Competition between Marine Mammals and Fisheries: Food for Thought

8
CHAPTER

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Introduction

Marine mammals and humans have co-existed on this planet for several hundred thousand years. Both rely heavily on the exploitation of marine resources, though whales, dolphins, and pinnipeds have been doing so for much longer, roaming the oceans for millions of years, long before the emergence of modern humans (Hoelzel 2002). It is not surprising that, when there is a "new kid on the block," co-existence is not always very peaceful, and many of the encounters between humans and marine mammals result in a variety of conflicts.

Room for Conflict

Many species of marine mammals are affected and frequently threatened by fisheries and other human activities (Northridge 1991, 2002). In the past the main threats were large-scale whaling (Clapham and Baker 2002) and sealing operations (Gales and Burton 1989; Knox 1994; Rodriguez and Bastida 1998). These focused initially on the waters of northern Europe and Asia, but soon extended all the way to Antarctica and reduced countless populations to small fractions of their former abundance (Perry, DeMaster, and Silber 1999) or wiped them out completely, as with the now-extinct Atlantic gray whale (Mitchell and Mead 1977) or the Caribbean monk seal (Kenyon 1977; Gilmartin and Forcada 2002). Today, humans adversely affect marine mammals mainly through incidental entanglement in fishing gear (Northridge 1991, 2002; Harwood et al. 1999; Kaschner 2003), chemical (Mossner and Ballschmiter 1997; Borrell and Reijnders 1999; Coombs 2004) and acoustical pollution (Johnston and Woodley 1998; Jepsen et al. 2003), and, in some cases, ship strikes (Clapham, Young, and Brownell 1999; Fujiwara and Caswell 2001). Some populations close to the point of extinction are the vaquita (D'Agrosa, Lennert-Cody, and Vidal 2000), the Mediterranean (Aguilar 1998; Ridoux 2001; Gucu, Gucu, and Orek 2004) and Hawaiian monk seals (Carretta et al. 2002), and the western North Atlantic right whale (Perry, DeMaster, and Silber 1999; Committee on the Status of Endangered Wildlife in Canada 2003). On the other hand, there are examples of some marine mammals potentially adversely affecting fisheries. Controversial cases include damaging of gear (e.g., harbor seals vs. fish farms) (Johnston 1997; Fertl 2002), devaluation of catch through depredation (killer whales vs. longline fisheries in Alaska) (Dahlheim 1988; Fertl 2002), or, indirectly, through costs incurred by gear modifications that are required to reduce anthropogenic impacts on marine mammal species (e.g., dolphin-excluder devices, pingers) (Harwood 1999; Palka 2000; Read 2000; Culik et al. 2001).

Is Competition a Problem?

Competition between marine mammals and fisheries for available marine food resources has often been mentioned as another issue of concern (Beddington, Beverton, and Lavigne 1985; Harwood and Croxall 1988; Plagányi and Butterworth 2002). This is understandable, since many marine mammal species, in common with humans, operate near or at the top of the marine food web (Pauly et al. 1998b). In recent years, as the fisheries crisis has developed from a set of regional problems to a global concern (Pauly et al. 2002, 2003), and the animal protein that millions of people depend on is in increasingly shorter supply, there is a growing need to find scapegoats for the collapse of fisheries. Most marine mammals are large—suggesting that they must eat a great deal—and visible to us, at least in comparison with other marine top predators, such as piscivorous fish. Moreover, some species—notably various species of fur seals (Torres 1987; Wickens and York 1997)—have recovered from previous levels of high exploitation and their populations are increasing, although population levels of most species are still far below their pre-exploitation abundance (Torres 1987; Wickens and York 1997; Perry, DeMaster, and Silber 1999). For these reasons, whales, dolphins, and pinnipeds are likely culprits behind the problems various fisheries are facing. Thus the voices of countries and corporations with large fishing interests, requesting "holistic management" that includes "the utilization of marine mammals such as whales...to increase catch from the oceans" (Institute of Cetacean Research 2001a, n.p.), have been growing louder. As a consequence, much political pressure has been applied in recent years in various international fora concerned with the management of global marine resources to begin to address competition between marine mammals and fisheries on a global scale (van Zile 2000; Food and Agriculture Organization of the United Nations 2001; Holt 2004).

What Is Competition?

From an ecological perspective, competition is a situation where the simultaneous presence of two resource consumers is mutually disadvantageous (Plagánzi and Butterworth 2002). A rarely acknowledged but implicit assumption is that removal of one of the players would translate into direct benefits for the remaining player. In the context of the proposed competition between marine mammals and fisheries, competition occurs when both marine mammals and fisheries consume the same types of food in the same general geographical areas (and water depths). More important though, competition occurs only if the removal of either marine mammals or fisheries results in a direct increase in food available to the other (Cooke 2002; International Whaling Commission 2003).

Measuring Competition

Many studies have attempted to qualitatively and quantitatively assess the ecological role of marine mammals and the extent of their trophic competition or overlap with fisheries (Harwood and Croxall 1988; Sigurjónsson and Vikingsson 1992; Bowen 1997; Trites, Christensen, and Pauly 1997; Hammill and Stenson 2000; Thomson et al. 2000; Yodzis 2001; Boyd 2002). To address this question, various approaches have been applied to the problem of modeling marine mammal food consumption and the potential effects of this intake on fishery yields, reviewed in detail elsewhere (Cooke 2002; Harwood and MacLaren 2002; International Whaling Commission 2003). Existing approaches range from simple, static "who-eats-how-much-of-what" models to very sophisticated trophodynamic ecosystems models that consider, among other things, interactions among multiple species changing over time and in space (Bogstad, Hauge, and Ulltang 1997; International Council for the Exploration of the Sea 1997; Bogstad, Haug, and Mehl 2000; Christensen and Walters 2000; Livingston and Jurado-Molina 2000). The "who-eats-how-much" models generally are regarded as inadequate to investigate potential competition since they largely ignore important issues of uncertainty and food web interactions (Harwood and MacLaren 2002; International Whaling Commission 2003). However, the application of more complex models, such as those recommended by the United Nations Environment Programme to investigate proposals for marine mammal culls (1999), is often hampered by the lack of availability of necessary data (Tjelmeland 2001; Harwood and MacLaren 2002; International Whaling Commission 2003) and the degree of uncertainty associated with their parameters.

It has been suggested that an undesired consequence of the efforts to focus on the uncertainties and difficulties associated with the application of complex models has been an effective rejection of the "scientific approach" by politicians, administrators, fishers, and laypeople. Thus many people end up considering the simpler "who-eats-how-much-of-what" approach as a "commonsense" notion wherein fewer marine mammals must mean more fish for humans to catch (Holt 2004). As another side effect of their data requirements, most complex models focus on relatively small geographic areas (Stenson and Perry 2001; Bjørge et al. 2002; Garcia-Tiscar et al. 2003). Although this may suffice for some coastal species, such small scales may be inappropriate for species that are highly migratory and range globally or across large ocean basins. As a result, perception of the extent of the problem in terms of resource overlap between fisheries and marine mammal species is distorted by models that are restricted to areas that represent only a fraction of a species' distributional range.

We propose a different type of approach, allowing some perspective on the issue of potential competition between fisheries and marine mammals on a global scale. By developing further the "who-eats-how-much-of-what" approach, we can demonstrate that the application of some true common sense[1] may be sufficient to counter claims that culling marine mammals will help us alleviate the major problems the world's fisheries are facing today, and even world hunger.

What We Do

In this essay we summarize the major flaws in the case for culling, put forward at international fora with increasing insistence, which blames marine mammals for the world's fisheries crisis and promotes the pre-emptive removal of marine mammals as a solution to problems such as globally dwindling fish stocks and world hunger. More important, however, we show that, even though this group of predators does collectively consume a large quantity of marine resources as part of its natural role in marine ecosystems, there is likely very little actual competition between "them" and "us," mainly because marine mammals, to a large extent, consume food items that humans do not catch and/or consume them in places where fisheries do not operate.

Who Eats How MUCH?

The Naïve Approach

Substantial political pressure has been applied in recent years to promote the claim that competition between marine mammals and fisheries is a serious global issue that needs to be addressed in the context of world hunger in general and dwindling fish stocks specifically (van Zile 2000; Food and Agriculture Organization of the United Nations 2001; Holt 2004). These claims are based on very simplistic food consumption models—crude so-called surplus yield calculations (Harwood and MacLaren 2002)—and are referred to here as the "naïve" approach. These models calculate the quantity of prey taken by marine mammal species by simply estimating the amount of food consumed by one animal of a specific species based on its estimated mean weight, multiplying this amount by the total estimated number of animals of this species, and then summing this estimate of food intake for all or major subgroups of marine mammal species. Estimates thus derived put the total amount consumed by cetaceans worldwide, for instance, at three to six times the global marine commercial fisheries catch (Institute of Cetacean Research 2001b; Tamura 2003). As a result it is often implied that a reduction in the predator population will translate directly into a corresponding increase in prey (Kenney et al. 1997; Sigurjónsson and Víkingsoon 1997; MacLaren et al. 2002; Tamura 2003) and that this increase would then be available for fisheries exploitation.

