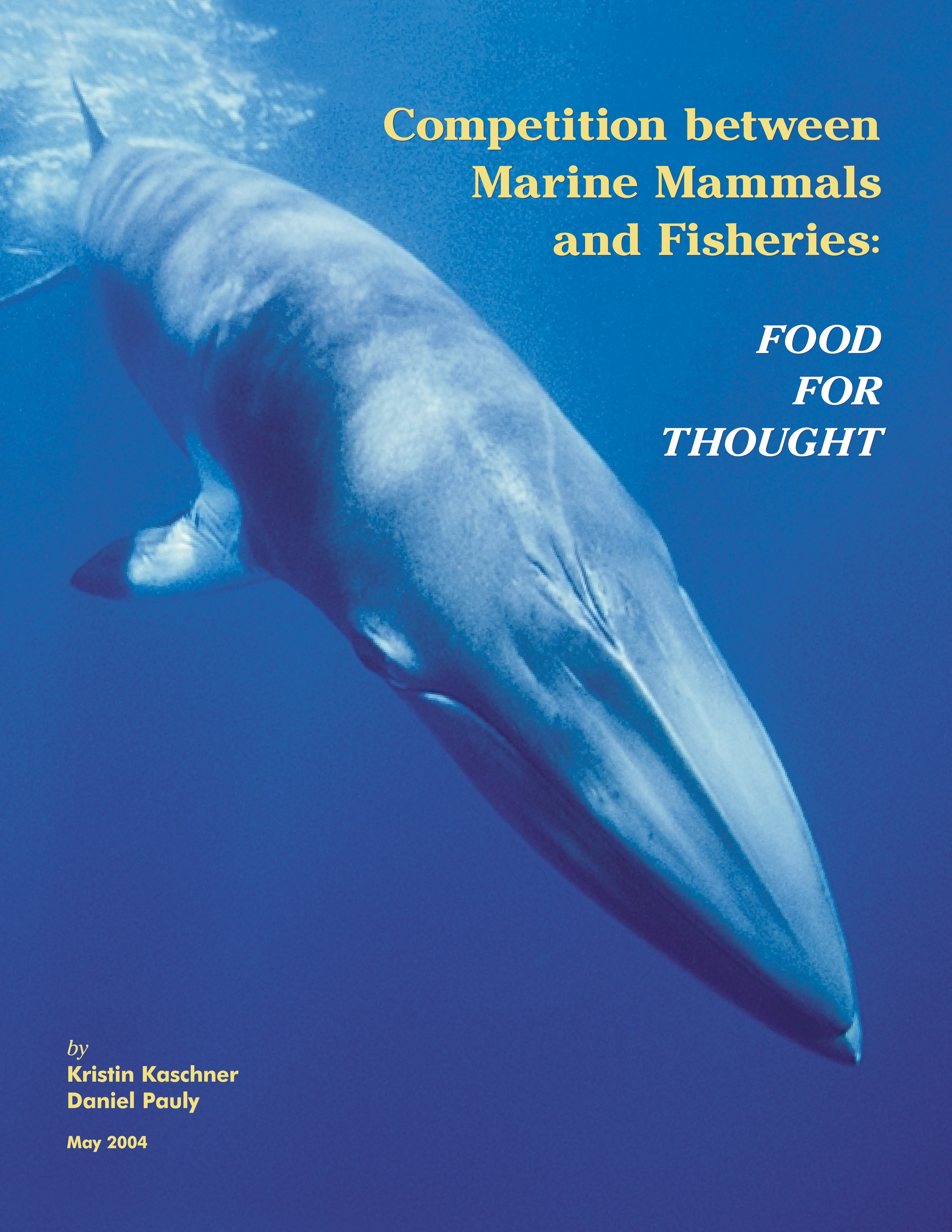

Competition between Marine Mammals and Fisheries:

FOOD FOR THOUGHT

by
Kristin Kaschner
Daniel Pauly

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As the current crisis of global fisheries worsens, the case has been increasingly put forward in international fora that culling marine mammals would not only resolve the problems of fisheries but also help alleviate world hunger. Here, we present results from modelling the degree of ecological food resource overlap on a global scale between marine mammals and fisheries; the model considers the types of food taken by each group, as well as the geographic areas where the food is taken. Our analysis clearly shows that there is no evidence that food competition between the two is a global problem, even when the uncertainties associated with the available information are considered. Consequently, 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, by reducing marine mammal populations.

