B_j * DC_{ij}) - Ex_i = 0 \tag{6}$$

where *i* indicates a component (stock, species, group of species) of the model, *j* indicates any of the predators of *i*, B_i indicates the biomass of *i*, P_i/B_i indicates the production/biomass ratio, which is equivalent to total mortality (Z) under the most circumstances (Allen, 1971), Q_i/B_i indicates the food consumption per unit biomass of *i*, DC_{ij} indicates the contribution of *i* to the diet of *j* (in terms of mass), EE_i indicates the ecotrophic efficiency of i, or the fraction of production that is consumed or caught within the system, and Ex_i indicates the export of *i* from the system (by emigration or fisheries catch).

In most cases, when all the information to run an *Ecopath* model is assembled, the model does not balance due to the inconsistencies in model parameters. In this case, the values of one or more of the terms can be changed iteratively until a balance is obtained. Indeed, there is more than one way to construct an *Ecopath* model and there is no unique solution to any model. However, if uncertainty associated with specific input parameters is low, then the number of plausible solutions is reduced. For the less certain parameters, sensitivity analyses can be used to examine impacts on model results.

The original food web model for our Northwest African model was previously developed by Samb and Mendy (2004) but adapted and averaged from six other published models for coastal ecosystems of Northwest Africa: Cape Verde (Stobberup *et al.* 2004), Gambia (Mendy 2004), Guinea (Diallo *et al.* 2004), Guinea-Bissau (Amorim *et al.* 2004), Mauritania (Sidi and Guénette 2004), and Morocco (Stanford *et al.* 2001). To examine the impact of whales on our three focal ecosystems, we modified their structure so that we could more readily compare changes between the three areas and incorporate additional details where necessary. Given the focus of our study, cetacean groups were included in these ecosystem models at a higher taxonomic resolution by expanding their trophic representation to ten trophic groups. Species relevant to IWC discussions or with a distinctly different diet than other species were assigned to a unique trophic group (e.g., all great whales including minke, fin, humpback, sei, Bryde's, blue and sperm whales but also killer whales), and other species were included as aggregated groups (i.e. o beaked whales or dolphins). We aggregated non-marine mammal trophic groups specified in earlier models into fewer distinct functional groups, following the criteria developed by Essington (2006). These groups were defined on the basis of similarities of food habits, habitats, and biological variables.

Input data

Consumption estimates

We used a basic food consumption model based on Trites *et al.* (1997). This model was used to generate the biomasses and consumption (Q/B) ratios needed for each *Ecopath* group. Annual food consumption was calculated as:

$$Q_i = 365 * \sum_s N_{i,s} R_{i,s} \qquad (7)$$

where the annual average food consumption Q of species i was assumed to be 365 times the daily food consumption. Daily food consumption is calculated based on the number of individuals N of the sex s of a species i, and a weight-specific daily ration R consumed by an individual with a species- and sex-specific mean body mass. Uncertainty on the annual food consumption parameter was addressed by increasing or decreasing the biomass to 10, 50, 500 and 1000 % of its initial to determine the impact on the outcomes of our analysis.

Abundance and biomass estimates

Reliable abundance estimates are lacking for almost all cetacean species in our three study areas. Estimates of local abundance were therefore based on the proportion of the global estimated abundance of each species that fell within the study area weighted by the relative suitability of the habitat in each of the study areas for each species. Species-specific global abundance estimates were compiled from the literature and are summarized in Appendix B of Kaschner (2004). Suitability of habitat for each species was predicted using a relative environmental suitability (RES) model (Kaschner *et al.*, 2006). Density estimates derived this way were ground-truthed using survey data from surveys conducted in the vicinity of our study areas or in similar types of habitat to the extent possible (Table 2). To facilitate comparison, observed abundance estimates were converted into density estimates by digitizing the survey area and calculating the area using GIS tools. We only included surveys that were conducted in similar habitats as Northwest African waters (i.e. the subtropical or tropical waters of known baleen whale breeding areas). Sex ratios as well as mean species and sex-specific body mass were obtained from Trites and Pauly (1998).

Feeding rate models

The annual food consumption calculated above also depends on the feeding rate of each species, representing an index of daily ration expressed as percent of body weight (Sergeant, 1969). This parameter is not only fundamental to describing animal energetics, but is also important for studies of energy flow through the food web in the ecosystem (Ohizumi and Miyazaki, 1998). For all cetaceans (except baleen whales), we used the empirical model developed by Innes *et al.* (1987) to estimate food consumption. This model was later modified by Trites *et al.* (1997) to account for the difference between consumption for growth and for maintenance and then applied to all marine mammal species. Food intake of specific species per day was calculated as follows:

$$R_{i,s} = 0.1 * W_{\mathrm{i,s}}^{0.8} \tag{8}$$

where R is the daily food intake of an individual of sex *s* belonging to species *i* and *W* is the mean body weight of that individual, in kilograms.

For all baleen whales, daily food intake was estimated based on a model by Armstrong and Siegfried (1991) for food consumption of minke whales in the Antarctic. These authors suggested a modification to the empirical model of Innes *et al.* (1986) equation for baleen whales to account for larger body sizes and seasonal variation in food intake. This approach was later used to estimate food consumption of whales around Iceland (Sigurjónsson and Víkingsson, 1997) and represents one of the methods used by Tamura (2003) to estimate global food intake of cetaceans. This feeding rate is calculated as:

$$R_{i,s} = 0.42 * W_{i,s}^{0.67} \tag{9}$$

Annual food consumption for each marine mammal species was then divided by the biomass estimates in order to estimate consumption to biomass (Q/B) ratios used in the *Ecopath* model. To account for the fact that most feeding activity occurs outside the system, we set a high diet proportion as ‘import’ in the *Ecopath* diet consumption matrix (Christensen *et al.,* 2005). Lockyer (1981) showed that most baleen whales feed considerably less in their breeding grounds than they would in feeding areas. She proposed that the average amounts consumed off breeding areas probably amount to about 10% or less of that in the feeding ground. The 10% estimate is thought represent the maximum for baleen whales consumption in breeding areas (e.g. Brown & Lockyer, 1984; Horwood, 1990). Following Mohammed (2003), we thus assumed that 10% of the annual food intake was consumed for of all baleen whales, except for Bryde’s whale. Because Bryde’s whales are known to remain in subtropical and tropical waters all year round, we did not reduce their annual food consumption estimates (i.e., we assumed they take 100 % of the total annual food intake in our study area).

Diet compositions for marine mammal groups

We found very few quantitative descriptions of diet for cetaceans in general, especially in tropical areas such as Northwest Africa where these whales are generally breeding (vs. feeding). For minke whales, since no diet study has been conducted in Northwest African countries, we used a set of six papers published in the literature about the diet of minke whales in the North Atlantic (Lydersen *et al.* 1991; Nørdoy and Blix, 1992; Haug *et al.* 1995; Haug *et al.* 1996; Olsen and Holst 2001 [two different areas]; Sivertsen 2006; Smout and Lindstrom 2007). The average diet was used as an input in our *Ecopath* model, while minimum and maximum values were used as ranges for calibration.

For fin whales, we used the study by Sigurjónsson and Víkingsson (1997) on the feeding of fin whales in Icelandic waters. Fin whales were mostly feeding on zooplankton, but fish remains were also found in their stomach. Diet information humpback whales were based on Mitchel (1973). However, since this study only listed proportions of “krill” and “fish” as prey in the diet, we used a more recent study by Witteveen *et al.* (2006) to distribute “fish” prey into more precise categories. Consequently, the diet of humpback whales used in the Northwest Africa model was mainly composed of zooplankton, coastal pelagic, and coastal demersal fish. Information on the diet of Bryde’s whales and sei whales come from the same study by Best (2001). Their diet composition is mainly made up of zooplankton, but also includes fish species, mainly coastal pelagics.

For sperm whales, most publications on diet indicate that they feed primarily on cephalopods (Kawakami 1980; Clarke *et al.* 1993; González *et al.* 1994; Roberts 2003). However, a study by Best (1999) also includes fish prey in the diet. In any case, no information was available specifically for the Northwest Africa region, and we thus used an average diet based on all information available in North Atlantic waters. The average diet was used as an input in our *Ecopath* model, while minimum and maximum values were used as ranges for calibration. Diet composition of killer whales was based on a model by Sidi and Guénette (2004) for Mauritania (after a study by Paul *et al.* 1998), who estimated that killer whales mainly feed on dolphins, coastal demersals, and cephalopods.

Information on the diet of beaked whales species were available for all three species included in our model. The diet was calculated as a weighted average of these three diets, based on our estimates that Cuvier's, Blainville's, and Gervais' beaked whales consume 66, 24 and 10 percent, respectively, of the food consumed by all beaked whales in our study area (Kaschner 2004, Kaschner et al, 2006). The resulting diet composition is mainly comprised of cephalopods and bathydemersal predators. Here again, the average diet was used as an input in our *Ecopath* model, while minimum and maximum values were used as ranges for calibration. Finally, diet information about dolphins was taken directly from the initial model by Samb and Mendy (2004). The diet was based on Northridge (1984) and mainly composed of coastal fish as well as zooplankton.

Catch data time series

Fisheries catch data for all three study areas were obtained from the *Sea Around Us database* (*Sea Around Us*, 2008). Time series of annual total catches taken between 1987 and 2004 were specified by the respective countries fishing in the area and by the taxa that were taken. We categorized taxa into different functional groups using available information about life history, ecology and habitat preferences of the taxa. Catches were then divided into local and foreign fisheries. Local fisheries were defined as all countries bordering on our study area, disregardful of whether or not catches were taken within each countries own EEZ waters or in adjacent waters. All other fishing countries were defined as foreign fleets.

Uncertainty

Pedigree of our input data

The pedigree of a model represents a summary of the coded statements quantifying the uncertainty related to each input value in *Ecopath* models. For each input parameter, a choice can be made to describe the kind of data used, and the confidence we have in these data. The routine uses percent ranges of uncertainty based on a set of qualitative choices relative to the origin of biomass, *P/B*, *Q/B*, catch and diet input or model estimates (model estimates have a high range of uncertainty). When these choices are made for each single input values, an overall pedigree of the model is calculated as the average of the individual pedigree values (Pauly *et al.,* 2000). This overall pedigree is may be used as a basis for comparison with other models (Christensen and Walters, 2004), allowing comparison to models with a different degrees of trophic compartmentalization. The overall pedigree for each model is then calculated as:

$$\tau = \sum_{i=1}^{n} \frac{\tau_{i,p}}{n} \tag{10}$$

Addressing uncertainty

Using models to illustrate the dynamics of marine mammals in an ecosystem context represents a great challenge, due to the large amount of uncertainty in estimating parameters (Taylor *et al.* 2000). Moreover, modeling ecosystems introduces uncertainties regarding model structure (Plagányi and Butterworth 2004, Morissette 2005, 2007; Plagányi 2007). Indeed, when using models, it is difficult to distinguish between errors which are related with the model structure and those which are due to the improper choice of parameter values (Schartau *et al.* 2001). Sources of uncertainty are virtually infinite in ecosystem modelling. The degree of predictability of ecosystem models is itself uncertain (Hilborn 1987). Another source of uncertainty can be called "predictable uncertainty" (Silvert 2004), which arises from the known stochastic nature of the environment (e.g., climate fluctuation that follows a historical pattern). A more fundamental source of uncertainty (and one much more difficult to take into account) is called "structural uncertainty" (Silvert 2004). Our lack of knowledge on marine ecosystems and fisheries is a good example of that (Gomes 1993).

In ecosystem modelling, there are different approaches to reach a balanced scenario. As a result, it is very important to examine how sensitive model results (or outputs) are to changes in the way it was constructed and balanced. Our models include such sensitivity analyses to test if the results are robust or if they are sensitive to changes in the way the models are constructed, or changes in the value of input parameters, in a way that a trivial change could radically affect the results.

We tested different scenarios to explore the impacts of changing assumptions on the feeding rates, biomass, and diet of the marine mammal groups in our model. For feeding rates estimates, along with the 10% used in our "best" model (based on Lockyer, 1981), we also examined the impact of increasingly high feeding rates (up to 50%) for baleen whales in breeding areas. Similarly, we tested different scenarios by increasing the initial whale biomass (assuming abundance estimates could be wrong) as described above. We also considered a lower biomass for fish and invertebrates, using only 10% of the initial biomass for these groups, expecting the impact from marine mammals would be more important on small biomasses of fish. Finally, we also explored the possibility that whale feed on different prey types in breeding areas that they do in feeding areas (where most of the diet information is available). This allowed us to examine the potential impacts of changes in model assumptions on model results.

One useful approach to validate ecosystem models is to fit the model's dynamic behaviour to independent time series of catch or biomass data (Christensen et al., 2004). We employed this approach for our study, using available time series that we collated from the literature and from the *Sea Around Us* database. Our model can be refined based as additional time series data become available. Using models that can reproduce observed historical response to disturbances such as fishing allowed us to gain confidence when analyzing the possible impact of removing marine mammals in these ecosystems.

As an additional test of the model's performance, we used the Monte Carlo tool in *Ecosim* to vary *Ecopath*'s biomass parameters for whales and fish groups. For this sensitivity analysis, groups were allowed to vary +/- 20% from their *Ecopath* biomass values, and the Monte Carlo was drawn from a uniform distribution. This routine allowed us to test the sensitivity of initial biomass parameters and generate error estimates for predictions.

Analyses and Simulations

Comparison of diets and total intakes

Diet composition of marine mammal species and fisheries catches were standardized to express diets and catches as proportions of each of the 27 trophic groups in our *Ecopath* model. Diet and catch composition were then compared between marine mammals and fisheries. Similarly, the *Ecopath* allowed us to calculate the total consumption by marine mammals as an annual rate, which could then be compared to the total catch from fisheries.

Overlap estimates

Using the diet compositions and total consumptions from *Ecopath*, we then calculated the extent of overlap in terms of resource use between different marine mammal functional groups and fisheries. The assessment of overlap between marine mammal food consumption and fisheries catches was performed using a modified version of an ecological niche overlap index (Morissette 2007, after Kaschner 2004), derived from or related to the 'competition coefficients' of the Lotka-Volterra equations by Morisita (1959) and Horn (1966). This index originally only considered the qualitative overlap of resource utilization of two players exploiting the same resources (i.e., the similarity of marine mammal diet and fisheries catch composition), but ignored the quantity of resources consumed. We therefore modified this index by introducing a weighting factor to provide a measure of the relative importance of each area for either fisheries or marine mammals based on overall quantity of catch or food taken by either consumer in this cell, leading to:

$$\alpha_{j,l} = \left(\frac{2\sum_{k} p_{l,k} p_{j,k}}{\sum_{k} p_{l,k}^{2} + p_{j,k}^{2}} \right) * \left(pQ_l * pC_j \right) \tag{11}$$

where *aj,l* describes the quantitative overlap between a fishery *j* and a marine mammal group *l* in each ecosystem, and the first term expresses the qualitative similarity in diet/catch composition between the marine mammal group *l* and fisheries *j* sharing the prey *k* as the ratio of 'niche proximity' to 'niche breadth' (MacArthur and Levins, 1967), with *pl,k* and *pj,k* representing the proportions of each prey in the diet or catch. This term is multiplied by the product of the proportion of total food consumption by mammal group *Q* and the total fisheries' catches *C* taken within the ecosystem.