Problems with the Naïve Approach

There are many problems associated with the naïve approach—so many that the scientific community has effectively refused even to consider a discussion about culling marine mammal species based on these simple estimates (International Whaling Commission 2003). One problem is that reliable and comprehensive abundance estimates are still lacking for the majority of marine mammal species throughout much of their distributional ranges—most global estimates represent only guesstimates at best. Moreover, since we cannot directly measure the amount of food consumed by the animals, our estimates of food intake rely on physiological models that are largely based on what we know about the relationship between the amount an animal must eat to sustain itself given a certain body mass (Boyd 2002; Leaper and Lavigne 2002). However, we still know very little about the factors that influence this relationship, and the naïve approach effectively ignores the large variations among individuals and species associated with differences in age and seasons, and the proportion of time spent on different activities, to mention only a few. More important, the naïve approach completely ignores the complex range of dynamic factors that affect how removal of high-level predators affects ecosystems (Parsons 1992), some of which we discuss later. For all of these reasons, gross estimates of the total amount of fish consumed by marine mammals, by themselves, provide little or no information about the net "gain" in fisheries catches that might result from a reduction in numbers of any marine mammal population.

But for the Sake of Argument...

It may seem intuitive that, because whales and other marine mammals are big and eat a great deal, having fewer of them should result in more fish being available for human consumption. There is as yet no model that is detailed enough and meets sufficiently stringent scientific requirements that would allow us to reliably investigate the effects, positive or negative, that reduction of marine mammal populations might have on net fisheries catches. Indeed, such a model may never be developed. Therefore, rather than focusing our efforts on attempting to do what probably cannot be done, we instead show the flaws in the arguments that favor resumption of whaling using the naïve approach—based on commonsense considerations and a few additional parameters.

We used a simple food consumption model, outlined briefly in the sidebar on page 98, to estimate global annual food consumption of

Basic Food Consumption Model: Who Is Eating How Much of What?

We generated estimates of annual food consumption during the 1990s for each marine mammal species using a simple food consumption model[17] (Trites, Christensen, and Pauly 1997) and syntheses of recently published information about the population abundances, sex ratios, sex-specific mean weights, and weight-specific feeding rates extracted from more than three thousand sources of primary and secondary literature compiled into a global database. To convey the extent of uncertainty associated with this total estimate of marine mammal food consumption, we generated minimum and maximum estimates by running the model with different feeding rates but ignoring effects such as seasonal differences in food intake (Kaschner 2004). Corresponding mean global fisheries catches for the 1990s were taken from the global fisheries catch database developed and maintained by the Sea Around Us Project at the Fisheries Centre (University of British Columbia, Canada) (sidebar on page 100) and averaged over the last decade. Note that this is an estimate of only the reported catches and that total takes by fisheries are probably closer to 150 million tons per year, if illegal, unreported, or unregulated (IUU) catches are taken into account (Pauly et al 2002) (Figure 1). The percentages of different food types in total marine mammal consumption were estimated based on the diet composition standardized across species, itself based on two hundred published qualitative and quantitative studies of species-specific feeding habits (Pauly et al. 1998a). The proportions of different food types represented in fisheries catches were obtained by assigning individual target species/taxa to the appropriate food type category based on life history, size, and habitat preferences of the target species or taxa. Food types included benthic invertebrates (BI), large zooplankton (LZ), small squid (SS), large squid (LS), small pelagic fishes (SP), mesopelagic fish (MP), miscellaneous fish (MF), higher vertebrates (HV), and an additional food type containing all catches of species targeted only by fisheries, such as large tuna, which we called non-marine mammal fishes (NM) (Figure 2).

different groups of marine mammals to compare them with catches taken by world fisheries (Figure 1). Mean estimates for all groups are indeed almost as high as or slightly higher than global reported fisheries catches (although it should be noted that total fisheries catches are likely underestimated (Pauly et al. 2002). To convey—at least to some extent—the degree of uncertainty associated with these estimates, we have also included minimum and maximum estimates generated by the model, which illustrate the wide margin for error that must be considered before attempting to use such estimates in a management context.

We arrive at maximum estimates of global mean food intake for baleen whales that are similar to those published previously (Institute of Cetacean Research 2001a; Tamura 2003). Although there are comparatively few of this species,[2] baleen whales do, indeed, take the bulk of the total food consumed by all marine mammals due to their large size. However, in terms of the type of food targeted also by fisheries (shown in red in Figure 1; mostly small pelagics, benthic invertebrates, and a group we have dubbed "miscellaneous fishes," which mainly includes medium-sized groundfish and pelagic fish species), baleen whales likely consume less or at least no more than fisheries do every year. The majority of what baleen whales (as well as toothed whales and pinnipeds) eat consists of food types that, for reasons of taste and accessibility, are of little interest to commercial fisheries. We expand on this important consideration of *what* is being eaten in the next section.

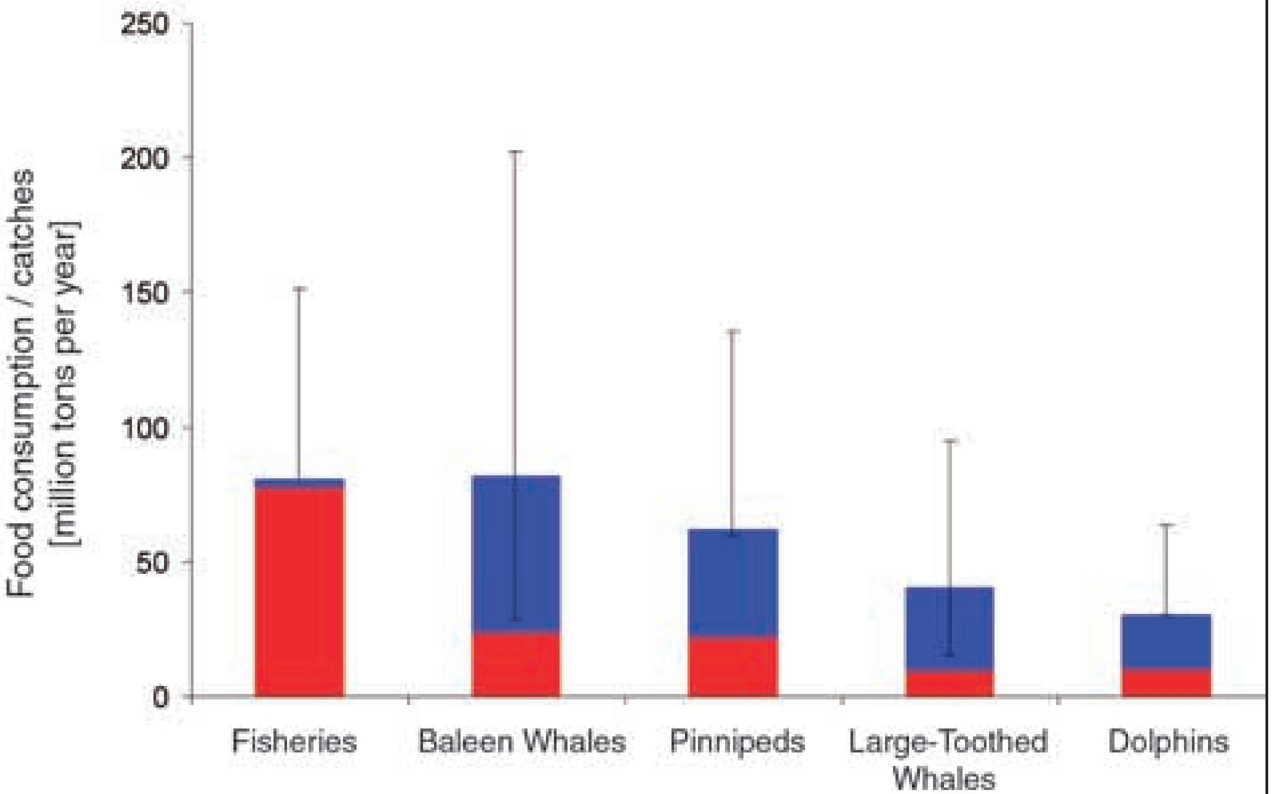
Who Eats How Much of What?

Different Species, Different Strokes

During their foraging dives, many marine mammal species regularly venture to depths of more than a thousand meters (Campagna et al. 1998; Hooker and Baird 1999; Hindell et al. 2002; Laidre et al. 2003) and far under the pack ice (Davis et al. 2003), into areas rarely if ever visited by humans. There, they feed on organisms about whose existence we often know only indirectly based on specimens collected from the stomachs of marine mammal species (Fiscus and Rice 1974; Clarke 1996).

Along similar lines, at least some of our favorite seafood delicacies, such as tuna, are rarely if ever consumed by marine mammals. In light of these and many other differences in taste and accessibility, the distinction between which food types are targeted by marine mammals and which by fisheries warrants serious attention. Based on the approach described in the sidebar at left, we specified the relative amount of nine different food types

Figure 1
Who Eats How Much?



Estimated mean annual global catch/food consumption of fisheries and major marine mammal groups during the 1990s (modified from Kaschner 2004). Error bars of marine mammal food consumption indicate minimum and maximum estimates based on different feeding rates (Leaper and Lavigne 2002). Total fisheries catches are probably closer to 150 million tons per year if illegal, unreported, and unregulated catches are taken into account (Pauly et al. 2002). Marine mammals' food intake consisting of prey types that are also major groups targeted by fisheries are presented in red (mainly small pelagic fishes, miscellaneous fishes, and benthic invertebrates). Note that, although mean global food consumption of all marine mammals combined is estimated to be several times higher than total fisheries catches, the majority of food types the various marine mammal groups consume are not targeted by fisheries.

consumed by major marine mammal groups and fisheries (Figure 2). The majority of all food consumed by any marine mammal group consists of food types that are of little interest to commercial fisheries. Diets of pinnipeds and dolphins appear to be most similar to global fisheries catch composition, while the diet of large toothed whales, which feed predominantly on large, deep-sea squid species not targeted by fisheries (Clarke, Martins, and Pascoe 1993), shows the least similarity.

Size—among Other Things—Matters

Like all other parameters in the basic food consumption model, the marine mammal diet composition is affected by uncertainties. Problems arise due to the difficulties associated with obtaining diet information from sufficient sample sizes in the wild (Barros and Clarke 2002). Diet composition estimates based on stomach content analyses tend to be biased toward cephalopods, as their hard parts are less readily digested than those of other prey groups (Zeppelin et al. 2004). Such biases may be addressed by applying correction factors that compensate for differential effects of digestion on different prey types (Tollit et al. 1997, 2003). More serious biases are introduced by the predominance of stranded animals in the overall sample. Such animals may not be representative of the rest of the population, as they are often sick and/or their stomach contents over-represent the coastal components of their diet (Barros

Modeling and Mapping of Global Fisheries Catches—You Couldn't Have Caught That There!

Until recently, the exact origin of fisheries catches of the world was mostly unknown. The reasons were many, and where fisheries landing statistics exist (and they do, in some form, for the overwhelming majority of the world's fisheries), they usually suffer from a number of deficiencies. Ignoring typical problems of missing/incomplete data and inconsistent units of measure, one of their most common weaknesses is that they are often quite vague, particularly about the identity of the harvested taxa as well as the exact location where they were caught. To overcome this problem, over the past four years, the Sea Around Us Project has developed a spatial allocation process that relies on what might be called the application of common sense (in conjunction with very large amounts of related data stored in supporting databases) to assign the coarse-scale reported landings from large statistical areas into the most probable distribution within a global grid system with 0.5° latitude by 0.5° longitude cell dimensions (approximately 180,000 ocean cells). The basic assumptions are that catches of a particular fish species (or other harvested taxa) by a specific country cannot occur where the reported species does not occur, and that they cannot stem from areas where the country in question is not allowed to fish. Therefore, information about species distributions and fishing access agreements can serve to limit the available area where reported catches can be made within the large statistical area. We developed and used a global database of species distributions based on published maps of occurrence (where available) or by using other sources of information to help restrict the range of exploited taxa, notably water depth (for non-pelagic species), latitudinal limits, statistical areas, proximity to critical habitats (such as seamounts, mangroves, or coral reefs), ice coverage, and historical records. In addition, we compiled large amounts of information describing the access agreements between fishing nations to the fisheries resources of other coastal countries based on formal bilateral agreements, existing joint ventures between governments and private companies and/or associations, and the documented history of fishing before the declaration of exclusive economic zones by various countries and other observations. The intersection of these databases with reported catches by countries from large statistical fishing areas allows the allocation of fine-scale fisheries catches to individual spatial cells. Predicted catch and biomass distributions of taxa exploited by fisheries of the world can be viewed online at *www.seaaround-us.org,* and average catch distribution for the 1990s is shown in Figure 3. (This sidebar is generally adapted from Watson et al. 2004.)

and Clarke 2002). Other, newer molecular methods, including stable isotope (Best and Schell 1996; Hooker et al. 2001; Das et al. 2003) and fatty acid (Iverson 1993; Hooker et al. 2001; Lea et al. 2002; Grahl-Nielsen et al. 2003) analyses, also have biases (Smith, Iverson, and Bowen 1997). Finally, there is substantial geographical and seasonal variation in the diet composition of marine mammal species (Haug et al. 1995; Nilssen 1995; Tamura 2001).

The standardized diet composition used here may be fairly robust to these sources of bias/uncertainty, as the food type categories are very broad.[3] However, due to these biases, the similarity in food types exploited by fisheries and marine mammals shown in Figure 2 is likely to be even lower than suggested here,[4] especially if other aspects, such as differences in prey size, are taken into consideration as well.

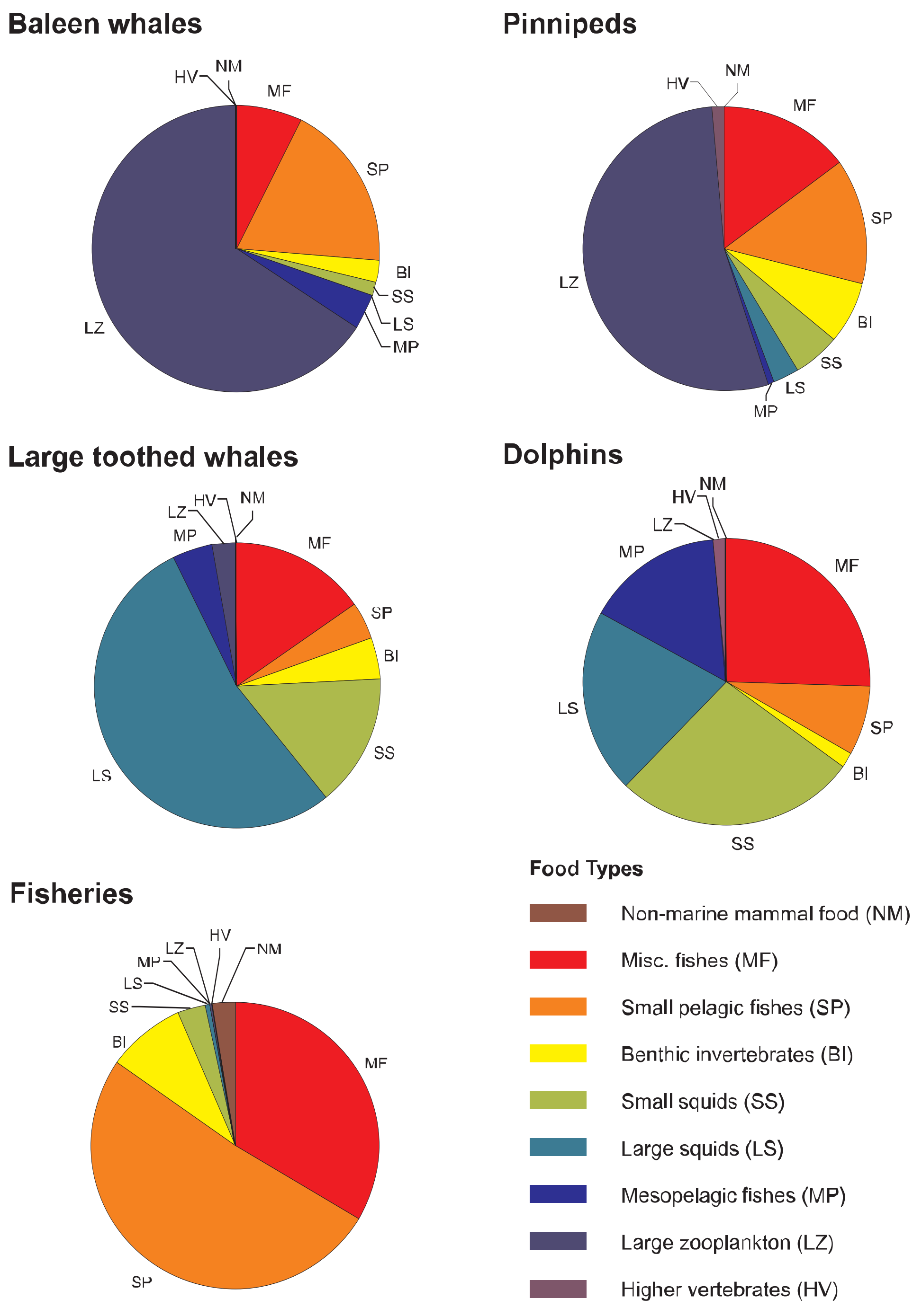
Who Eats How Much of What WHERE?