Ecosystem indices

The mixed trophic impact (*MTI*) routine of the *Ecopath* program allows assessment of the direct and indirect interactions between species in the ecosystem. This routine synthesizes the effects that a small change in the biomass of a group will have on the biomass of other groups in a system (Ulanowicz and Puccia, 1990). The approach is derived from Leontief economic input-output analysis, and quantifies all the direct and indirect trophic impacts of all groups in the system based on the assumption that the direct impact between group *i* and group *j* can be estimated from the difference between the proportion that group *i* contributes to the diet of group *j*, and the proportion that group *i* takes from the production of group *j* (Christensen, 1995). The MTI for living groups is calculated by constructing a matrix, where the *i,j*th element representing the interaction between the impacting group *i* and the impacted group *j* is:

$$MTI_{ij} = DC_{ij} - FC_{j,i} \tag{12}$$

where DC_{ij} is the diet composition term expressing how much *j* contributes to the diet of *i*, and $FC_{j,i}$ is a host composition term giving the proportion of the predation on *j* that is due to *i* as a predator. When calculating the host compositions, the fishing fleets are included as "predators".

The TL is based on Lindeman's (1942) concept of trophic levels, but can be fractional (e.g., 1.3, 2.7, etc.) as suggested by Odum and Heald (1975). A routine assigns definitional trophic levels (TL) of one to producers and detritus. For the remaining species of the ecosystem, TL is calculated as:

$$TL = 1 + \left(\sum_i p_j * TL_j \right) \tag{13}$$

where p_j is the proportion (in weight) of each prey group in the diet of its predator. TL_j is the trophic level of each prey group *j*.

The mean trophic level of marine mammals' consumption (TL_Q) and of fisheries catch (TL_C) were derived from *Ecopath* outputs. The TL_C is a dimensionless index computed by *Ecopath* to measure ecosystem health (Christensen *et al.* 2005), and is an indicator of the ecosystem health and the state of the fisheries (Pauly and Watson 2005). The mean trophic level of the catch is calculated from:

$$TL_C = \sum_i \left(TL_i \left(\frac{Y_i}{\sum Y} \right) \right) \tag{14}$$

where Y_i is the total landings of species *i* (in tons), ΣY is the sum of landings for all species, and TL_i is the trophic level for species *i*.

Similarly, Morissette (2007) developed an approach to calculate the trophic level of consumption (TL_Q) by marine mammals using an equation derived from the TL_C, and modified to represent the consumption by marine mammals and make it comparable with the fisheries catch:

$$TL_Q = \sum_i \left(TL_i * \left(\frac{\sum_{j=1}^{n} Q_{ij}}{\sum_{j=1}^{n} Q_j} \right) \right) \tag{15}$$

where Q_{ij} is the consumption of prey *i* (in tons) by marine mammal *j*, Q_j is the total consumption of all species by marine mammal *j*, and TL_i is the trophic level for species *i*. Eq. 15 represents the average trophic level on which marine mammals feed, i.e., the average TL of each species, multiplied by their proportion in the consumption matrix (tonnes per km^{-2} per year that marine mammals consume).

Dynamic simulations

Ecosim is a dynamic simulation tool embedded in the *EwE* software which enables efficient modelling of the biomass changes at the ecosystem level. The model behaviour is based on a 'foraging arena' theory (Walters and Martell, 2004), which assumes that predator and prey behaviours cause partitioning of prey populations, which are either available or unavailable to predators. There is continuous change between these two stages for any given potential prey, whether it is hiding from predation in some refuge, or it is out to feed. This availability of prey to predators is called 'vulnerability' in *Ecosim*. Mackinson *et al.* (2003) demonstrated the importance of setting the vulnerabilities to fit model predictions to time-series data, as *Ecosim* predictions are very sensitive to this parameter. Using default values for *v* has strong implications for assumptions about species abundance relative to their carrying capacity (Morissette, 2007).

Instead of using default vulnerability settings across the predation matrix, *v*'s were adjusted to fit to time series of biomass for each species or trophic group for which it was available in the three ecosystems. Vulnerabilities were adjusted based on the specific ecology of each species or trophic groups (if their behaviour, niche, or diet make them more or less vulnerable to predators).

A hunting pattern which generated a dramatic increase in cetacean mortality was employed in order to drive their populations close to extinction. Vasconcellos *et al.* (1997) showed that for fish species, a 5-fold increase in anthropogenic predation leads to serious depletion in a group. Also, such an extreme scenario is routinely applied to many fish populations and often associated with stock collapse (Patterson, 1992). For marine mammals, Morissette (2007) proposed that the same kind of increase in anthropogenic mortality is needed to simulate a crash in marine mammal biomass. Thus, we employed a similar approach for our analysis. A 19 years simulation was performed (from 1986 to 2004), and the biomass trends before and after the removal of whales were compared.

PRELIMINARY RESULTS

Data quality and overall pedigree of the model

The pedigree of our model is 0.615 which is above average of *Ecopath* models published between 1990 and 2006 (*n* = 200 models, pedigree ranging from 0.151 to 0.676; Morissette, 2007). Moreover, this is one of only a few models that include detailed information about cetaceans (see Martell *et al.* 2002; Guénette *et al.* 2006; Aydin and Mueter 2007).

For the Northwest African model, the sensitivity analysis tool of *Ecopath* was conduced on biomass, production, consumption and ecotrophic efficiency (EE) inputs and it suggests that the sensitivity of these estimated parameters to a change in input values is relatively low. Indeed, a 50% change in any of the input parameters of any trophic group generate an overall response of ± 35% in the estimated parameters of other groups. The most impacted parameter seems to be the EE, which is particularly sensitive to a change in the production inputs.

Our results are preliminary because we hope to obtain additional time series data for Northwest Africa to strengthen the fit of our model. As data become available, we will further examine the sensitivity of our conclusions to different parameters and assumptions. Nonetheless, our preliminary results are robust to a wide range of assumptions about model structure and parameters, thus we do not anticipate that our final results will dramatically diverge from what is reported here.

Ecosystem indices

The primary production required (PPR) to sustain the consumption of any marine mammal species is lower than PPR to sustain the fisheries for all scenarios (Table 3). Globally, PPR for fisheries is two orders of magnitude higher than PPR for most baleen whales species (Table 3; see also Pauly and

Christensen, 1995). In terms of percentage of the PPR, dolphins, sperm whales and killer whales have the highest marine mammal PPR, but this is still 60% lower than the PPR for fisheries (10% versus 32%). Fin and humpback whales have the lowest PPR (they require less than 1% of the total primary production of the system).

In the Northwest African ecosystem, baleen whales feed on lower trophic level species (on average 2.4 compared to 2.8 for fisheries; Table 3). TL_Q has higher values than TL_C for beaked whales and sperm whales, which feed mainly (more than 90% of their diet) on cephalopods (TL = 3.12). The largest discrepancy between TL_Q and TL_C is observed between fisheries and baleen whales and fin whales, where the TL_C is about 40% larger than the TL_Q (2.8 versus 2.0).

Marine mammal consumption is diverse and represents a great array of marine organisms, while the catches are much more concentrated on clupeids, which represents more than 50% of the catch composition for either local or foreign fleets (*Fig.* 2). While marine mammals can consume different prey groups, more than 75% of the catches from local fleets in Northwest Africa are composed of four prey groups: clupeids, other coastal pelagics, coastal demersals, and cephalopods. Foreign fleets are even less diversified, spending more than 75% of their catch on only two groups: clupeids and other coastal pelagics.

When comparing the total amounts of each prey groups taken by either cetaceans or fisheries (Fig. 3), we see that except for mesopelagics, cephalopods and zooplankton, the fisheries catches are always substantially larger than what is eaten by cetaceans. Commercially important species such as coastal demersals, clupeids, other coastal pelagics, and coastal tunas are much more taken (by an order of magnitude) by fisheries than by cetaceans' consumption. The highest discrepancy between marine mammals consumption and fisheries catch was estimated for large pelagics, where the fisheries (0.0127 $t*km^{-2}$) catch 50 times more than cetaceans consume (0.0003 $t*km^{-2}$). Finally, some prey groups, such as sharks, rays, and coastal tunas are exclusively targeted by fisheries (but not consumed by marine mammals).

Mixed trophic impacts (MTI) show the overall impacts of marine mammals or fisheries on other groups of the foodweb, due to direct and indirect interactions. The MTI of marine mammals and fishery in the model of Northwest Africa model show that both marine mammals and fishery have an overall negative impact on all other species of the ecosystem (MM = -0.04; local fleets = -1.17; foreign fleets = -0.89). The MTI of baleen whales is three orders of magnitudes smaller than the MTI from fisheries for any species (Fig. 4C), and has an overall positive effect on most fish species of the ecosystem (due to the fact that toothed whales feed on top predators and thus release predation on other fish species). The groups that are mostly impacted by marine mammal consumption (all species included) are cephalopods and mesopelagic predators (Fig. 4B). When only baleen whales are considered (Fig. 4C), the most impacted species are mesopelagic predators, coastal demersals, and other coastal pelagics. In contrast to fisheries where this effect is negligible (Fig. 4A), we see some cases of beneficial predation by marine mammals on species such as large pelagics, bathydemersal predators, sharks, rays, coastal tunas, coastal demrsals, and clupeids. The same phenomenon is observed for the MTI of baleen whales on large pelagics, bathydemersal predators, clupeids, and cephalopods. Local and foreign fisheries are actually positively related to the presence of killer whales in the ecosystem (MTI of 0.0039 and 0.0015 for killer whales on local and foreign fleets, respectively).

The same MTI analysis for the fishery shows that the negatively impacted groups of the Northwest African ecosystem are sharks, rays, and coastal tunas (Fig. 4A). Conversely, other fish groups such as coastal demersals and clupeids are positively related to fisheries when indirect effects are included.

Assuming an increased feeding rate for baleen whales in breeding areas of 50% (instead than the 10% proposed by Lockyer 1981), the MTI of baleen whales was still two orders of magnitudes lower than the MTI of fisheries on any other trophic group in the ecosystem.

Similarly, even when assuming whales biomasses that are an order of magnitude higher (1000% of original biomass), the MTI of baleen whales was still one order of magnitude lower than the MTI of fisheries on any other trophic group in the Northwest African ecosystem.

Dynamic simulations

We first ran our Northwest Africa model with the real time series of fishing mortality (F), and then compared the model's predictions when removing baleen whales. Here, we illustrate this approach by presenting preliminary results for cephalopods (a commercially important species group for which we have a good fit). The same analysis was done for all the trophic groups of the ecosystem. In general, after simulating marine mammal extirpation in the ecosystem, we found no significant change in biomass compared to the initial scenario with marine mammals included in the ecosystem (see an example for cephalopods in Fig. 5, and overall simulation results in Fig. 6). To be conservative, we then examined the assumption of a 50% feeding rate in breeding areas (compared to the common 10% proposed by Lockyer [1981]). For this scenario, we found a slight increase of biomass (less than 1%) for large pelagics, mesopelagic predators, bathydemersal predators, after 21 years. These are the only species for which we see a positive change.

Given the high uncertainty associated with our cetacean abundance estimates, we also tested the impact of substantial increases in baleen whale biomass (up to one order of magnitude higher) on model results. Even under the most extreme scenario, we found no important effect on the biomasses of commercially important fish, basically because the baleen whales are not consuming significant amounts in these tropical breeding areas. Regardless of the initial biomass estimate, our "best model" scenario shows that even a complete removal of baleen whales does not lead to a measurable increase in fish biomass.

To investigate alternative management scenarios, we also conducted simulations that assumed substantial reductions in fishing effort of either foreign or local fleets. Reducing fishing effort (F, or if effort was not available reducing the catch, C) for all commercially important species by 50 % resulted in a reduction in total biomass in the ecosystem. This result reflects the complex dynamics of the system and the potentially counterintuitive interactions between all predators and prey. However, for some species such as large pelagics, a reduction in fishing effort results in a higher biomass. Because the large pelagics represent important top predators in the ecosystem (TL = 3.31), such an increase is likely to create an increase of predation on the lower trophic levels. This may explain the overall decrease in biomass in the system under these assumptions. Conversely, a simulation with a fishing effort increased by 50% resulted in a decline in biomass for most commercially important species, suggesting that the ecosystem is currently heavily exploited.

DISCUSSION

Strengths and weaknesses of our modelling efforts

Our study sites occur in low latitude breeding areas for baleen whales, thus it was not expected a priori that there is a significant ecological interaction between whales and fisheries. Our goal is use the best available scientific data and estimates of uncertainty in these data to understand the plausible range of potential interactions between whales and fisheries in this region. The 'whales eat fish' issue is one directed towards many species of whales, and the many different prey they feed on. Consequently, debate is an ecosystem issue, and is more complex than the simple predator-prey relationship. Indirect effects such as competition, predation, and even beneficial predation (Morissette *et al.* 2006) can occur and move the simplistic view of a predator eating its prey to an ecosystem framework where many species are taken into account (i.e., from a predator eating a prey, but also a competitor of that prey for the same food resources).

In order to address such issues involving many species, an ecological modelling approach is crucial. The need of ecosystem models to specifically address the interactions between cetaceans and fisheries have been pointed out at the IWC Modelling workshop on cetacean-fishery competition held in La Jolla, California in June 2002, where it was proposed that "cetaceans form just one part of the system that needs to be modelled in order to try to answer the IWC questions posed in the terms of reference of this workshop" (IWC, 2004). Other conclusions from this workshop include recommendations that: 1) modelling approaches must explicitly allow for uncertainty in all aspects of their use including model specification and assumptions; 2) they should be used to determine data requirements in terms of quality and quantity; 3) they should include consideration of how they might be validated, and 4) they should try taking into account the effects of short- medium- and long-term ecosystem changes. The authors also propose that fisheries must be modelled realistically, particularly taking into account uncertainty in data;

the level of detail and realism required for reasonable single species management may be insufficient for multispecies analyses. We have embraced these recommendations in our approach, and we hope that our results will provide initial insights about the interactions between whales and fisheries in tropical waters.

In their review of the strengths and weaknesses of the *EwE* approach, Plagányi and Butterworth (2004) listed a variety of caveats and the problems they pose when interpreting modelling outputs. In this study, we addressed several of these issues. First of all, the 'steady state' and life history assumptions used as a starting point in *Ecosim* might lead to tenuous extrapolations when moved far from 'equilibrium'. To address that issue, we performed different levels of sensitivity analysis in order to validate the inputs and outcomes of our models with observed data. Plagányi and Butterworth also mention the risk of errors in the choice of representative diet composition when aggregating functional groups. Consequently, we carefully selected the key species of each or our aggregated trophic group, based on local documentation on the abundance and trophic importance or the species. Moreover, for aggregated groups of marine mammals (beaked whales, and dolphins), we calculated the diet as a weighted average of all species, based on their total consumption in the ecosystem. Finally, one major problem with such easily accessible and user-friendly software is that there is a potential for the misuse and misinterpretation of model applications. Preset parameter values are almost certainly not appropriate in all ecosystems, and users need to bear in mind that all *Ecosim* models are not created equally. Because the level of confidence attached to the *Ecosim* predictions is in large part a product of the quality of the input data and the level of statistical testing, we put great efforts in using the most robust approach, with the best available data, a validation by local experts, and multiple levels of uncertainty analyses.

Using ecosystem modelling to address the natural dynamics of marine systems in the context of a 'whale eat fish' issue helps to identify major shortcomings in the data and provides important reference points for more specific research on ecosystems. Such an ecosystem point of view also allows an understanding of the inter-connections between the species groups, and indicates which species play a key role in the food webs. From a management point of view, knowing that impacting one group will cause changes in another can provide tools for long-term and multispecies management. Using ecosystem models allow us to identify knowledge gaps, and to pursue research on particularly important species or functions of the ecosystem and the species within.

Due to the general complexity of marine ecosystems, the use of ecosystem modelling to study the dynamics between a predator and its prey is crucial. Indeed, putting all the available biological information for each species in an ecosystem context enables a global overview, and helps to verify that all information collected for a given species is compatible with information on other species. Moreover, using a common modeling technique and model structure for our three study areas allowed us not only to compare the three ecosystems, but also to compare these tropical areas with other ecosystem models where whales are important for the structure of the food web (Morissette 2007).