The spatial overlap of resource exploitation is necessary for competition to occur. In this section, we assess the degree of overlap between marine mammal food consumption and fisheries by comparing on a global scale the areas where marine mammals are likely to feed to the areas in which most fishing activities occur.

Where Are Fisheries?

To illustrate where most human fishing activities occur, we used the mapped distribution of global fisheries for an average year during the 1990s (Figure 3) using a modeling process described briefly in the sidebar at left. As can be seen, the vast majority of fisheries catches is taken along the continental shelves of Europe, North America, Southeast Asia, and the west coast of South America. Highest catches occur where continental shelves are wide, such as the Bering, East China, and North seas, or in highly productive upwelling systems, such as those that can be found along the west coasts of South America and South Africa. However, despite the distant water fleets roaming the oceans and the development of deep-sea fisheries operating far off-

Figure 2
Who Eats How Much of What?



Estimated mean annual global catch/food consumption of marine mammals and fisheries by nine major food types during an average year in the 1990s expressed as proportions of total (from Kaschner 2004). The percentages of different food types in marine mammal consumption were computed based on diet composition standardized across species (Bonfil et al. 1998). Corresponding percentages of different food types in fisheries catches were obtained by assigning individual target species/taxa to the appropriate food type category based on life history, size, and habitat preferences of the target species or taxa. Food types mainly consumed by marine mammals are presented in hues of blue and green, and food types that are major fisheries target groups are presented in yellows and reds. Note that food types primarily targeted by fisheries represent only a small proportion of the diet of any marine mammal group.

shore, major fishing grounds generally lie in close proximity to areas with high human populations, off the coasts of industrial fishing nations. It is noteworthy that comparatively little catch is taken off the coasts of developing countries, such as in East Africa or even the Indian subcontinent, where fish, caught mostly by small-scale fishers, still represents a major form of sustenance and is often the only source of animal protein (Delgado et al. 2003). Moreover, the majority of catches that are taken along the coasts of developing countries (e.g., along the coast of northwest Africa) are not harvested by local fishers, but rather by the large trawlers of distant water fleets of industrial nations (Bonfil et al. 1998).

Where Are Marine Mammals?

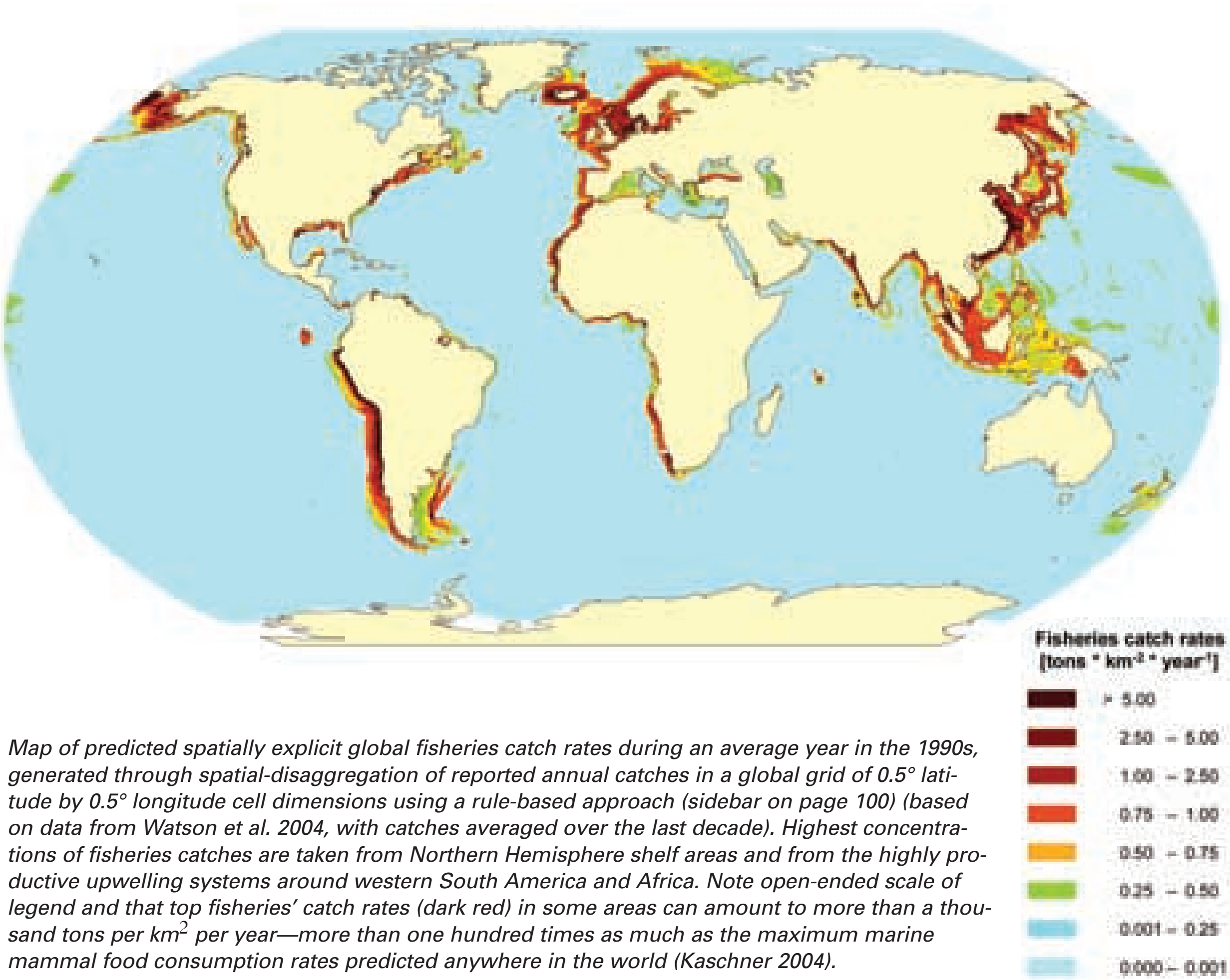
Unlike humans, marine mammals are true creatures of the sea and spend the majority, if not all, of their time living and feeding in the oceans. Except for a few species that haul out on land during reproductive seasons or have very small coastal ranges, distribution of marine mammals is not restricted by the distance to the nearest landmass or the climatic conditions that largely influence the locations of fishing grounds and major human settlements. Conversely, many species occur predominantly in geographic areas still largely inaccessible and/or rarely frequented by humans, such as the ice-breeding seals of the Northern and Southern hemispheres or many of the dolphin or whale species predominantly occurring in tropical offshore waters. Because of the vastness of the oceans and the elusiveness of many species, it is difficult to determine accurately where they occur and feed.

Here we have used a novel habitat suitability modeling approach, outlined in the sidebar below, to map the likely occurrence of marine mammal species based on the relative suitability of the environment, given what is known about their habitat preferences. Based on our predictions, most of the food that marine mammals consume is taken far offshore, in areas where the majority of fishing boats rarely venture. Often cosmopolitan in their distributions, the baleen and large toothed whale species, for example, likely are feeding mostly in the open oceans. Due to the sheer size of the feeding ranges of these species, consumption densities (annual food intake per km^2) are comparatively low and fairly homogeneous across large areas. Food intake of the smaller dolphin species is even lower and appears to be concentrated in temperate waters. Pinniped food consumption, in contrast, tends to be associated more closely

Modeling and Mapping Large-Scale Marine Mammal Distributions: We May Know More than We Think We Know...

Delineation of marine mammal distributions is greatly hampered by the vastness of the marine environment and the low densities of many species. Since marine mammals spend the majority of their lives under water and roam widely throughout oceans, it is difficult to determine whether a species fails to occur in a particular area or whether we have not spent enough time looking for it or simply missed it when we did look there. All of these factors contribute to the difficulties we encounter when trying to map distributions of any whale, dolphin, or pinniped species. Consequently, most published maps of distribution are tentative, often consisting only of outlines, sketched by experts who represent what they believe to be the maximum boundaries of a given species' occurrence. We have developed a rule-based approach to map the distributions of 115 marine mammal species in a more objective way by exploiting various types of quantitative and qualitative ecological information, including (but not limited to) expert knowledge and general observations (Kaschner 2004). Within a global grid (described in the sidebar on page 100) we used our model to relate quantitatively what is known about a species' general habitat preferences to the environmental conditions in an area, thus effectively showing where the environment may be suitable for a particular whale, dolphin, or pinniped species, given what we know about the types of habitat they tend to prefer. Or put differently, the model rigorously defines the geographic regions that experts describe when they talk about a "coastal, tropical species" (e.g., the Atlantic humpbacked dolphin) or a species that "prefers offshore, polar waters" (e.g., the hooded seal). Although the actual occurrence of a species will depend on a number of additional factors, extensive testing of the model shows that it can already describe, even in its present simple form, known patterns of species occurrence quite well (Kaschner et al. in review; Kaschner et al. in prep.). The predicted distributions for the 115 marine mammal species considered here can be viewed online at *www.seaaroundus.org.*

Figure 3
Where Are Fisheries?



Map of predicted spatially explicit global fisheries catch rates during an average year in the 1990s, generated through spatial-disaggregation of reported annual catches in a global grid of 0.5° latitude by 0.5° longitude cell dimensions using a rule-based approach (sidebar on page 100) (based on data from Watson et al. 2004, with catches averaged over the last decade). Highest concentrations of fisheries catches are taken from Northern Hemisphere shelf areas and from the highly productive upwelling systems around western South America and Africa. Note open-ended scale of legend and that top fisheries' catch rates (dark red) in some areas can amount to more than a thousand tons per km^2 per year—more than one hundred times as much as the maximum marine mammal food consumption rates predicted anywhere in the world (Kaschner 2004).

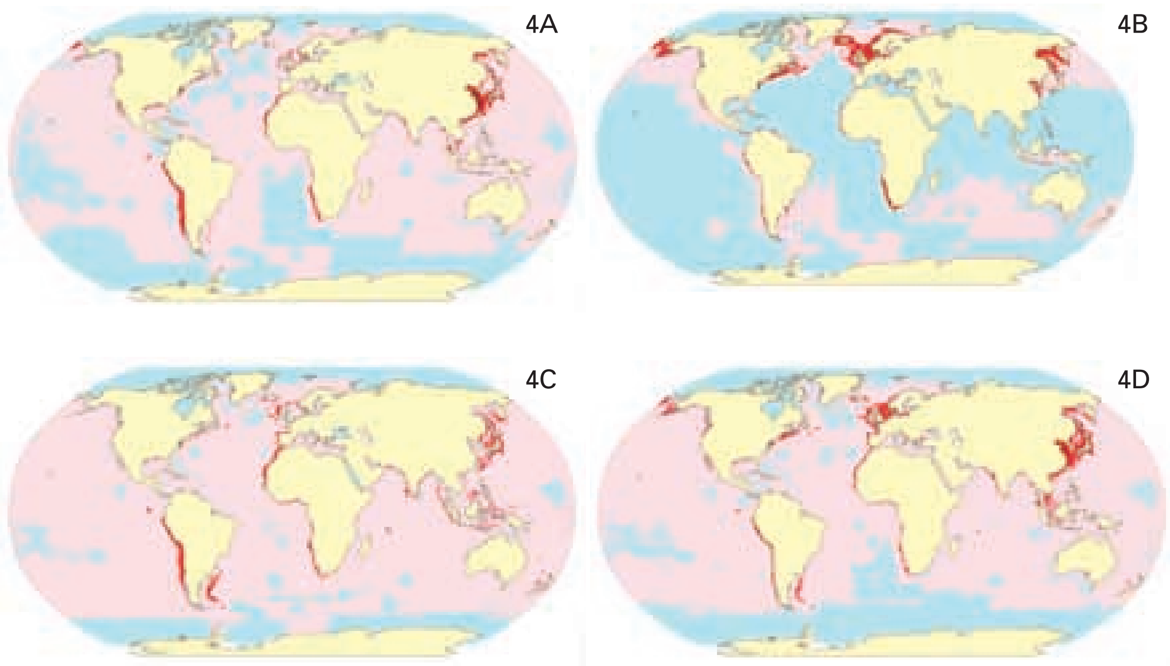
with coasts and shelf areas, with feeding taking place mostly in the polar waters of both hemispheres and the restriction to smaller areas in combination with high abundances of most species results in much higher, locally concentrated feeding densities.

Overall, the concentration of food intake in the higher latitude, polar waters would be even more pronounced if seasonal migrations and feeding patterns of different species were incorporated into our model, particularly those of baleen whales. We also need to stress that some areas of apparent high consumption, such as the South and East China seas for the baleen whales, represent overestimates of food intake rates that are related to a specific feature of our modeling approach, which relies on global abundance estimates to generate local densities and which currently ignores, for example, the effects of population structure and differences in the recovery status or relative abundance between individual subpopulations.[5]

Where They Meet

Using the predicted geographic distributions of marine mammal food consumption and fisheries catches, we now investigate the extent to which they overlap. Again, however, to address the issue of potential competition, we must consider not only how much both players take where, but also what they take. To assess this, we produced global maps showing the overlap in resource exploitation between the major marine mammal groups and fisheries (Figure 4), using an approach that considers not only the extent of spatial and dietary overlap, but also the relative importance of a given area to either group (sidebar on page 105). Areas of overlap between fisheries and marine mammal groups are mostly concentrated in the Northern Hemisphere and appear to occur primarily between pinnipeds and fisheries. In contrast, fisheries' overlap with baleen whales is relatively low, and pre-

Figure 4
Where Do They Meet?



Maps of estimated spatially explicit resource overlap between baleen whales and fisheries (4A), pinnipeds and fisheries (4B), large toothed whales and fisheries(4C), and dolphins and fisheries (4D) (from Kaschner 2004). Maps were produced by computing a modified niche overlap index for each cell in the global grid (sidebar on page 105). The overlap index is based on a comparison of similarity in the composition of diets of marine mammal species and catches of global fisheries in a particular cell, as represented by the proportions of different food types taken by each player in this cell, then weighted by the proportion of total global catch and food consumption taken in the cell. Overall predicted overlap between any marine mammal group and fisheries is quite low from a global perspective, with only a few potential, isolated hot spots concentrated in shelf areas. Specifically, overlap between pinnipeds and dolphins is predicted to be higher in the Northern Hemisphere, while overlap between baleen whales and large toothed whales appears to be higher in the Southern Hemisphere. Comparison with mapped fisheries catch rates suggests that areas of potential high conflict are largely driven by high concentrations of fisheries catches taken from relatively small areas. Predictions of high overlap in some areas, such as the northwestern Pacific for the baleen whales, are misleading because these are based on overestimates of food consumption in these areas. Overestimates are due to a specific feature of our modeling approach that does not account for the effects of population structure and varying degrees of depletion of different populations of the same species (Kaschner 2004).

dicted hot spots in the western North Pacific are largely due to the biases associated with determining food consumption discussed in the previous section. Partially due to dolphins' comparatively low total food intake, the overlap between fisheries and this group is quite low and again mostly concentrated in the Northern Hemisphere. Not surprising, the lowest overlap occurs between fisheries and deep-diving, large toothed whales, whose diets primarily consist of large squid species and mesopelagic fish, not currently exploited by fisheries.

How Big of a Problem Is That?

Overlap between marine mammal groups and fisheries is probably not a global issue but is restricted to a few relatively small geographic regions and a few species.

The skewed perception of this problem by nations in close vicinity to these hot spots of interaction becomes understandable, if still somewhat myopic. However, to put the size of the potential overlap problem into perspective, we calculated the proportion of food consumption that stems from areas of predicted high overlap (Figure 5). In the 1990s, on average, only about 1 percent of all food taken by any marine mammal group was consumed in areas with significant spatial and/or dietary overlap with fisheries catches, indicating that both players should be able to coexist quite peacefully in most of the world's oceans.[6]

The 10–20 percent of global fisheries catches taken in areas of potential high overlap represents a relatively significant amount, of course. Recall, however, that overlap does not automatically equal competition, and our results likely over- rather than underestimate overlap for the reasons outlined in the previous sections. Moreover, as shown by comparing the maps of food consumption and fisheries catches, areas of high overlap appear to be associated largely with areas of extreme concentrations of fisheries extractions, rather than locally concentrated food intake by marine mammals. It is therefore more likely for fisheries to affect marine mammal species adversely in these areas of intense fishing than vice versa, as has already been suggested elsewhere (DeMaster et al. 2001). For species with large distributional ranges, such as the minke whale, the reaction to any potential local depletion of prey species by fisheries may only be to shift to alternate feeding grounds. For those species with very restricted ranges, such as the vaquita in the Gulf of California or South Africa's Heaviside's dolphins, such local depletions of food resources by intensive fisheries may pose serious threats to the survival of the species.

Overall, our analysis indicates that potential competition may be addressed better at a local level. We also note that most of the potential hot spots highlighted by our approach are in areas that have been the focal point of much debate about marine mammal-fisheries interactions, such as in the Bering Sea, with the potential negative effects of U.S. groundfish fisheries on the endangered western population of Steller sea lions (Fritz, Ferrero, and Berg 1995; Loughlin and York 2000) or the Benguela system off southwest Africa, with the potential effects of the increasing population of South African fur seals on the hake stocks in this area (Wickens et al. 1992; Punt and Butterworth 2001). These and other hot spots will require much more detailed investigation to establish the true extent of the problem at hand.