Challenges associated with data scarcity

As indicated above, the kind of data required for ecosystem modelling is very limited for our study areas. Notably the lack of dedicated surveys and existing abundance estimates of cetacean species in the area greatly hamper the estimation of cetacean biomass and consequently food consumption. However, as shown in Table 2, the predicted density estimates used in our model appear reasonable for most species given the range of observed densities in survey areas representing similar types of habitat. The extremely high densities of humpback whales reported in a few areas around Africa were observed in coastal waters where this species is known to aggregate during its breeding season (Clapham 2002). Given that our study area includes a large proportion of offshore water, the lower density estimate used in the model probably represents an appropriate average estimate. Similarly the highest density for fin whales has been reported from the Mediterranean where there is a resident population of fin whales, which likely shows different aggregation and movement patterns than the North Atlantic populations (Notarbartolo-di-Sciara *et al.* 2003).

It should be noted that our results are preliminary and may change based on expert advice obtained from regional workshops in each study area. These will represent important steps for validating the models with local experts and also for gathering additional data fill the gaps in our knowledge. Additional data that are available may thus be included in the model, and such an inclusion will improve the predictive ability of our model simulations. Specific data that would enhance the quality of our model include:

- Local diet information for the key species of our fish groups (in % of wet weight);

- Local time series of biomass (in tones*km^{-2}) from the 1980s and beyond, for any important species (marine mammals, fish, crabs, cephalopods, plankton) of the ecosystem;
- Local time series of effort from the 1980s and beyond, for any important species (marine mammals, fish, crabs, cephalopods, plankton) of the ecosystem;
- Consumption rates (yr^{-1}) and diet information (% of wet weight) for marine mammals when they are breeding off the coast of Northwest Africa;
- Estimates of total mortality (Z) for fish species in the area, which could be transformed into P/B ratios;
- Any data about species abundance, biomass or fishery yield in the NW Africa ecosystem.

However, we do not expect major sources of data to emerge, suggesting that our general results would not dramatically change with data availability. This also underscores the general problem of data paucity in these areas and the possible effects of the assumptions we had to make.

Applying time series of catch to larger or more global areas comes with several caveats (Reg Watson, *Sea Around Us Project [SAUP]*, pers. comm.). In our case, time series of biomass found for Northwest Africa were very local, and most of the time applied to one particular country, while our time series of catches (driving the *Ecosim* predictions) were from the SAUP database and representing the whole area. Consequently, it was difficult to find a good fit between models predictions, global fisheries catches, and biomass trends. Nonetheless, even though data are sparse, we can make reasonable assumptions about some basic things such as feeding rates, diets, and biomass, and explore a wide range of possible scenarios. These tested variations did not generate different patterns in terms of whales interacting with fisheries.

Would fisheries' catch increase if whales are removed from tropical ecosystems?

The role of marine mammals in ecosystems has received growing attention in recent years, and the use of models to try to understand this complex dynamics is growing (Mori and Butterworth 2004, 2005, 2006; Morissette *et al.* 2006; Aydin and Mueter 2007). Our results suggest that, for a wide range of model assumptions, reducing the abundance of whales would not lead to an increase in fishery yield in Northwest African waters. We applied a novel approach to corroborate what was proposed by previous authors before (Yodzis 2001; Kaschner 2004): great whales, despite their large size and their recurrent presence in tropical waters, likely do not influence local fish populations because they generally do not feed in these areas. Nonetheless, it is possible that some migratory fish of the Northwest African coast could be affected by these whales in their feeding grounds. However, like other species of whales (e.g., sperm whales) that do not appear to modify feeding rates in tropical waters, these cetaceans tend to feed on different trophic levels than what is targeted by fisheries. It should be noted that our results about the potential overlap between whales and fisheries are specific to tropical waters. Competition between marine mammals and fisheries has been documented in some areas such as the Bering Sea, the east coast of North America, the Benguela upwelling system off southwest Africa, the North Sea, the Gulf of Thailand, and the Strait of Georgia (Morissette 2007). However, it is generally marine mammals other than the great whales that experience significant competition with fisheries in these areas. Also, as we have shown in this study, due to complex ecosystem dynamics it is far from clear whether there is a direct relationship between marine mammal predation and loss to fisheries. Thus, even in areas for which there is overlap, it remains unclear if culling marine mammals would improve fishery yield (Yodzis 2001, Morissette 2007). In the management context, the controversies that have led to the idea that reducing whale abundance will increase fishery yield have largely focused on tropical breeding areas. In light of the low relative abundance of whales and their low consumption rates in these areas, the removal of whales in these areas is unlikely to benefit fisheries.

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Table 1: List of trophic groups and species included in the Ecopath model for Northwest Africa. Species **in bold** represent the key species (the species assumed to represent the whole group in terms of ecological parameters such as Q/B, P/B, and diet composition) for each trophic group.

***Ecopath* group**	**Species**
1. Minke whales	*Balaenoptera acutorostrata*
2. Fin whales	*Balaenoptera physalus*
3. Humpback whales	*Megaptera novaeangliae*
4. Sei whales	*Balaenoptera borealis*
5. Bryde's whales	*Balaenoptera brydei*
6. Sperm whales	*Physeter macrocephalus*
7. Killer whales	*Orcinus orca*
8. Other baleen whales	*B. musculus*
9. Beaked whales	*Mesoplodon densirostris*, *M. europaeus*, *Ziphius caviostris*
10. Dolphins	*Delphinus delphis, Feresa attenuate, Globicephala macrorhynchus, Grampus griseus, Kogia breviceps, Kogia simus, Lagenodelphis hosei, Peponocephala electra, Pseudorca crassidens, Sousa teuszii, Stenella attenuate, Stenella clymene, Stenella coeruleoalba, Stenella frontalis, Stenella longisrostris, Steno bredanensis, Tursiops truncates*
11. Seabirds	*Actitis hypoleucos, Calidris ferruginea, Calonectris diomedea, Ceryle rudis, Chlidonias niger, Halcyon malimbica, Limosa lapponica, Numenius phaeopus, Oceanites oceanicus, Pagrodama nivea, Pelecanus rufescens, Phalacrocorax africanus, Phoenicopterus rubber, Pluvialis squatarola, Sterna caspia, Sterna hirundo*
12. Large pelagics	*Acanthocybium solandri, Brama brama,* Centrolophidae*, Coryphaena hippurus, Cubiceps gracilis,* Istiophoridae, *Istiophorus albicans, Istiophorus platypterus,* ***Katsuwonus pelamis****, Makaira nigricans, Ranzania laevis, Ruvettus pretiosus, Schedophilus medusophagus, Tetrapturus albidus, Tetrapturus pfluegeri, Thunnus alalunga,* ***Thunnus albacares****,* ***Thunnus obesus****, Thunnus thynnus, Xiphias gladius*
13. Mesopelagics predators	***Aphanopus carbo****, Astronesthes niger, Atherina presbyter, Benthosema glaciale, Borostomias elucens, Chauliodus danae, Diplospinus multistriatus, Evermannella balbo, Lampris guttatus, Lepidocybium flavobrunneum, Leptostomias gladiator, Maurolicus muelleri, Micromesistius poutassou,* ***Micromesistius poutassou****, Mora moro,* Moridae*, Myctophum asperum, Myctophum nitidulum, Myctophum punctatum, Nealotus tripes, Photonectes margarita, Polyacanthonotus challengeri, Rhadinesthes decimus, Sternoptyx diaphana, Stomias boa boa,* Stomiidae, Trachichthyidae*, Trachyrincus scabrus, Vinciguerria nimbaria, Xenodermichthys copei*
14. Bathydemersal predators	*Beryx* sp.*, Beryx decadactylus, Caelorinchus caelorhincus caelorhincus,* Caproidae*, Chimaera monstrosa, Coryphaenoides rupestris, Coryphaenoides zaniophorus,* Gadiformes, Gempylidae*, Helicolenus dactylopterus dactylopterus,* Lophiidae, ***Lophius budegassa****, Lophius piscatorius, Lophius vaillanti,* Lotidae, Merlucciidae, ***Merluccius merluccius****, Merluccius polli,* ***Merluccius senegalensis****, Muraena helena, Nezumia aequalis, Nezumia sclerorhynchus,* Phycidae*, Phycis blennoides, Phycis phycis, Polyprion americanus, Pristis pectinata, Spectrunculus grandis, Synaphobranchus kaupii*

15. Sharks	*Alopias* sp., *Alopias superciliosus, Alopias vulpinus,* Alopiidae*, Carcharhinidae, Carcharhinus falciformis,* ***Carcharhinus limbatus****, Carcharhinus longimanus, Carcharhinus obscurus, Carcharhinus plumbeus,* Centrolophidae*, Centrophorus granulosus, Centroscyllium fabricii, Centrophorus squamosus, Centrophorus uyato, Centroscymnus coelolepis, Centroscymnus cryptacanthus, Centroscymnus crepidater, Cetorhinus maximus, Dalatias licha, Deania calcea,* Elasmobranchii, Etmopteridae*, Etmopterus princes, Etmopterus pusillus, Galeorhinus galeus, Galeus melastomus, Galeus polli, Ginglymostoma cirratum, Hexanchus griseus, Isurus* sp.*, Isurus oxyrinchus, Lamna nasus,* Lamnidae*, Mustelus asterias, Mustelus mustelus, Prionace glauca,* Pristidae*, Rhizoprionodon acutus,* Scyliorhinidae*, Scyliorhinus canicula, Scyliorhinus stellaris, Sphyrna lewini, Sphyrna zygaena,* Sphyrnidae*,* Squalidae*, Squalus acanthias, Squalus blainville, Squalus megalops, Squatina squatina,* Squatinidae*,* Triakidae
16. Rays	Dasyatidae, *Dasyatis margarita, Dasyatis pastinaca, Dipturus batis, Dipturus oxyrinchus, Gymnura altavela*, *Leucoraja naevus,* Myliobatidae, *Myliobatis aquila,* ***Raja clavata****, Raja miraletus, Raja montagui, Raja straeleni,* Rajidae, Rajiformes, Rhinobatidae, *Rhinobatos cemiculus,* ***Rhinobatos rhinobatos****, Rhinoptera bonasus, Rhinoptera marginata,* Torpedinidae, Torpedo sp.
17. Costal tunas	*Auxis rochei, Auxis thazard,* ***Euthynnus alletteratus****, Orcynopsis unicolor,* ***Sarda sarda,Scomberomorus tritor***

18. Coastal demersals	Acanthuridae, *Albula vulpes,* Ammodytidae, *Anthias anthias, Aphia minuta, Apogon imberbis,* Apogonidae, *Argentina sphyraena, Argyrosomus regius, Ariomma bondi,* **Ariidae**, *Ariomma melanum, Arius heudelotii, Arnoglossus laterna, Aulopus cadenati,* Balistidae, *Boops boops, Bothidae, Bothus podas, Brachydeuterus auritus, Brotula barbata, Campogramma glaycos, Capros aper, Cepola macrophthalma, Chaetodon hoefleri, Charis charis, Chelidonichthys obscurus, Chlorophthalmus agassizi, Conger conger,* Congridae, *Ctenolabrus rupestris,* Cynoglossidae, *Cynoglossus senegalensis, Dentex angolensis, Dentex canariensis, Dentex dentex, Dentex gibbosus, Dentex macrophthalmus*, *Dentex maroccanus*, *Dicentrarchus* sp.,*Dicentrarchus labrax*, *Dicologlossa cuneata*, *Diplodus bellottii*, *Diplodus cervinus cervinus*, *Diplodus sargus cadenati*, Diplodus vulgaris, *Drepane africana*, Echeneidae, Emmelichthyidae, *Epinephelus marginatus*, Epinephelus aeneus, *Epinephelus goreensis*, *Eucinostomus melanopterus*, *Fistularia tabacaria*, *Gaidropsarus* sp., Galeoides sp., *Galeoides decadactylus*, *Gerres nigri*, *Gobius niger*, *Gobius paganellus*, Haemulidae, *Halobatrachus didactylus*, Labridae, *Lepidorhombus* sp., *Lepidotrigla cadmani, Lepidotrigla dieuzeidei, Lethrinus atlanticus*, *Lithognathus mormyrus, Liza aurata, Liza dumerili, Liza falcipinnis, Liza grandisquamis, Liza ramado, Lutjanus* sp., *Lutjanus goreensis*, *Macroramphosus scolopax*, *Molva* sp., *Microchirus* sp., *Microchirus boscanion*, *Microchirus variegates, Monochirus hispidus*, Mugilidae, *Mugil capurrii*, *Mugil cephalus*, Mullidae, *Mullus barbatus*, *Mullus* sp., *Mullus surmuletus*, Muraenidae, *Mycteroperca rubra*, *Oblada melanura*, *Plectorhinchus macrolepis*, *Pagrus* sp., *Pagrus pagrus, Pagrus caeruleostictus, Pagellus* sp., *Pagellus bellottii bellottii, Pagellus acarne, Pagellus bogaraveo, Pagellus erythrinus, Pegusa lascaris*, *Pentanemus quinquarius*, *Platichthys flesus*, *Plectorhinchus macrolepis*, *Plectorhinchus mediterraneus*, Pleuronectidae, Pleuronectiformes, *Pleuronectes platessus*, Polynemidae, Pomacentridae, *Polydactylus quadrifilis*, *Pontinus kuhlii*, *Pomadasys jubelini, Pomadasys incisus*, *Pomadasys perotaei*, *Pomadasys rogerii*, *Pseudotolithus typus*, *Pseudotolithus senegalensis, Pseudotolithus elongatus, Pseudotolithus senegallus*, *Pseudupeneus prayensis*, *Pteroscion peli*, *Pseudupeneus prayensis*, *Rachycentron canadum*, Sarpa salpa, Saurida brasiliensis, Scaridae, **Sciaenidae**, Sciaena umbra, *Schedophilus pemarco*, Scophthalmidae, *Scophthalmus rhombus*, Serranidae, *Selene dorsalis*, Scorpaenidae, *Scorpaena maderensis, Scorpaena notata, Syacium guineensis*, Soleidae, *Solea senegalensis, Solea solea*, **Sparidae**, *Sparus auratus,* Sparus caeruleostictus, *Spondyliosoma cantharus*, *Stephanolepis hispidus*, *Stromateus fiatola, Symphodus mediterraneus, Symphodus melops*, *Synagrops microlepis*, *Synaptura lusitanica lusitanica, Trachinus draco*, *Trachinocephalus myops*, Triglidae, Tetraodontidae, *Trisopterus minutus*, *Trisopterus luscus*, *Umbrina cirrosa, Umbrina canariensis, Zeus faber*, *Zenopsis conchifer*
19. Clupeids	*Alosa alosa*, Clupeidae, Clupeiformes, *Engraulis encrasicolus,* ***Ethmalosa fimbriata***, *Ilisha Africana, Sardina pilchardus, Sardinella* sp., ***Sardinella aurita***, ***Sardinella maderensis***, *Sprattus sprattus*
20. Other coastal pelagics	*Alectis alexandrinus, Aphanopus intermedius*, Belonidae, Carangidae, *Caranx* sp., *Caranx hippos,* ***Caranx rhonchus***, *Caranx senegallus, Cheilopogon heterurus*, *Chloroscombrus chrysurus, Decapterus* sp., *Decapterus punctatus, Dicentrarchus punctatus, Elops lacerta,* Exocoetidae, *Exocoetus obtusirostris,* Hemiramphidae, *Hemiramphus* sp., *Lepidopus caudatus*, *Lichia amia*, Pomatomus saltatrix, Promethichthys pometheus, *Regalecus glesne*, *Scomber* sp., ***Scomber japonicus***, Scomber scombrus, *Scomberesox saurus saurus, Scomberomorus* sp., Scombridae, *Seriola* sp., *Sphyraena* sp., *Sphyraena barracuda, Spicara* sp., *Trachinotus* sp., *Trachinotus ovatus*, *Trachurus* sp., *Trachurus mediterraneus, Trachurus picturatus, Trachurus trachurus,* ***Trachurus trecae***, Trichiuridae, *Trichiurus lepturus, Tylosurus acus acus*