Biological Complications

It is generally agreed that far more complex models are needed, incorporating many additional parameters and requiring more, often still unavailable data (DeMaster et al. 2001; Harwood 2001; International Whaling Commission 2003) to

Spatial Overlap of Marine Mammal Food Consumption and Fisheries Catches: Where They Meet

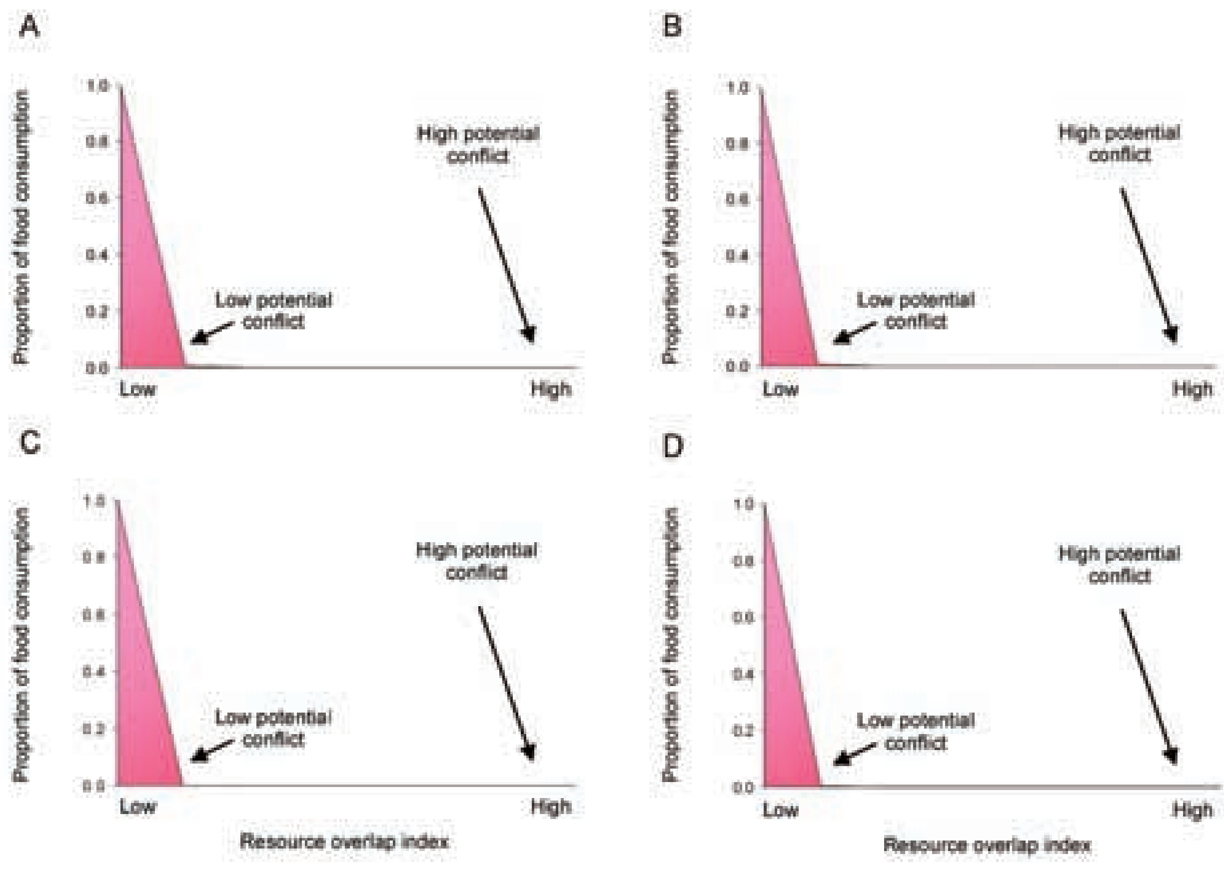
In assessing potential competition between top predators in marine ecosystems, such as humans and many marine mammals, the question of who is eating/catching what where is very important, as this greatly determines the degree of overlap between the two. This question could not be addressed—at least not on a large scale—before the development of mapping techniques for marine mammal distributions and fisheries catches, such as those described in the sidebars on pages 100 and 102. Thanks to our novel approach for mapping large-scale distributions of marine mammal species, we were able to produce global maps showing where specific species are likely to feed by linking our predictions about the likely occurrence of individual species (sidebar on page 102) to the outputs from the basic food consumption model (sidebar on page 98). Food consumption maps for groups of species were then generated by totaling food consumption rates across all species within each group of marine mammals. To assess the degree to which there may be conflict between fisheries and marine mammals, we quantitatively compared "who is likely taking what where" by computing an index of resource exploitation overlap for each individual cell in our global raster with 0.5° latitude by 0.5° longitude cell dimensions. The index is a modified version of one developed initially to investigate the overlap in ecological niches between two species (MacArthur and Levins 1967), based on the comparison of similarity in resource exploitation of both species. Here, we compared the similarity in the composition of diets of marine mammal groups and catches of global fisheries in a particular cell represented by the proportions of different food types taken by each player in this cell, then weighted the qualitative index of diet similarity by the proportion of total global catch and food consumption taken in this cell to get a sense of the relative contribution of each cell to either total marine mammal food consumption or fisheries catches (MacArthur and Levins 1967; Trites, Christensen, and Pauly 1997; Kaschner 2004)[18]. The resulting maps (Figure 4) represent the area where conflicts between specific groups of marine mammals and fisheries may occur: both players potentially are taking comparatively large amounts of similar food types in the same geographic region.

adequately address interactions between marine mammals and fisheries—and the potential far-reaching effects of the removal of top predators from marine ecosystems (Ray 1981; Parsons 1992; Pauly et al. 1998b; DeMaster et al. 2001) in those areas where competition may occur. The assumptions, structures, and data needed for such models have been reviewed extensively elsewhere (DeMaster et al. 2001; Harwood 2001; International Whaling Commission 2003). However, here we highlight the problems associated with attempts to increase fisheries catches by culling marine mammals in those areas where competition is most likely.

Beneficial Predation: We May Be in for Surprises

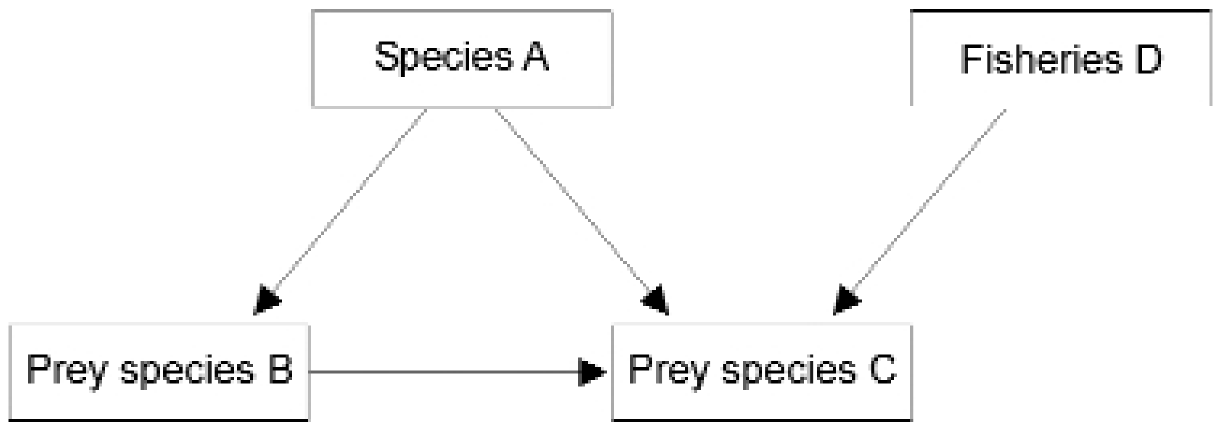
Although the term food chain is often used when describing the feeding interactions underlying marine ecosystem structure, we should speak of "food webs."[7] Finely patterned food webs do not function as efficiently as a simple food chain would: much of the biomass synthesized by phytoplankton fails to reach higher trophic levels and is diverted instead into unproductive pathways, notably the so-called microbial loop. On the other hand, this diversity of pathways protects predators against the disappearance of any of their favorite prey species (Neutel, Heesterbeek, and de Ruiter 2002). It is not surprising therefore that higher-level predators, such as sharks or dol-

Figure 5
And How Big a Problem Is That?



Proportion of mean annual global catch/food consumption taken by baleen whales (A), pinnipeds (B), large toothed whales (C), and dolphins (D) in the 1990s in areas of predicted high or low resource overlap, respectively (from Kaschner, 2004). Note that in all cases more than 99 percent of all marine mammal food consumption stems from areas of very low overlap. Similarly, more than 85 percent of all fisheries catches are taken in areas of very low overlap (Kaschner 2004).