21. Cephalopods	*Alloteuthis subulata*, Cephalopoda, *Illex coindetii*, Loliginidae, *Loligo* sp., ***Loligo vulgaris***, Octopodidae, ***Octopus vulgaris***, Ommastrephidae, *Sepia bertheloti*, *Sepia elobyana*, *Sepia officinalis*, *Sepia orbignyana*, Sepiidae, Teuthida, *Todarodes sagittatus*
22. Crustaceans	Aristeidae, *Aristeus antennatus*, *Aristeus varidens*, **Brachyura**, *Calappa rubroguttata*, *Cancer pagurus*, *Carcinus maenas*, *Crangon* sp., *Crangon crangon*, Crangonidae, Geryon sp., *Geryon maritae*, *Homarus gammarus*, Leucosiidae, *Maja squinado*, Metapenaeus, Munidae, Natantian decapods, *Necora puber*, *Nephrops norvegicus*, Paguridae, Palaemonidae, *Palinurus* sp., *Palinurus elephas*, *Palinurus mauritanicus*, *Panulirus regius*, *Panulirus* sp., *Parapenaeopsis* sp., *Parapenaeopsis atlantica*, ***Parapanaeus longirostris***, Penaeidae, ***Penaeus* sp.**, ***Penaeus kerathurus***, ***Penaeus notialis***, *Pleoticus robustus*, *Plesionika heterocarpus*, *Plesiopenaeus edwardsianus*, Portunidae, Scyllaridae,
23. Benthos	Anthozoa, *Arca* sp., Arcidae, Bivalvia, Cardiidae, *Cardium edule, Chama crenulata*, Conidae, *Crassostrea* sp., *Crepidula porcellana*, *Cymbium* sp, Donacidae, *Donax* sp., Epizoanthidae, Gastropoda, Glycymerididae, Haliotidae, *Haliotis tuberculata*, *Modiolus* sp., *Murex* sp., Muricidae, Mytilidae, Naticidae, *Ostrea edulis*, *Patella* sp., *Pecten maximus*, Pectinidae, Porifera, *Pyura dura, Ruditapes decussates*, *Solen* sp., Solenidae, *Tapes* sp., *Thais haemastoma*, Veneridae, *Venus rosalina*, *Venus verrucosa,* Volutidae
24. Benthic producers	Algae, benthic bacteria
25. Zooplankton	Copepoda, Hydrozoa, Scyphozoa, fish larvae, eggs
26. Phytoplankton	Different diatoms species, and a mixture of autotrophic and mixotrophic organisms including: Cryptophytes, dinoflagellates, prasinophytes, and prymnesiophytes
27. Detritus	Non-living particulate organic material, including the bodies of dead organisms or fragments of organisms or fecal material.

Table 2: Comparison of predicted cetacean densities in study area and observed densities in similar habitats (subtropical & tropical waters). A = aerial surveys, S = ship based surveys. Density estimates that are corrected for animals missed on the track-line are indicated in the G(0) corrected column. All other observed estimates might represent underestimations. Bold observed density values represent lowest and highest observed estimates, respectively for each species.

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Blue whale	0.03	**0.07**	0.24	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Blue whale	0.03	1.10	0.33	yes	NE Pacific, Baja California	1993	S	Calambokidis & Barlow, 2004
Blue whale	0.03	0.00	0.00	yes	NE Pacific, west coast US	1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	3.11	0.28	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Blue whale	0.03	0.95	0.44	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Blue whale	0.03	0.11	0.99	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Blue whale	0.03	3.27	0.24	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Blue whale	0.03	1.26	0.27	yes	NE Pacific, California offshore	1991-1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	**4.96**	0.13	yes	NE Pacific, California inshore	1991-1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	0.76	0.50	no	SW Indian Ocean, Madagaskar plateau (southern block)	1996	S	Best et al 2003
Blue whale	0.03	0.82	0.65	no	SW Indian Ocean, Madagaskar plateau (northern block)	1996	S	Best et al 2003
Brydes whale	0.49	0.11	0.61	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004
Bryde's whale	0.49	**0.67**	0.20	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Bryde's whale	0.49	**0.67**	0.21	no	Eastern Tropical Pacific	1998	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.50	0.24	no	Eastern Tropical Pacific	1999	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.48	0.20	no	Eastern Tropical Pacific	2000	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.19	0.45	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Bryde's whale	0.49	0.06	0.53	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Bryde's whale	0.49	0.02	1.01	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Bryde's whale	0.49	0.09	1.09	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
Bryde's whale	0.49	**0.04**	0.85	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
Bryde's whale	0.49	0.05	1.07	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
Bryde's whale	0.49	0.43	1.05	no	NW Atlantic, northern Gulf of Mexico (GulfCet I EPA survey)	1996-1997	S	Davis et al, 2000
Fin whale		0.00	0.00	yes	NOAA 91-96 California inshore	1991	A	Forney et al, 1995
Fin whale	0.22	**16.09**	0.22	no	NW Mediterranean	1992	S	Forcada et al 1995
Fin whale	0.22	3.18	0.34	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Fin whale	0.22	3.92	0.56	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Fin whale	0.22	**0.07**	0.72	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2003
Fin whale	0.22	0.19	1.01	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Fin whale	0.22	1.97	0.35	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Fin whale	0.22	0.07	1.15	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Fin whale	0.22	1.85	0.48	no	NW Atlantic, Virginia Capes	2002	S	Garrison et al, 2003

Table 2 (cont.):

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Humpback whale	0.10	1.22	0.41	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Humpback whale	0.10	3.50	0.21	yes	NE Pacific, California inshore	1991-1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	**0.03**	0.37	yes	NE Pacific, California offshore	1991-1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	1.46	0.42	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Humpback whale	0.10	0.00	0.00	yes	NE Pacific, Baja California	1993	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	0.66	0.41	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Humpback whale	0.10	0.14	0.72	yes	NE Pacific, west coast US	1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	1.81	0.44	yes	NE Pacific, west coast US	1996	S	Barlow. 2003
Humpback whale	0.10	0.89	0.49	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Humpback whale	0.10	7.44	0.48	no	SE Atlantic, Gabon waters (northern strata)	2002	A	Rosenbaum et al, 2004
Humpback whale	0.10	24.34	0.31	no	SE Atlantic, Gabon waters (southern strata)	2002	A	Rosenbaum et al, 2004
Humpback whale	0.10	46.49	0.47	no	SW Indian Ocean, Madagaskar (eastern block)	1994	S	Best et al, 1996
Humpback whale	0.10	**112.32**	0.27	no	SW Indian Ocean, Madagaskar (southern block)	1994	S	Best et al, 1996
Humpback whale	0.10	67.47	0.15	no	SW Indian Ocean, Mozambique	2003	S	Findlay et al, 2004
Minke whale	1.28	0.42	0.68	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Minke whale	1.28	0.28	0.62	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Minke whale	1.28	0.27	0.44	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Minke whale	1.28	**0.93**	0.51	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Minke whale	1.28	0.86	0.77	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Minke whale	1.28	**0.03**	1.29	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Sei whale	0.10	0.06	0.53	yes	NE Pacific, west coast US	1991	S	Barlow, 2003
Sei whale	0.10	0.05	0.79	yes	NE Pacific, west coast US	1991	S	Barlow, 2003
Sei whale	0.10	0.10	0.73	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Sei whale	0.10	**0.03**	1.01	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Sei whale	0.10	0.03	1.06	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2003
Killer whale	0.11	0.44	0.37	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Killer whale	0.11	0.31	0.76	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Killer whale	0.11	0.25	0.69	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Killer whale	0.11	0.55	0.50	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Killer whale	0.11	0.74	0.61	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Killer whale	0.11	0.58	0.73	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Killer whale	0.11	**0.14**	0.98	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Killer whale	0.11	0.69	0.42	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
Killer whale	0.11	**0.79**	0.48	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
Killer whale	0.11	0.17	1.01	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
Killer whale	0.11	0.37	0.49	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004

Table 2 (cont.):

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Sperm whale	1.09	1.33	0.22	yes	Eastern Tropical Pacific	1986-1990	A & S	Wade & Gerrodette, 1993
Sperm whale	1.09	0.92	0.38	no	Eastern Tropical Pacific	1998	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	1.24	0.60	no	Eastern Tropical Pacific	1999	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	**0.19**	0.73	no	Eastern Tropical Pacific	2000	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	3.36	0.81	yes	Northeastern Tropical Pacific	1997	S	Barlow & Taylor, 2005
Sperm whale	1.09	**4.10**	0.36	no	Northeastern Tropical Pacific	1997-2000	S	Barlow & Taylor, 2005
Sperm whale	1.09	0.20	1.07	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Sperm whale	1.09	3.42	0.99	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Sperm whale	1.09	1.41	0.40	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Sperm whale	1.09	0.47	0.56	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Sperm whale	1.09	1.90	0.59	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Sperm whale	1.09	0.90	0.13	yes	NE Pacific, Hawaiin waters	1993-1998	A	Mobley et al, 2000
Sperm whale	1.09	2.79	0.81	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Sperm whale	1.09	2.06	0.51	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Sperm whale	1.09	1.14	0.85	no	NW Atlantic, Virginia Capes	2002	S	Garrison et al, 2003
Sperm whale	1.09	2.31	0.31	yes	NW Atlantic, northern Gulf of Mexico (SEFSC)	1991-1994	S	Hanson et al, 1995
sperm whale	1.09	1.31	0.31	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
sperm whale	1.09	1.74	0.30	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
sperm whale	1.09	0.96	0.45	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
sperm whale	1.09	1.62	0.56	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1996-1997	S	Davis et al, 2000
Sperm whale	1.09	0.85	0.57	no	NW Atlantic, northern Gulf of Mexico (GulfCet I EPA survey)	1996-1997	S	Davis et al, 2000
Sperm whale	1.09	3.80	0.23	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004

Table 3. Primary production required (PPR) and mean trophic level (TL) for fisheries' catches and marine mammal consumption off the coast of Northwest Africa.

	PPR	PPR (% of total PP)	Mean TL of the catch / consumption
Northwest Africa			
Fisheries	94.93	0.42	2.80
Minke whales	1.06	< 0.01	2.54
Fin whales	0.24	< 0.01	2.01
Humpback whales	0.19	< 0.01	2.44
Bryde's whales	53.87	0.24	2.39
Sei whales	0.05	< 0.01	2.02
Sperm whales	62.37	0.28	3.12
Killer whales	63.18	0.28	2.94
Baleen whales	0.04	< 0.01	2.00
Beaked whales	1.38	0.01	3.21
Dolphins	62.91	0.28	2.54

List of Figures

Figure 1. Map showing A) the studies areas that were the focus of this project, and B) the spatial boundaries of the Northwest African area for which the results are presented here. The coordinates of the Northwest African area are 8.5N - 36N and 30W - 6.5W, covering a total area of approximately 3,6 million km^2.

Figure 2: Comparison of proportional diet compositions of different marine mammals groups and catch composition of different fishing fleets.

Figure 3: Comparison of total annual fisheries catches (grey bars) and cetacean consumption (black bars), per trophic group in Northwest Africa.

Figure 4. Mixed trophic impacts of fisheries (A), baleen whales (B) and all marine mammals (C) on the species groups of the Northwest Africa model. Bars below zero represent a negative impact, while bars above zero represent a positive impact. Note that the scale of the y-axis had to be reduced by two orders of magnitude for marine mammals in order to see the effect on the impacted groups.

Figure 5. Simulation of biomass changes for cephalopods after the removal of all baleen whales from the ecosystem of Northwest Africa. Grey lines represent biomass trends over 21 years with marine mammals, while black dashed lines show the biomass trends after the removal of baleen whales. The time series of observed biomass data for cephalopods is also shown on the graph.

Figure 6. Biomass change after a 21-year simulation in the Northwest African ecosystem, with all marine mammals (grey) and without baleen whales (white).