Figure 6
We May Be in for Surprises



Schematic representation of beneficial predation: whale species A feeds on both prey species B and prey species C, the latter a commercially harvested species. In addition, prey species B also feeds on prey species C. This means that a decrease in whale species A actually may result in a net increase of predation on prey species C through B, resulting in an overall decrease of commercially harvested species C. Thus, a reduction in predators will not necessarily result in an increase in a particular prey species.

phins, consume a wide range of prey and concentrate on distinct species only in certain places or at certain times of the year. This feature of marine food webs is also the reason why removing a higher-level predator does not necessarily lead to an increase of what, at certain times and places, appears to be its "preferred" prey (Parsons 1992; Cooke 2002). Basically, predators not only consume their favorite prey but also the competitors and, in many cases, the predators of their prey (Parsons 1992; Punt and Butterworth 2001; Cooke 2002). This is illustrated schematically in Figure 6 in the form of a feeding triangle, representing a ubiquitous feature of marine food webs. Here, a high-level predator, represented by a toothed whale (A), feeds on two species (B and C), with C being the preferred prey, which is also exploited by commercial fisheries (D). B, however, also preys on C (and other organisms—E, F, and so on—of no concern here). In such cases, removing species A will not necessarily make it possible for the biomass of C to increase or even for its production to become available to a fishery. Rather, it is more likely that B (whose numbers were also depressed by A) will increase and consume more of C (Walters and Kitchell 2001). If B happens to be a species that fisheries do not exploit, this will result in the production of C being wasted from the standpoint of fishery D. Indeed, to acquire the production of C, we would have to cull B as well and so on ad infinitum. This conundrum has caused ecologists to coin the term "beneficial predation"—that is, a form of predation wherein the predator (here, A) enhances the production of its prey (here, C) by suppressing potential competitors or predators (here, B). This effect is very common in marine food webs. Indeed, essentially all marine food webs can be conceived as composed of interlinked sets of feeding triangles shown schematically in Figure 6. Removing what appears to be a top predator in such cases only creates new top predators, and the would-be fishery enhancer will find himself ultimately culling 20-centimeter fish so that he can catch more 5-centimeter fish, thus competing with birds, squids, and jellyfish.

Beneficial predation is not an ad hoc concept invented to discourage would-be cullers of marine mammals. Rather, counterintuitive results of removing high-level predators from ecosystems have been well demonstrated in various cases, based on a number of modeling approaches (Parsons 1992; Caddy and Rodhouse 1998; Yodzis 1998, 2001; Crooks and Soulé 1999; Pauly, Christensen, and Walters 2000; Punt and Butterworth 2001, Bjørge et al. 2002; Okey et al. 2004; Morisette, Hammill, and Savenkoff, submitted for publication).[8] In fact, it has been proposed as one reason for a stagnation in global groundfish landings since the 1970s, as it is possible that the reduction of toothed whales and other high-level predators that feed on desirable fish species but also on various squids, which in turn feed on juvenile groundfish, has contributed indirectly—through an increase of cephalopod consumption of juvenile fish—to the inhibition of finfish population recovery (Caddy and Rodhouse 1998; Piatkowski, Pierce, and Morais da Cunha 2001).

How Much Culling—If Any—Is Enough?

One important assumption in the context of competition is that marine mammal food consumption increases directly with marine mammal abundance. Though this is obviously true in general,[9] other factors, such as the vulnerability of prey species to predation (Mackinson et al. 2003), the ability of the predator to switch between prey species, and movements of animals between different areas, greatly influences how much a given species eats in a specific area. The flip side of this, then, is that it may be impossible to determine exactly how many animals would need to be culled to achieve the desired increase in fisheries catches. A study investigating this showed that, even for a very simple food web, many likely scenarios existed in which consumption of a given prey species by a marine mammal species would only decrease noticeably if the predator population was reduced by more than 50 percent (Cooke 2002). Given the wide-ranging movements of most species and the fact that fish and marine mammals tend not to respect human management boundaries, it is highly questionable that we would ever be able to manage marine mammal populations in a manner guaranteed to produce a measurable, long-term increase in fisheries catches.

Other Legitimate Questions

Who Would Get the Fish?

Although this may seem beside the point, we must highlight the questionable use of world hunger as a justification for culling marine mammals and subsequently targeting their prey.[10]

Though an estimated 950 million people worldwide currently rely on fish and shellfish for more than one-third of their animal protein (Plagánzi and Butterworth 2002), the per capita supply of wild-caught fish for human consumption has been declining since the mid-1980s, particularly in developing countries.[11] This is due in part to overfishing, which has led to the decline of global catches since the late 1980s (Watson and Pauly 2001; Pauly et al. 2002, 2003), but also to human population growth. Indeed, no natural resource, including wild-caught fish, could ever meet our ever-growing demand. We will not elaborate on the fact that of the 120–150 million or so tons of fish and invertebrates killed annually by fisheries, only about half is actually eaten by people: about thirty million tons of bycatch are discarded or killed by lost gear (ghost fishing), while a huge amount is lost to spoilage (Ward and Jeffries 2000) and during processing (e.g., gutting, filleting) (Bykov 1983) or left uneaten, in richer countries, at the edge of consumers' plates. Another thirty million tons, however, are fed to various livestock (Pauly et al. 2002) and carnivorous fish—notably salmon, sea bass, groupers, and tuna—in fish farming industries, which are one of the driving factors behind the increased fish exports from developing to developed countries, especially to the United States, the European Union, and Japan (Naylor 2000; Alder and Watson, in prep.).

Contrary to popular opinion, the herrings, sardines, mackerels, and other species ground up to produce the fish meal that is fed to carnivorous fish are, when suitably handled, perfectly edible by humans and are indeed appreciated in many parts of the world. These fish are increasingly hard to find in the markets of developing countries, in areas such as West Africa, where, being relatively cheap, they represented the major source of animal protein for poor people (Naylor 2000).[12] Given these trends, and increasing fish exports from developing to developed countries, it would be completely unrealistic to assume, and disingenuous to claim, that the meat of culled marine mammals or that of their former prey would become a substitute for the fish that is now exported from countries where people "do not have adequate food" (Institute of Cetacean Research 2001b). Indeed, it is precisely the low purchasing power of the people in these countries that prevents them from competing successfully with fish meal producers and fish feedlot operators.

Are We Simply Looking for Scapegoats?

Unlike earlier fisheries declines, which passed mostly unnoticed by the general public, the massive fisheries collapses of the last decades had a broad public impact, so they have generated widespread calls for mitigation (Food and Agricultural Organization of the United Nations 1995). In particular, people have noted that fisheries management has tended so far to focus on single stocks, thus neglecting feeding and other interactions among different species/stocks and their dependence on the health of their ecosystems. There have been, as a result, increasing demands for ecosystem-based fisheries management, or even "ecosystem management."[13] The scientific community has accepted this challenge, and, for the last few years, a lively scientific debate has been conducted in many national and international arenas on this topic. The principal questions asked deal with how to implement such a broad form of management and how to identify suitable indicators and formulate fisheries target and reference points within an ecosystem context.[14] This includes the challenge of achieving set conservation objectives for predators of species targeted by fisheries (Constable 2001).

Those who advocate a broad-based attack on marine mammals, on the other hand, behave as if they already have the answers. Because most fish stocks of the world have been overexploited (including those on which marine mammals rely), the mantra coming from this latter group is that all we have to do is remove marine mammals until the original balance is re-established. Here is a quote to that effect: "When a single species is protected, ignoring its role in the ecosystem, the balance in the ecosystem is disrupted" (Institute of Cetacean Research 2001b, n.p.). Albert Einstein is supposed to have noted that "all complex problems have one simple solution; however, it happens to be completely wrong." Here, not only have the fish been overexploited, but so have the marine mammals. Given reduced fishing pressure, fish can be expected to recover faster[15] than marine mammals (Best 1993; Trites et al. 1999), given their respective reproductive abilities. Indeed, all recent evidence confirms that baleen whales are far less abundant than they were historically (Brownell, Best, and Prescott 1983; Perry, DeMaster, and Silber 1999; Clapham, Young, and Brownell 1999; Clapham and Baker 2002; Holt 2002). Re-establishing the disrupted balance of ecosystems is therefore hardly a simple matter of reducing whale numbers.

What we have is an attempt to find a convenient scapegoat for the mismanagement of fisheries (Holt 2004) and the reduction of catches caused by excess fishing effort throughout the world. This puts the following quotation in context:

> The FAO considers that we cannot increase the harvest from the ocean if we continue present practices. To increase the catch from the ocean, holistic management and sustainable utilization of marine resources including marine mammals, such as whales, is essential. (Institute of Cetacean Research 2001a, n.p.)

This, indeed, is a beautiful example of a non sequitur: yes, we cannot increase landings "if we continue present practices." But the present practices are characterized by waste (e.g., bycatch [Northridge 1984, 1991; Alverson et al. 1994], discarding [Alverson et al. 1994] ghost fishing [Breen 1990]), and pathological management structures (e.g., excess fishing capacity [Mace 1997] and subsidies [Munro and Sumaila 2002]), and these are the practices that, all experts agree, must be overcome, rather than killing more whales, even if we think holistically.