Figure 1

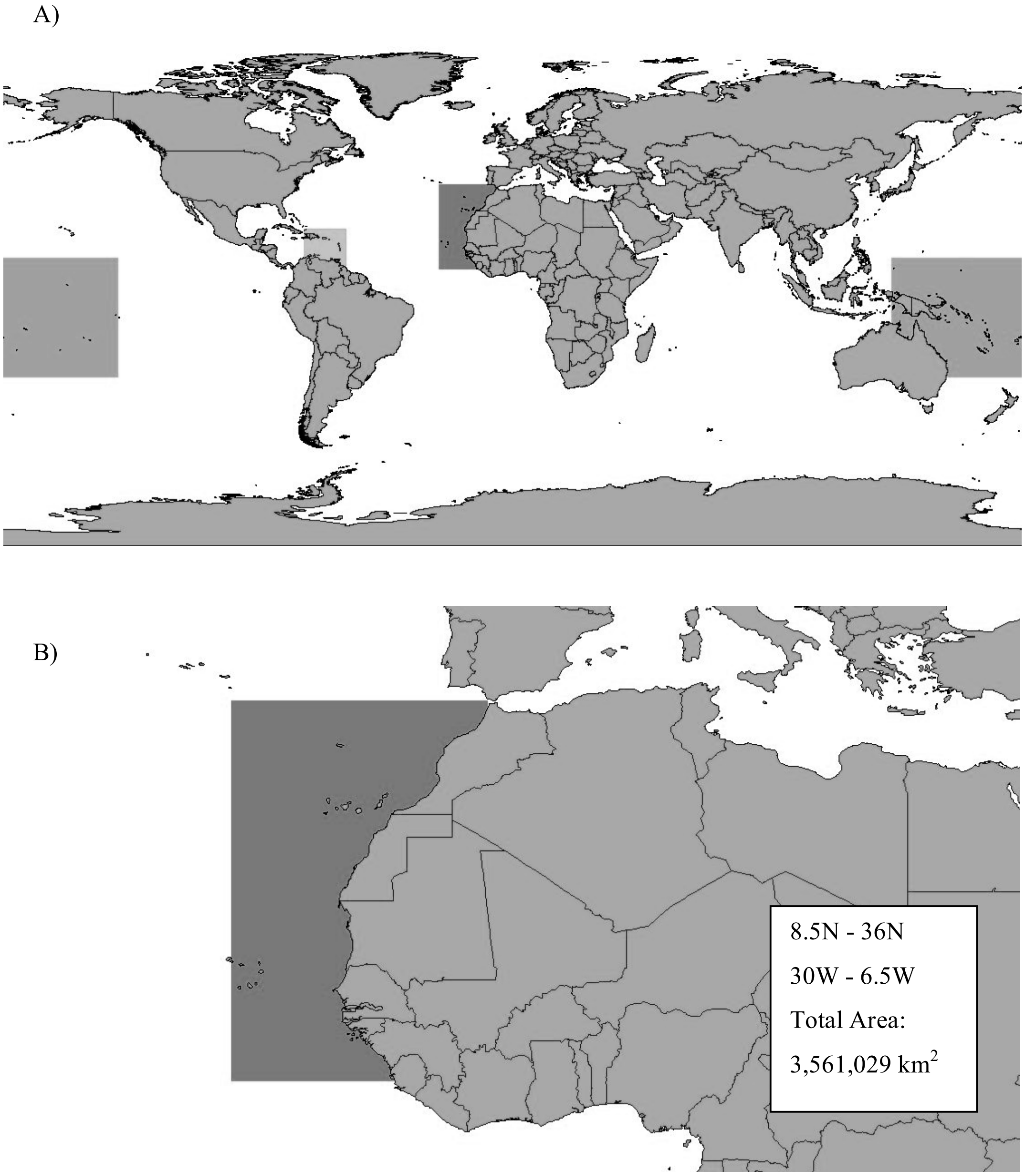


Figure 2

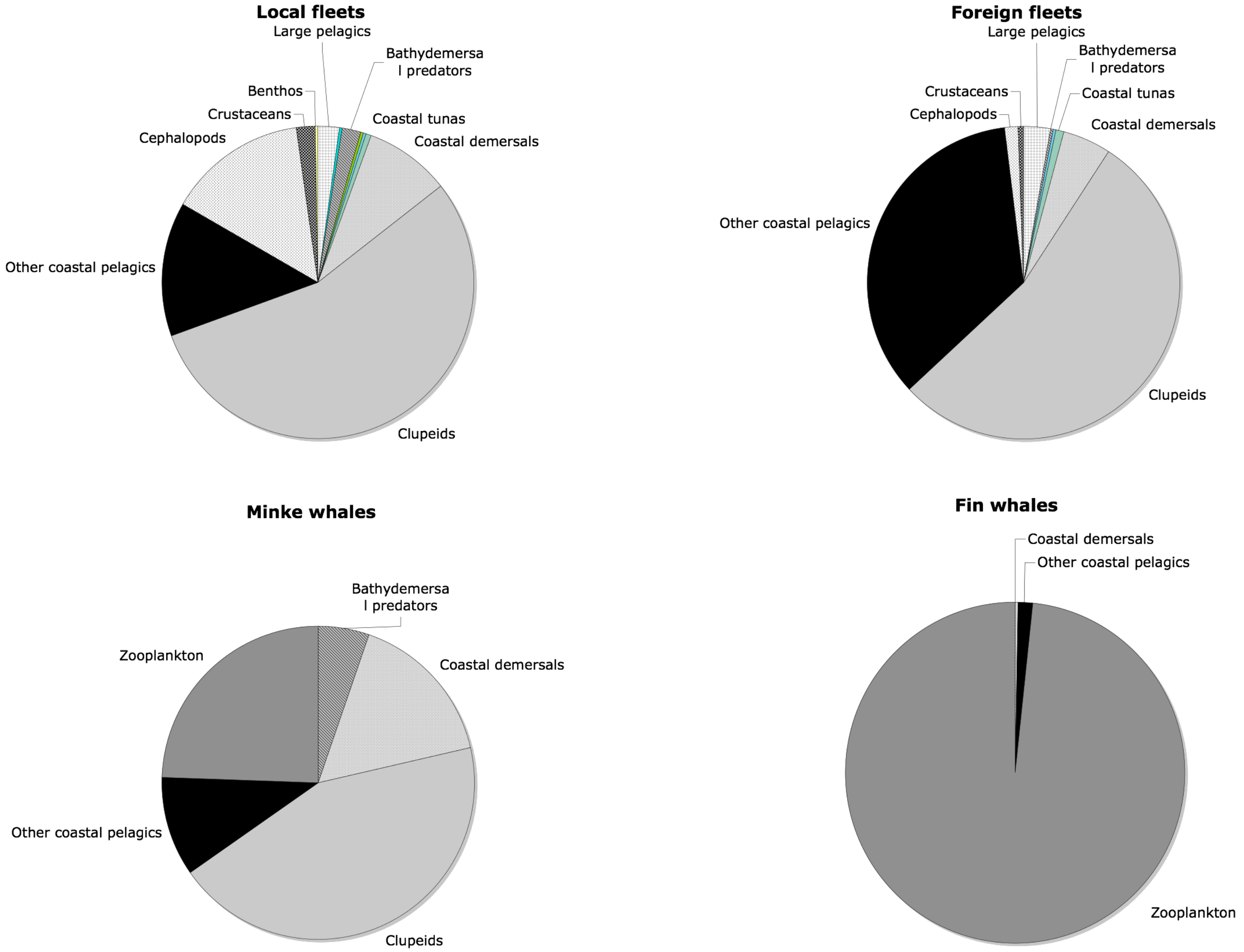
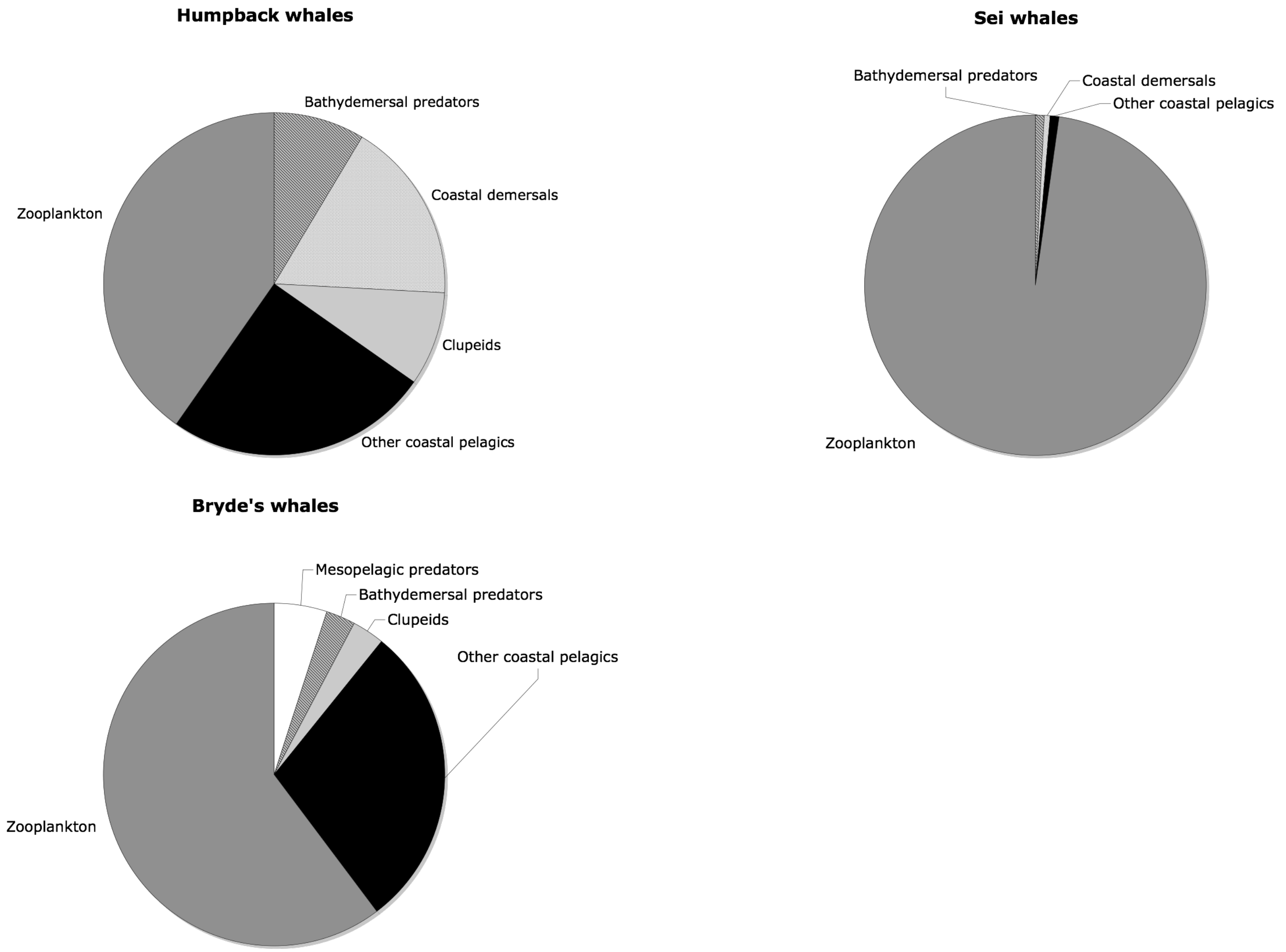

Local fleets
Large pelagics
Bathydemersal predators
Benthos
Crustaceans
Coastal tunas
Cephalopods
Coastal demersals
Other coastal pelagics
Clupeids
Foreign fleets
Large pelagics
Bathydemersal predators
Crustaceans
Coastal tunas
Cephalopods
Coastal demersals
Other coastal pelagics
Clupeids
Minke whales
Bathydemersal predators
Zooplankton
Coastal demersals
Other coastal pelagics
Clupeids
Fin whales
Coastal demersals
Other coastal pelagics
Zooplankton

Figure 2 (cont.)



Humpback whales

Sei whales

Bryde's whales

Figure 3

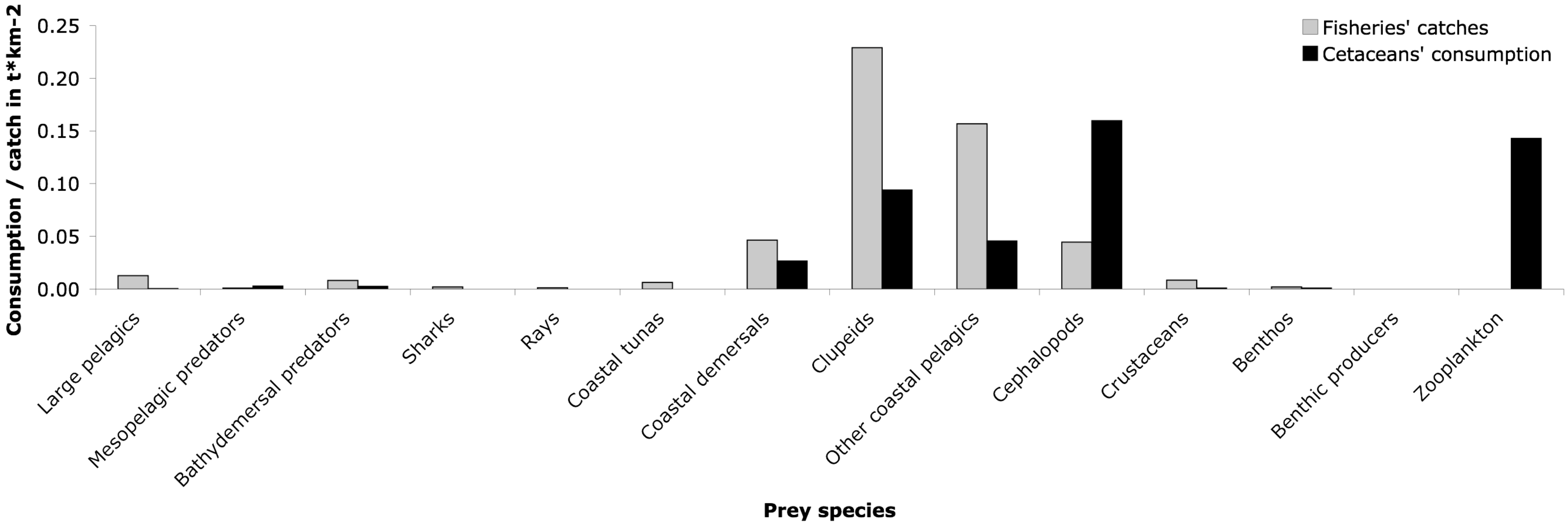

Consumption / catch in t*km-2
0.25
0.20
0.15
0.10
0.05
0.00
Fisheries' catches
Cetaceans' consumption
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Prey species

Figure 4

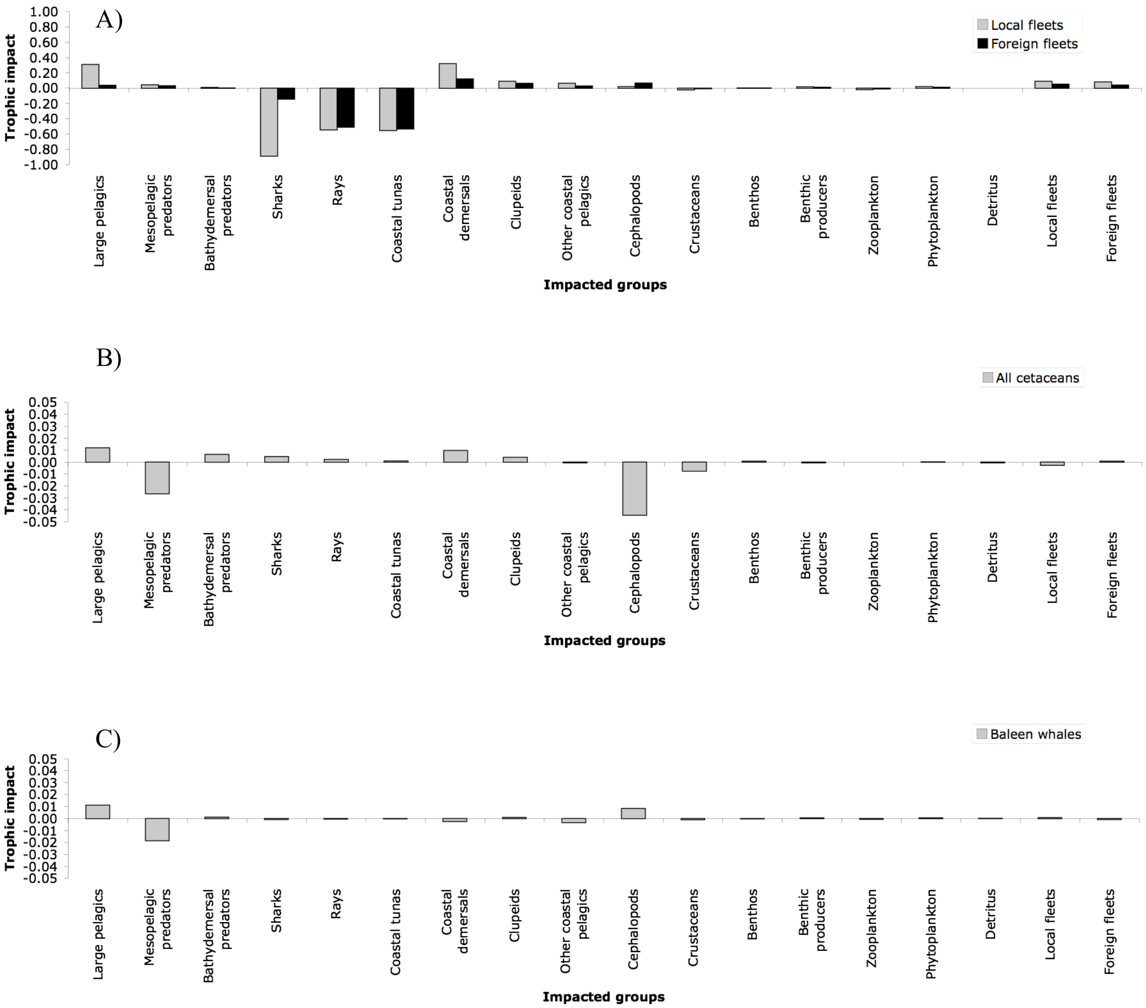

A)
Local fleets
Foreign fleets
Trophic impact
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
B)
All cetaceans
C)
Baleen whales
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Local fleets
Foreign fleets
Impacted groups

Figure 5.