And How about the Birds?

No one has proposed (so far!) killing all seabirds to increase fish available for human consumption. There are millions of seabirds in the world, consuming massive amounts of fish, squid, and other valuable invertebrates. Although birds tend to weigh little individually, their high metabolic rate leads to very high food consumption rates (Ellis and Gabrielsen 2002). Thus, in the aggregate, seabirds have been estimated to consume 50 to 80 million tons of fish and invertebrates per year (de L. Brooke 2004), at least half of what humans kill annually. Yet no one has proposed that seabirds be culled, and, indeed, saving seabirds from death (e.g., by entanglement in fishing gear) is one of the few conservation-related activities that is never disparaged in public, even though it greatly affects the manner in which some fisheries operations are conducted.

Clearly, if those proposing a global attack on marine mammals were consistent, they also should propose that we go after the seabirds. More important, we should eliminate all large fish as well, since they eat immense numbers of other fish, shrimps, and squids, generally far more than taken by marine mammals and seabirds (Livingston 1993; Trites, Christensen, and Pauly 1997). Indeed, the greatest predators of fish are other fish (Trites, Christensen, and Pauly 1997; Furness 2002). But again we are eliminating large predatory fish anyway, as we fish down marine food webs, reducing high-level predator biomasses as we go along (Pauly et al. 1998b; Christensen et al. 2003; Myers and Worm 2003). Nevertheless, overall catches are decreasing,[16] notably because, in the process, we are eliminating beneficial predation.

Conclusions

We have shown that, even though marine mammals consume a large quantity of marine resources as a whole, there is likely relatively little actual competition between "them" and "us" from a global perspective, mainly because they, to a large extent, consume food items that we do not catch in places where our fisheries do not operate. This is not to say that there may not be potential for conflict in the small geographic regions in which marine mammal food consumption overlaps with fisheries. These areas warrant further investigation. But even in these cases, it seems likely that the most common type of competitive interaction will be one where fisheries have an adverse impact on marine mammal species, especially those with small, restricted distributional ranges (DeMaster et al. 2001; Holmes 2004; Kaschner 2004). Our analysis clearly shows that these are isolated, regional issues to be addressed at the appropriate scale, and that there is no evidence that food competition between marine mammals and fisheries is a global problem, even when the uncertainties associated with the available information are considered. Thus, there is little basis to blame marine mammals for the crisis world fisheries are facing today. There is even less support for the suggestion that we could solve any of these urgent global problems, caused by a long history of mismanagement of fisheries and other resources, by reducing marine mammal populations. We may spend some time, however, thinking about the fact that marine mammals—and other top predators—have been managing marine resources successfully, consuming larger amounts than those taken by global fishing operations today, for millennia. Unlike us, they appear to have done so sustainably, without causing their prey species to collapse. Perhaps we could learn something from them. It's food for thought.

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Notes

[1]Granted, in combination with some fairly sophisticated spatial modeling techniques (Kaschner 2004; Kaschner et al. in review; Kaschner in prep.; Watson et al. 2004).

[2] We estimated only about 1 million baleen whales worldwide, versus about 35 million pinnipeds and 16 million dolphins (Kaschner 2004).

[3]That is, the effects of a species switching between feeding on 50 percent herring and 50 percent capelin in different seasons or in different areas of its range can be ignored, because it would still have a proportional diet composition consisting of 50 percent of the "small pelagics" food type.

[4]For example, though the "diet" of both a fishery and a marine mammal species may consist of 50 percent "small pelagics," the fishery may be targeting different small pelagic species from those consumed by the marine mammal.

[5]As a result, in the North Pacific, for example, the healthy and growing Eastern subpopulation of eighteen to twenty thousand gray whales that feeds and breeds along the Pacific coast of North America (Angliss and Lodge 2002; Perryman et al. 2002; Wade 2002) effectively "subsidizes" the highly depleted Western subpopulation. This latter subpopulation historically occurred all along the coasts of Russia and Japan and probably as far down as the East China Sea, but is now on the brink of extinction, reduced to barely a hundred animals concentrated in the Sea of Okhotsk (Weller et al. 2002a,b).

[6]When viewed from the perspective of fisheries, the overlap is slightly more pronounced, with less than 15 percent of all fisheries catches likely being caught in the areas that show up as hot spots on our maps (Kaschner 2004).

[7]Thus, the basic food produced at the bottom of marine food webs, mainly by minute phytoplankton, is consumed by herbivores of various sizes, some with a narrow range of preferred algal species, while others, facultative herbivores, also consume fellow zooplankters. From there, the pathways that biomass can follow along the food web branch even further, leading to small fish or large zooplankton, both consumed by larger fish or invertebrates, themselves consumed by a wide array of higher-order predators.

[8]Incidentally, the trophic dynamic software package Ecopath & Ecosim, widely applied to construct, balance, and analyze marine food webs and often used to investigate the effects of beneficial predation, was also used recently by ardent advocates of massive culls based at Japan's Institute of Cetacean Research. They conveniently failed to notice this feature of the software, however.

[9]That is, many whales will eat more than no whales at all.

[10]An example of a quotation: "Whaling can contribute to the world food shortage and environmental protection in several ways. [...] whaling is a means of obtaining high quality food from the sea without diminishing biodiversity and,[...] may allow more fish to be directed to human use" (Institute of Cetacean Research 2001a).

[11]Available at: *www.fao.org/fi/statist/nature_china/30jan02.asp*. .

[12]Another example: Chilean sardine, once a staple food, is now scarce on Chilean markets, because most of the catch is ground up into fish meal to feed an export-oriented salmon industry so huge that it has consumed the bulk of the stocks of small pelagic fish once available in the rich waters of that country (Fulton 2003). Our last example is the rapid development in several Mediterranean countries of massive tuna feedlot operations in which immense quantities of the sardine and other small fish much appreciated around the Mediterranean are used to fatten tuna, which are then flown to Japan, where, like salmon, they enter a developed-country luxury market (Aguis 2002).

[13]For example, at the World Summit on Sustainable Development held in Johannesburg, South Africa, in 2002, organized by the United Nations Commission on Sustainable Development (*www.johannesburgsummit.org*).

[14]For example, at the Quantitative Ecosystem Indicators for Fisheries Management symposium, Paris, 2004, organized by the IOC International Ocean Commission/Committee at UNESCO headquarters (*www.ecosystemindicators.org*).

[15]As they did, for example, during World War II in the North Sea, which was mined and too dangerous to fish (Beverton and Holt 1957).

[16]Given that biological production is greater at lower than at higher trophic levels (TL), fisheries catches, initially at least, will tend to increase when TL decline (i.e., when the fisheries target species is lower in the food web) (Pauly et al. 1998b). This led to the suggestion of an FiB index, which, given an estimate of the biomass (or energy) transfer efficiency (TE; often set at 0.1[Pauly and Christensen 1995]) between TL, maintains a value of zero when a decrease in TL is matched by an appropriate catch increase (and conversely when TL increase) and deviates from zero otherwise. The FiB index is defined, for any year y, by

$$FiBy = \log\{[Yy \cdot (1/TE)TLy] / [Yo \cdot (1/TE)TLo]\}$$

where Yy is the catch at year y; TLy is the mean trophic level of the catch at year y; Yo is the catch and TLo is the mean trophic level of the catch at the start of the series being analyzed (Pauly et al. 1998b). Note that the FiB index is designed so that it does not vary during those periods when changes in TL are matched by catch changes in the opposite direction, that is, periods within a time series where the FiB index does not appear to change. Conversely, an increase of the FiB index indicates that the underlying fishery is expanding beyond its traditional fishing area (or ecosystem), while a decrease indicates a geographic contraction, or a collapse of the underlying food web, leading to "backward-bending" plots of TL vs. catch (Pauly et al. 1998b). All applications done so far of the FiB index indicate that once an area is extensively fished, "fishing down" (i.e., removing predators) does not increase catches as much as would be predicted from the higher production at lower trophic levels, so, based on the FiB index as well, removing top predators from marine food webs appears not to be an efficient strategy for increasing fisheries catches in a sustainable fashion.

[17] $Qi = \sum Nis^* Wis^* Ris$, where Q represents the estimated food consumption of species i, which is calculated based on the abundance N, mean body mass W and daily ration consumed R, by both sexes s of the species (Trites, Christensen, and Pauly 1997).

[18] $$a_{jl} = \left(\frac{{}^{2}\sum_{k} p_{lk} p_{jk}}{{}^{2}\sum_{k} p_{lk}^{2} + p_{jk}^{2}} \right) {}^{*}(pQ_{l} {}^{*} pC_{j}),$$ where for each cell the resource overlap index a between marine mammal species group l and fisheries j is calculated based on the proportion of resource k in the total diet or catch of the species group or fisheries and weighted by the proportion of total catch and food consumption summed across all species (MacArthur and Levins 1967; Trites, Christensen, and Pauly 1997; Kaschner 2004).

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