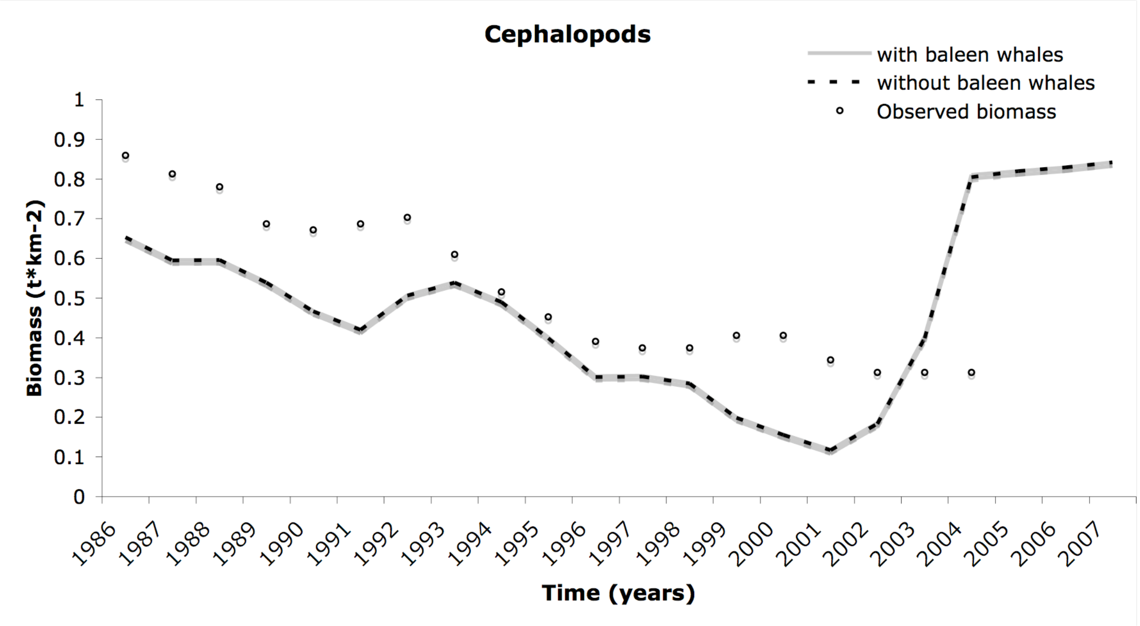
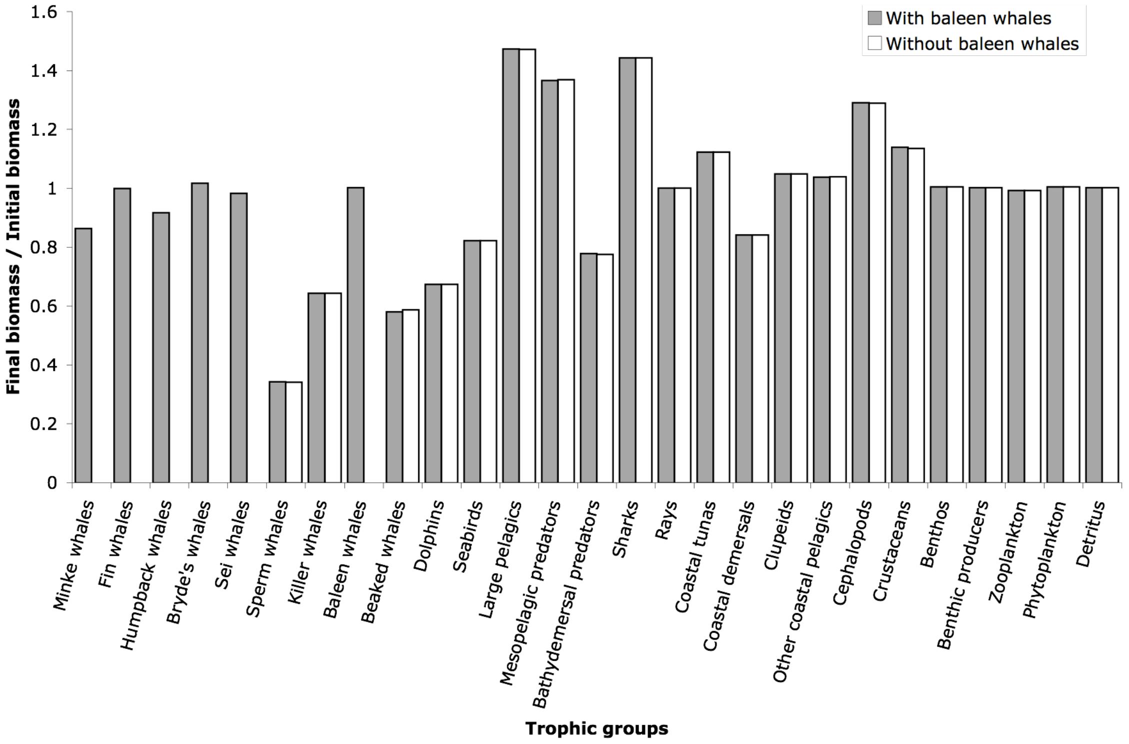

Cephalopods
with baleen whales
without baleen whales
Observed biomass
Biomass (t*km-2)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Time (years)

Figure 6.


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Final biomass / Initial biomass
With baleen whales
Without baleen whales
Minke whales
Fin whales
Humpback whales
Bryde's whales
Sei whales
Sperm whales
Killer whales
Baleen whales
Beaked whales
Dolphins
Seabirds
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Trophic groups

APPENDIX 1

Whales & Fish Interactions: Are Great Whales a Threat to Fisheries?

Organised by
WWF WAMER & the Lenfest Ocean Program

08 & 09 May 2008

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WWF for a living planet®

LENFEST OCEAN PROGRAM

Recent studies have proposed that whales are the culprits behind decreased fish populations and as a result they should be culled.

The rationale for such arguments is questionable in light of documented overfishing occurring on a global scale, the lack of scientific evidence for existing large-scale competition between marine mammals and fisheries, and the unpredictable consequences of culling. Nonetheless, the "whales eat fish" issue has become a significant point of contention.

To understand the impact of whales on fisheries, it is necessary to analyze the situation in the context of ecosystems in order to consider the complex indirect and direct interactions through which these two groups might influence each other. To this end the Lenfest Ocean Program is conducting a project to examine the scientific evidence for the assertion that commercial fisheries are negatively impacted by whales.

As the project is underway, but not concluded, we are organizing the Dakar Workshop in order to share preliminary findings concerning a study area located off the coast of Northwest Africa.

Highlights:

- Area under review: the area defined by NOAA as the Canary Current Large Marine Ecosystem (CCLME).
- Morocco, Mauritania, Senegal, Guinea-Bissau, the Canary Islands, Gambia, Cape Verde and Western Saharan Coastline.

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Whales & Fish Interactions: Are Great Whales a Threat to Fisheries?

Organised by WWF WAMER & the Lenfest Ocean Program

08 & 09 May 2008

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Contact person:
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WEDNESDAY 7th MAY

20h00 EVENING DINNER RECEPTION FOR WORKSHOP PARTICIPANTS

THURSDAY 8th MAY

09h00 OPENING SESSION

Welcome Address – Dr. Papa Samba Diouf, Coordinator, WWF WAMER

Introduction - Dr. Margaret Bowman, Director, Lenfest Ocean Program

Opening remarks by His Excellency Mr. Souleymane Ndéné Ndiaye, State Minister of Maritime Economy, Fisheries and Aquaculture of Senegal (tbc)

10h00 COFFEE BREAK

10h30 SESSION 1 MORNING – PRESENTATION OF LENFEST OCEAN PROGRAM SCIENTIFIC REVIEW

Presentation and adoption of the draft programme - Dr. Mamadou Diallo, Program Manager, WWF WAMER

Whales and Fish interactions: the Scientific and Policy Debate – Dr. Daniel Pauly, Professor and Director of the Fisheries Centre, Univeristy of British Colombia, Canada

Modelling & Methodology - Dr. Lyne Morissette, Lenfest Ocean Program

Preliminary results 1: Ecosystem structure and trophic interactions - Dr. Lyne Morissette & Dr. Kristin Kaschner (LOP)

- Diet composition of marine mammals vs fisheries catch composition
- Total catches vs total consumption by Marine Mammals
- Mixed trophic impacts
- Overlap index

13h00-14h00 LUNCH

14h30 SESSION 1 AFTERNOON– PRESENTATION OF PEW SCIENTIFIC REVIEW (CONT.)

Preliminary results 2: Dynamic simulations (the 'what if' scenarios) - Dr. Lyne Morissette & Dr. Kristin Kaschner

- What happens to fish stocks when whales are eradicated?
- Would a massive cull of baleen whales benefit pelagic and inshore fisheries?
- Testing of different assumptions

Preliminary results 3: Implications for management and policy

15h45-16h00 COFFEE BREAK

Discussion 1: Model structure and data collection

Discussion 2: Exploration of potential alternative scenarios

General discussion and conclusion

17h30 END OF DAY 1 WORK SESSION

09 MAY

09h00 MORNING – TOWARDS SCIENCE-POLICY SYNERGY

Welcome to additional Day 2 participants - Dr. Bakhayokho Workshop Facilitator

Outline of Day 1 discussions - Dr. Margaret Bowman

Implications in the policy context - Dr. Mamadou Dallio

Intervention by His Excellency Mr. Lamine Thiam, President of the Environment Parliamentary Network of the Senegalese National Assembly

Discussion

Wrap up and conclusion

13h00 LUNCH

16h00 AFTERNOON – PRESS BRIEFING

Table 2: Comparison of predicted cetacean densities in study area and observed densities in similar habitats (subtropical & tropical waters). A = aerial surveys, S = ship based surveys. Density estimates that are corrected for animals missed on the track-line are indicated in the G(0) corrected column. All other observed estimates might represent underestimations. Bold observed density values represent lowest and highest observed estimates, respectively for each species.

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Blue whale	0.03	**0.07**	0.24	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Blue whale	0.03	1.10	0.33	yes	NE Pacific, Baja California	1993	S	Calambokidis & Barlow, 2004
Blue whale	0.03	0.00	0.00	yes	NE Pacific, west coast US	1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	3.11	0.28	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Blue whale	0.03	0.95	0.44	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Blue whale	0.03	0.11	0.99	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Blue whale	0.03	3.27	0.24	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Blue whale	0.03	1.26	0.27	yes	NE Pacific, California offshore	1991-1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	**4.96**	0.13	yes	NE Pacific, California inshore	1991-1996	S	Calambokidis & Barlow, 2004
Blue whale	0.03	0.76	0.50	no	SW Indian Ocean, Madagaskar plateau (southern block)	1996	S	Best et al 2003
Blue whale	0.03	0.82	0.65	no	SW Indian Ocean, Madagaskar plateau (northern block)	1996	S	Best et al 2003
Brydes whale	0.49	0.11	0.61	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004
Bryde's whale	0.49	**0.67**	0.20	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Bryde's whale	0.49	**0.67**	0.21	no	Eastern Tropical Pacific	1998	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.50	0.24	no	Eastern Tropical Pacific	1999	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.48	0.20	no	Eastern Tropical Pacific	2000	S	Gerrodette & Forcada, 2002
Bryde's whale	0.49	0.19	0.45	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Bryde's whale	0.49	0.06	0.53	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Bryde's whale	0.49	0.02	1.01	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Bryde's whale	0.49	0.09	1.09	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
Bryde's whale	0.49	**0.04**	0.85	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
Bryde's whale	0.49	0.05	1.07	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
Bryde's whale	0.49	0.43	1.05	no	NW Atlantic, northern Gulf of Mexico (GulfCet I EPA survey)	1996-1997	S	Davis et al, 2000
Fin whale		0.00	0.00	yes	NOAA 91-96 California inshore	1991	A	Forney et al, 1995
Fin whale	0.22	**16.09**	0.22	no	NW Mediterranean	1992	S	Forcada et al 1995
Fin whale	0.22	3.18	0.34	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Fin whale	0.22	3.92	0.56	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Fin whale	0.22	**0.07**	0.72	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2003
Fin whale	0.22	0.19	1.01	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Fin whale	0.22	1.97	0.35	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Fin whale	0.22	0.07	1.15	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Fin whale	0.22	1.85	0.48	no	NW Atlantic, Virginia Capes	2002	S	Garrison et al, 2003

Table 2 (cont.):

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Humpback whale	0.10	1.22	0.41	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Humpback whale	0.10	3.50	0.21	yes	NE Pacific, California inshore	1991-1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	**0.03**	0.37	yes	NE Pacific, California offshore	1991-1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	1.46	0.42	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Humpback whale	0.10	0.00	0.00	yes	NE Pacific, Baja California	1993	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	0.66	0.41	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Humpback whale	0.10	0.14	0.72	yes	NE Pacific, west coast US	1996	S	Calambokidis & Barlow, 2004
Humpback whale	0.10	1.81	0.44	yes	NE Pacific, west coast US	1996	S	Barlow. 2003
Humpback whale	0.10	0.89	0.49	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Humpback whale	0.10	7.44	0.48	no	SE Atlantic, Gabon waters (northern strata)	2002	A	Rosenbaum et al, 2004
Humpback whale	0.10	24.34	0.31	no	SE Atlantic, Gabon waters (southern strata)	2002	A	Rosenbaum et al, 2004
Humpback whale	0.10	46.49	0.47	no	SW Indian Ocean, Madagaskar (eastern block)	1994	S	Best et al, 1996
Humpback whale	0.10	**112.32**	0.27	no	SW Indian Ocean, Madagaskar (southern block)	1994	S	Best et al, 1996
Humpback whale	0.10	67.47	0.15	no	SW Indian Ocean, Mozambique	2003	S	Findlay et al, 2004
Minke whale	1.28	0.42	0.68	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Minke whale	1.28	0.28	0.62	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Minke whale	1.28	0.27	0.44	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Minke whale	1.28	**0.93**	0.51	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Minke whale	1.28	0.86	0.77	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Minke whale	1.28	**0.03**	1.29	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Sei whale	0.10	0.06	0.53	yes	NE Pacific, west coast US	1991	S	Barlow, 2003
Sei whale	0.10	0.05	0.79	yes	NE Pacific, west coast US	1991	S	Barlow, 2003
Sei whale	0.10	0.10	0.73	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Sei whale	0.10	**0.03**	1.01	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Sei whale	0.10	0.03	1.06	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2003
Killer whale	0.11	0.44	0.37	no	Eastern Tropical Pacific	1986-1990	S	Wade & Gerrodette, 1993
Killer whale	0.11	0.31	0.76	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Killer whale	0.11	0.25	0.69	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Killer whale	0.11	0.55	0.50	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Killer whale	0.11	0.74	0.61	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Killer whale	0.11	0.58	0.73	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Killer whale	0.11	**0.14**	0.98	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Killer whale	0.11	0.69	0.42	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
Killer whale	0.11	**0.79**	0.48	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
Killer whale	0.11	0.17	1.01	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
Killer whale	0.11	0.37	0.49	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004

Table 2 (cont.):

Common Name	Estimated density [animals / 1000 km2]	Observed density [animals / 1000 km2]	CV	G(0) corrected	Geographic area	Survey years	Survey type	Source
Sperm whale	1.09	1.33	0.22	yes	Eastern Tropical Pacific	1986-1990	A & S	Wade & Gerrodette, 1993
Sperm whale	1.09	0.92	0.38	no	Eastern Tropical Pacific	1998	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	1.24	0.60	no	Eastern Tropical Pacific	1999	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	**0.19**	0.73	no	Eastern Tropical Pacific	2000	S	Gerrodette & Forcada, 2002
Sperm whale	1.09	3.36	0.81	yes	Northeastern Tropical Pacific	1997	S	Barlow & Taylor, 2005
Sperm whale	1.09	**4.10**	0.36	no	Northeastern Tropical Pacific	1997-2000	S	Barlow & Taylor, 2005
Sperm whale	1.09	0.20	1.07	yes	NE Pacific, California waters	1991	A	Forney & Barlow, 1993
Sperm whale	1.09	3.42	0.99	yes	NE Pacific, California inshore	1991-1992	A	Forney et al, 1995
Sperm whale	1.09	1.41	0.40	yes	NE Pacific, west coast US	1991-1993	S	Barlow, 2003
Sperm whale	1.09	0.47	0.56	yes	NE Pacific, west coast US	1996	S	Barlow, 2003
Sperm whale	1.09	1.90	0.59	yes	NE Pacific, west coast US	2001	S	Barlow, 2003
Sperm whale	1.09	0.90	0.13	yes	NE Pacific, Hawaiin waters	1993-1998	A	Mobley et al, 2000
Sperm whale	1.09	2.79	0.81	yes	NE Pacific, Hawaiin waters	2002	S	Barlow, 2006
Sperm whale	1.09	2.06	0.51	no	NW Atlantic, US east coast, south of Maryland	1998	S	Mullin, 2003
Sperm whale	1.09	1.14	0.85	no	NW Atlantic, Virginia Capes	2002	S	Garrison et al, 2003
Sperm whale	1.09	2.31	0.31	yes	NW Atlantic, northern Gulf of Mexico (SEFSC)	1991-1994	S	Hanson et al, 1995
sperm whale	1.09	1.31	0.31	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1991-1994	S	Hansen et al. 1995
sperm whale	1.09	1.74	0.30	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1991-1994	S	Davis & Fargion, 1996
sperm whale	1.09	0.96	0.45	no	NW Atlantic, northern Gulf of Mexico (Oceanic Surveys)	1996-1997	S	Davis et al, 2000
sperm whale	1.09	1.62	0.56	no	NW Atlantic, northern Gulf of Mexico (GulfCet I survey)	1996-1997	S	Davis et al, 2000
Sperm whale	1.09	0.85	0.57	no	NW Atlantic, northern Gulf of Mexico (GulfCet I EPA survey)	1996-1997	S	Davis et al, 2000
Sperm whale	1.09	3.80	0.23	no	NW Atlantic, northern Gulf of Mexico (SEFSC)	1996-2001	S	Mullin and Fulling, 2004

Table 3. Primary production required (PPR) and mean trophic level (TL) for fisheries' catches and marine mammal consumption off the coast of Northwest Africa.

	PPR	PPR (% of total PP)	Mean TL of the catch / consumption
Northwest Africa			
Fisheries	94.93	0.42	2.80
Minke whales	1.06	< 0.01	2.54
Fin whales	0.24	< 0.01	2.01
Humpback whales	0.19	< 0.01	2.44
Bryde's whales	53.87	0.24	2.39
Sei whales	0.05	< 0.01	2.02
Sperm whales	62.37	0.28	3.12
Killer whales	63.18	0.28	2.94
Baleen whales	0.04	< 0.01	2.00
Beaked whales	1.38	0.01	3.21
Dolphins	62.91	0.28	2.54

List of Figures

Figure 1. Map showing A) the studies areas that were the focus of this project, and B) the spatial boundaries of the Northwest African area for which the results are presented here. The coordinates of the Northwest African area are 8.5N - 36N and 30W - 6.5W, covering a total area of approximately 3,6 million km^2.

Figure 2: Comparison of proportional diet compositions of different marine mammals groups and catch composition of different fishing fleets.

Figure 3: Comparison of total annual fisheries catches (grey bars) and cetacean consumption (black bars), per trophic group in Northwest Africa.

Figure 4. Mixed trophic impacts of fisheries (A), baleen whales (B) and all marine mammals (C) on the species groups of the Northwest Africa model. Bars below zero represent a negative impact, while bars above zero represent a positive impact. Note that the scale of the y-axis had to be reduced by two orders of magnitude for marine mammals in order to see the effect on the impacted groups.

Figure 5. Simulation of biomass changes for cephalopods after the removal of all baleen whales from the ecosystem of Northwest Africa. Grey lines represent biomass trends over 21 years with marine mammals, while black dashed lines show the biomass trends after the removal of baleen whales. The time series of observed biomass data for cephalopods is also shown on the graph.

Figure 6. Biomass change after a 21-year simulation in the Northwest African ecosystem, with all marine mammals (grey) and without baleen whales (white).

Figure 1

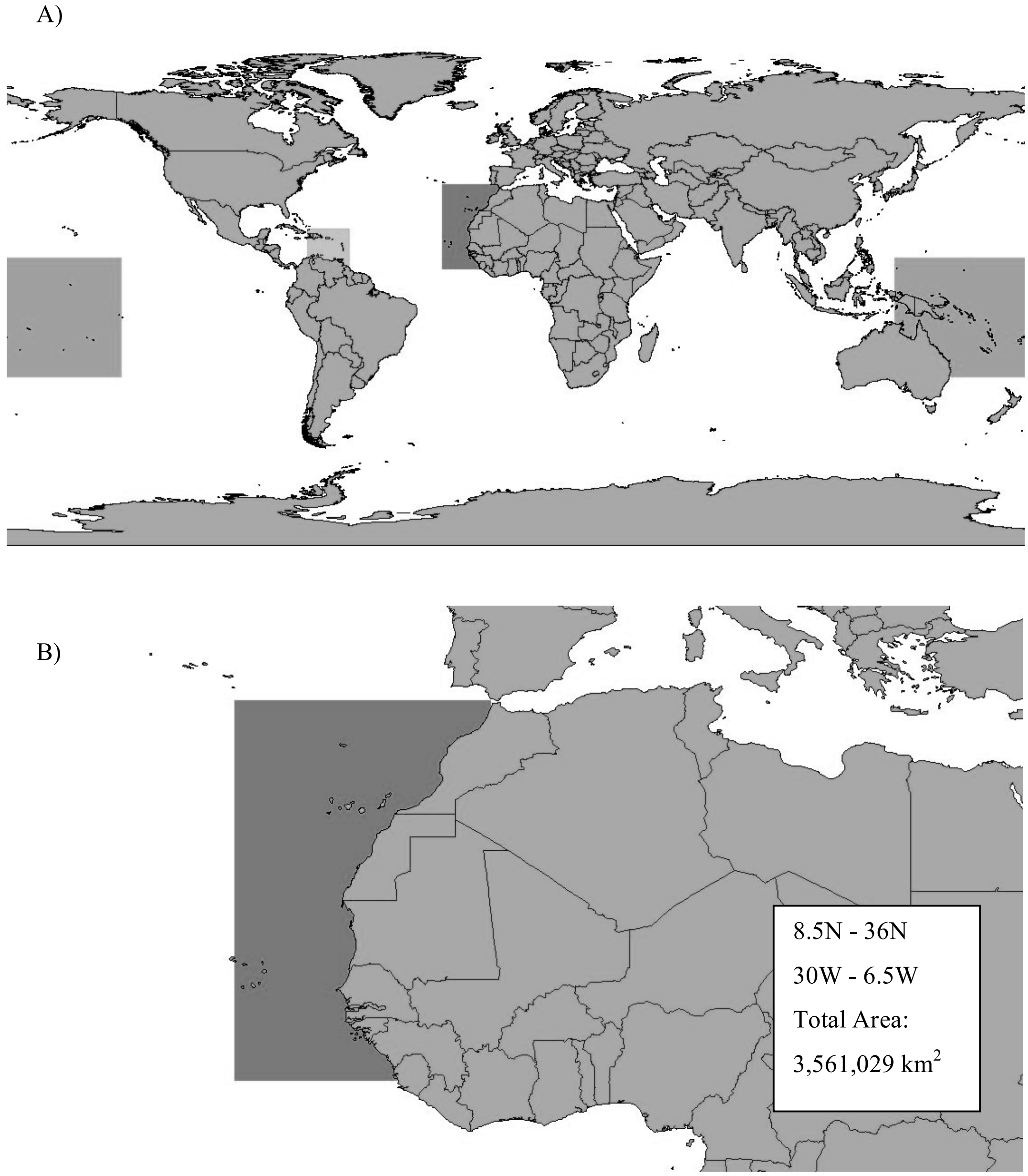


Figure 2

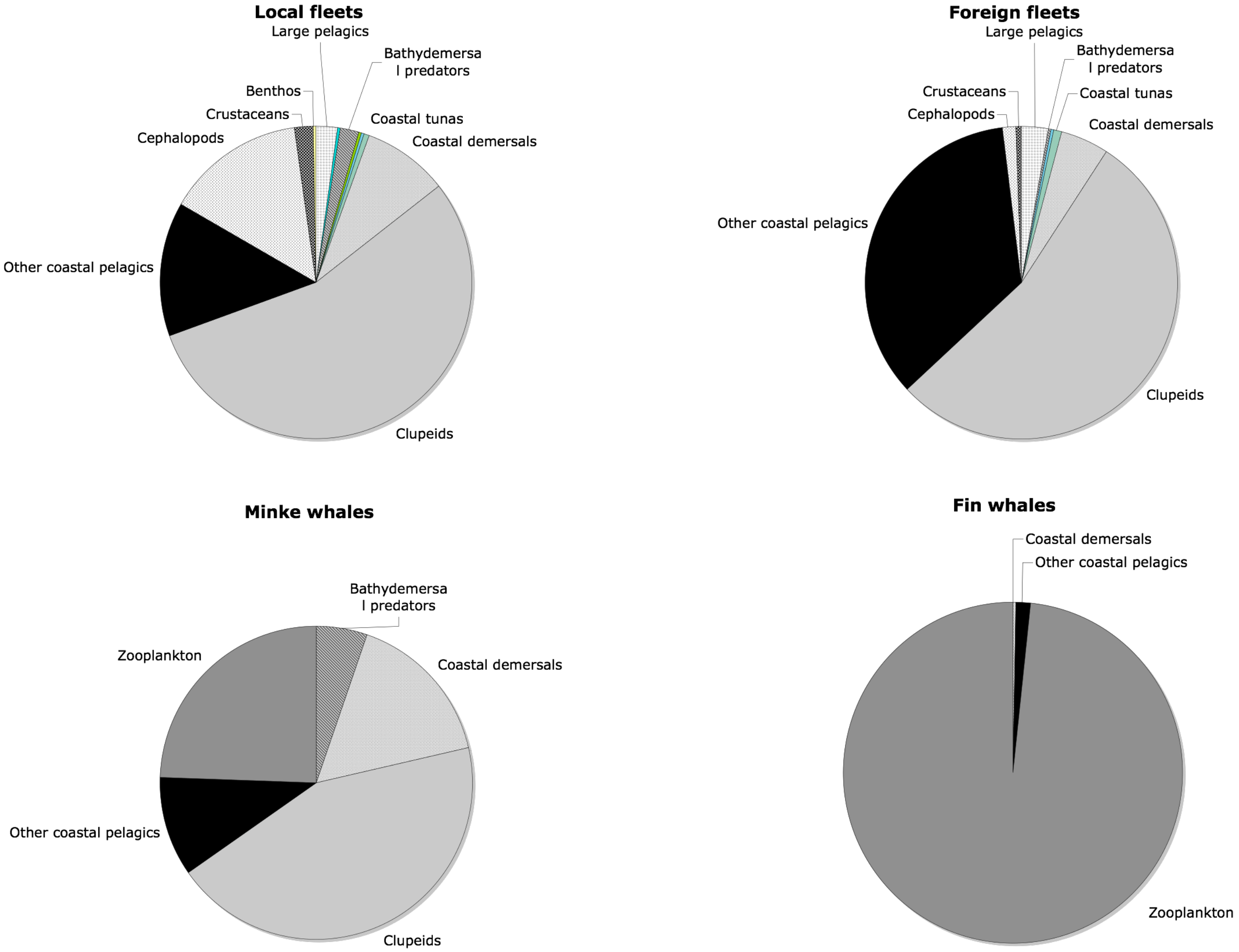

Local fleets
Large pelagics
Bathydemersa l predators
Benthos
Crustaceans
Coastal tunas
Cephalopods
Coastal demersals
Other coastal pelagics
Clupeids
Foreign fleets
Large pelagics
Bathydemersa l predators
Crustaceans
Coastal tunas
Cephalopods
Coastal demersals
Other coastal pelagics
Clupeids
Minke whales
Bathydemersa l predators
Zooplankton
Coastal demersals
Other coastal pelagics
Clupeids
Fin whales
Coastal demersals
Other coastal pelagics
Zooplankton

Figure 2 (cont.)

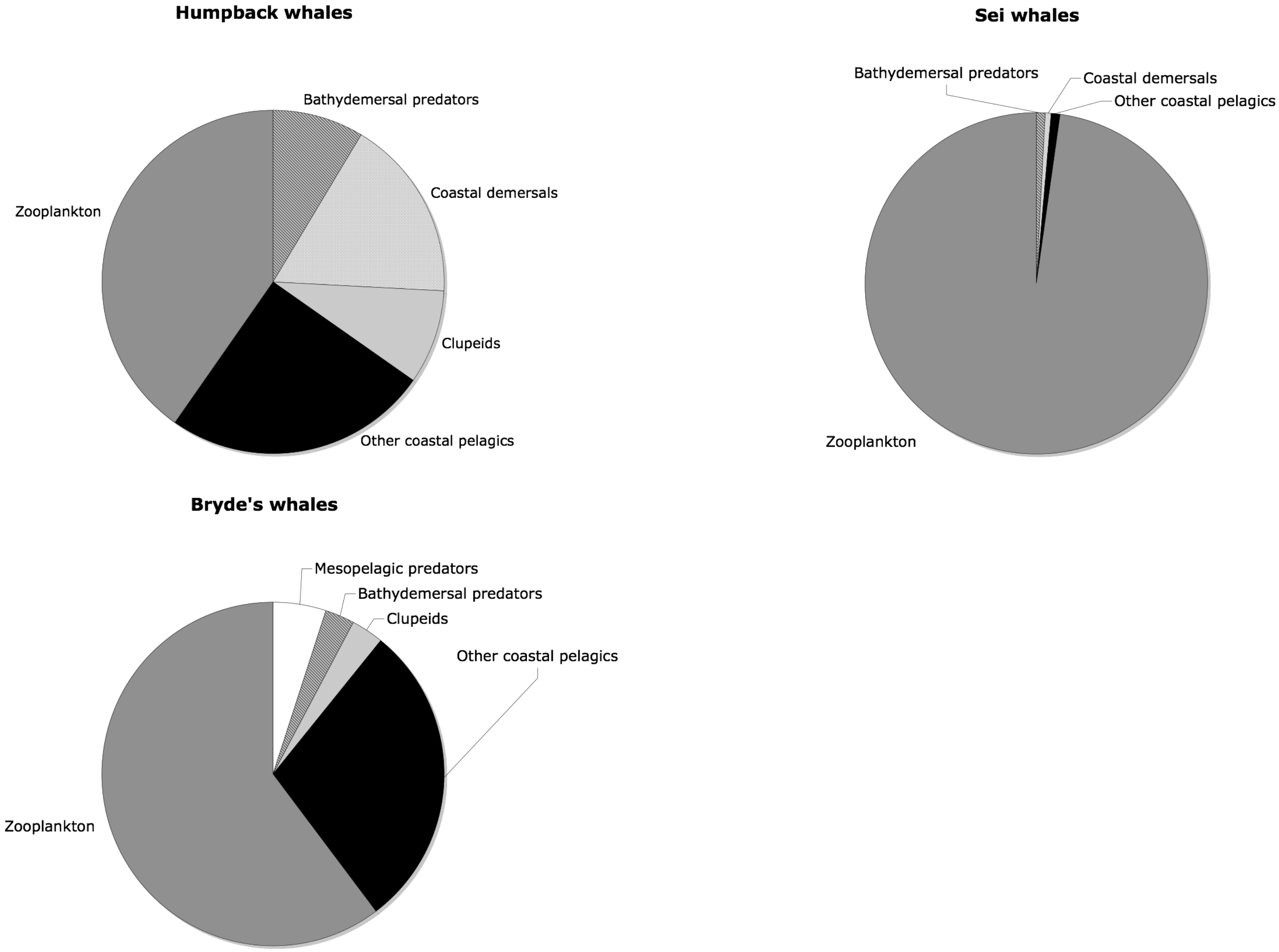


Figure 3

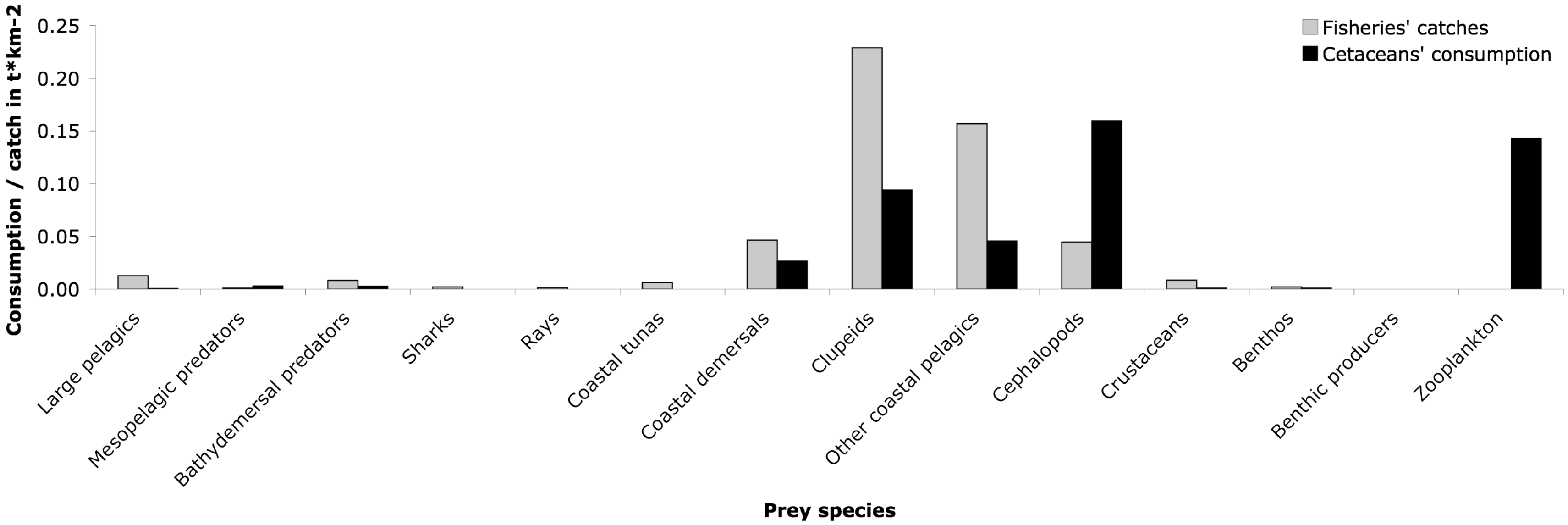

Consumption / catch in t*km-2
0.25
0.20
0.15
0.10
0.05
0.00
Fisheries' catches
Cetaceans' consumption
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Prey species

Figure 4

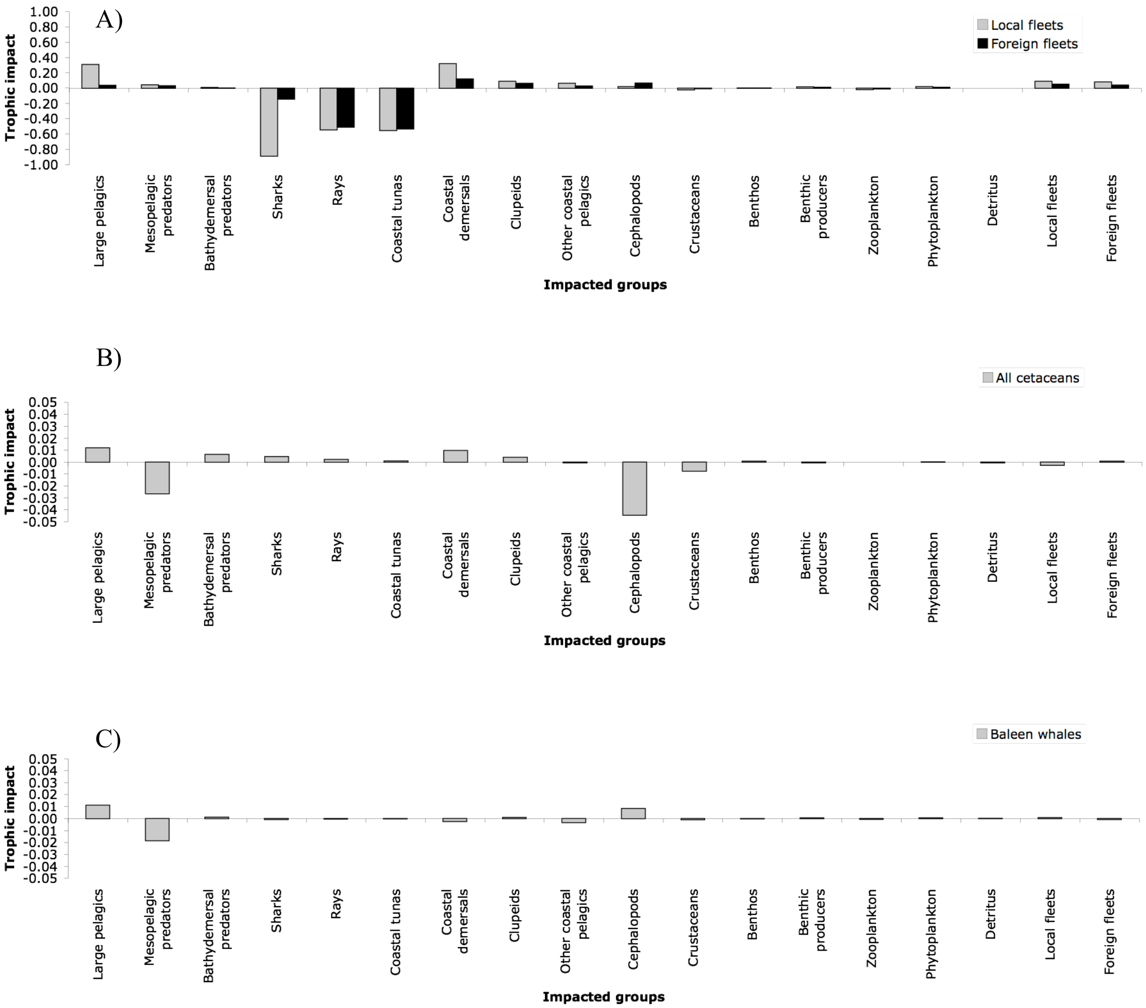

A)
Local fleets
Foreign fleets
Trophic impact
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Local fleets
Foreign fleets
Impacted groups
B)
All cetaceans
Trophic impact
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Local fleets
Foreign fleets
Impacted groups
C)
Baleen whales
Trophic impact
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Local fleets
Foreign fleets
Impacted groups

Figure 5.

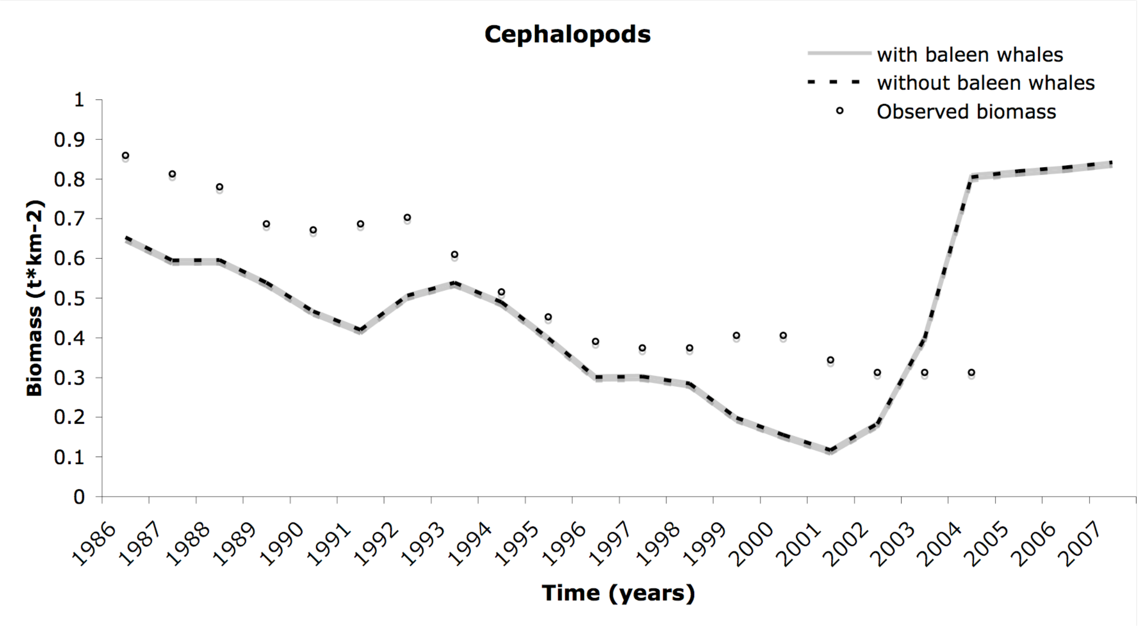
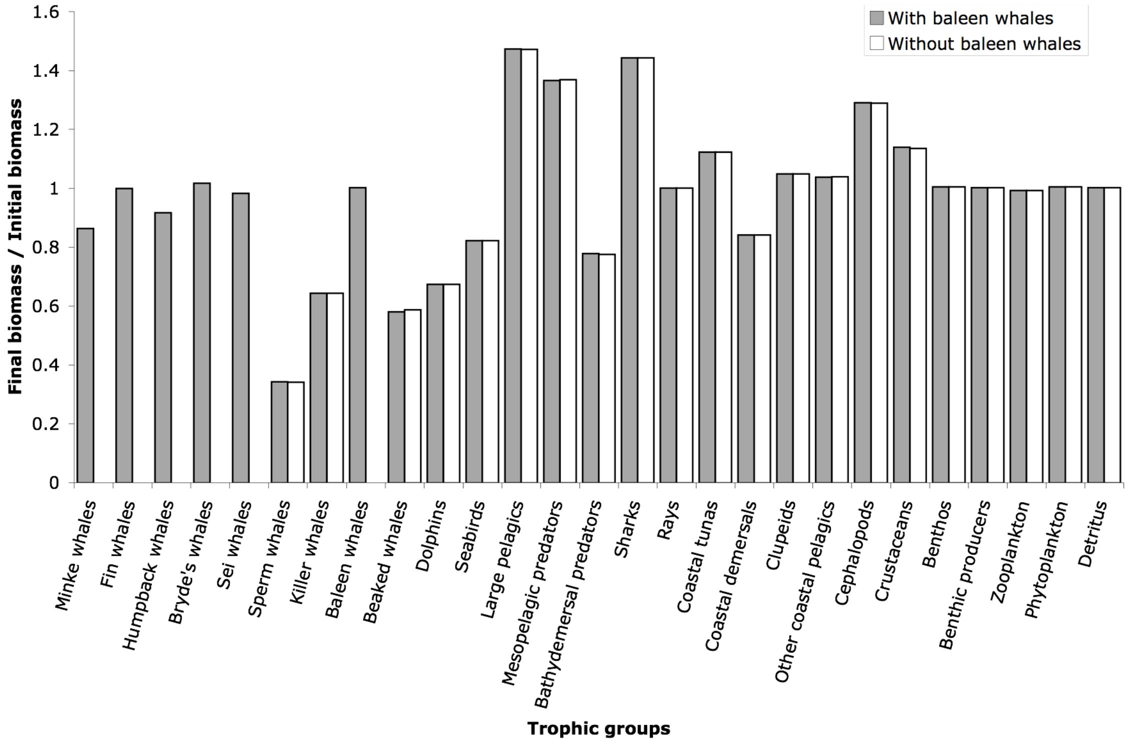

Cephalopods
with baleen whales
without baleen whales
Observed biomass
Biomass (t*km-2)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Time (years)

Figure 6.


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Final biomass / Initial biomass
With baleen whales
Without baleen whales
Minke whales
Fin whales
Humpback whales
Bryde's whales
Sei whales
Sperm whales
Killer whales
Baleen whales
Beaked whales
Dolphins
Seabirds
Large pelagics
Mesopelagic predators
Bathydemersal predators
Sharks
Rays
Coastal tunas
Coastal demersals
Clupeids
Other coastal pelagics
Cephalopods
Crustaceans
Benthos
Benthic producers
Zooplankton
Phytoplankton
Detritus
Trophic groups

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CONCLUSIONS OF THE LENFEST OCEAN PROGRAM-WWF WAMER JOINT WORKSHOP

"WHALES AND FISH INTERACTIONS: ARE THE GREAT WHALES A THREAT TO FISHERIES?"

DAKAR, SENEGAL, 08-09 MAY, 2008

1. The Workshop "Whales and Fish Interactions: Are Great Whales a Threat to Fisheries?" took place on 08-09 May 2008 in Dakar. The opening ceremony was chaired by His Excellency M. Souleymane Ndéné Ndiaye, Minister of State, Minister for Maritime Economy, Fisheries and Aquaculture. The Workshop was heightened by the participation of a delegation of Senegalese Parliamentarians member of the Parliamentarians' Network for the Protection of the Environment. It gathered scientific experts from the West African sub-region and elsewhere, and high level civil servants with responsibilities in fisheries management. The purpose of the workshop was to examine the work undertaken by the Lenfest Ocean Program on whales and fish interactions and to make recommendations for the continuation of this work.

2. The work on-going under the aegis of the Lenfest Ocean Program[1] in cooperation with the WWF West African Marine Eco-Region Office (WWF-WAMER[2]) constitutes an important step for a better understanding of the role of cetaceans, particularly the great whales, in the ecosystem of the West African sub-region.

3. On the basis of detailed presentations on the work underway, the workshop participants made recommendations to the Lenfest team to improve the data and analysis of the project. This requires taking account of additional data currently available in several countries in the sub-region, separating in the simulations the Bryde's whales and sei whales from the other baleen whales, and applying a 100% feeding rate to the Bryde's whale because it is resident in the study area. Data on illegal, unregulated or unreported (IUU) fishing should also be taken into account. It would also be useful to publish or make otherwise publicly available the sightings data collected during joint Japan-West African line transect surveys of cetaceans off Northwest African coasts so that they can be incorporated into the analysis, as well as where available stomach content analysis from whale strandings or other non-lethal methods for analysis of feeding habits.

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[1] http://www.lenfestocean.org

[2] http://www.panda.org/about_wwf/where_we_work/africa/solutions_by_region/wamer/index.cfm

4. The workshop welcomes the fact that the Lenfest study is largely based on the best available data published by scientific experts from the sub-region, and that Lenfest scientific experts have come to Dakar in a spirit of collaboration in order to identify opportunities for work in common and for the sharing of additional data with a view to improving the quality of the results and seeking to partner with scientists from the sub-region.

5. In order to secure transparent partnerships, scientific cooperation requests should be communicated in advance and in writing to the local scientific institutions and NGOs likely to hold them.

6. The importance of capacity building and financial support for local researchers from within the sub-region must be emphasized and reminded to intergovernmental, governmental and non-governmental institutions. The study of whale strandings in the sub-region is an example of a regional research opportunity that is currently lacking resources.

7. The workshop appreciates the fact that the Lenfest scientists plan to present their preliminary results to the Scientific Committee of the International Whaling Commission in June 2008 in Santiago, Chile. It is hoped that the data from Japanese-West African scientific sighting surveys will be available for them to be taken into account.

8. The research results presented at the workshop are preliminary, but they suggest no competition between great whales and local or foreign fisheries in the sub-region. Recognizing the shortage of data available in the sub-region, the Lenfest scientists tested the significance of their data assumptions by making extreme assumptions, and still found that their analysis suggested no competition between whales and fisheries in the sub-region. The comments collected at the workshop will be taken into account to improve data and model quality and the accuracy of the results.

9. Noting that with the current state of knowledge it is not possible to conclude whether great whales have an effect on fisheries in the sub-region, it is important to improve the characterization of the Canary Current ecosystem and to clarify the role of whales in it.

10. The participants appreciate the active participation of Senegalese Parliamentarians at the workshop, especially their contributions about the need to respect all of nature’s creatures so they can live in balance, the need to respect local fishing communities and their culture and the need to provide information accessible to the general public.

11. At the end of the day, the final goal must be restoring the balance of marine ecosystems, including the recovery of fisheries and marine biodiversity including the great whales, and having in mind the well-being of humans whose economy and lives depend on healthy marine ecosystems.

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