The claims of competition promoted by culling advocates are usually based on estimates of the total food consumed annually by all or some species of marine mammals, which—depending on the geographic scale and species considered—amount to several times more than the annual catches taken by the fisheries. It is then implied that the amounts consumed would be available

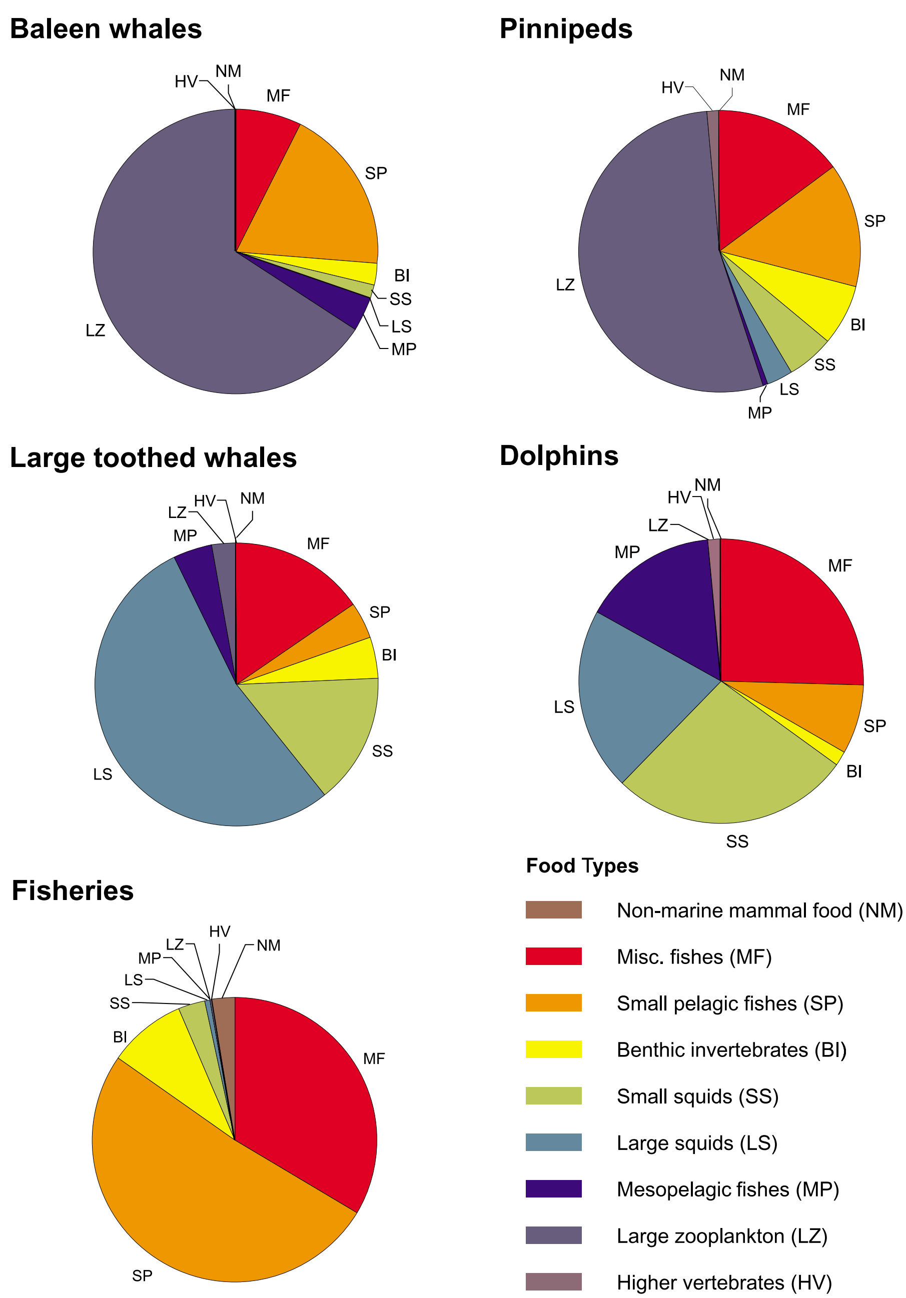


Figure 1. Who Eats How Much of WHAT? *Estimated mean annual global catch/food consumption of marine mammals and fisheries by 9 major food types during an average year in the 1990s expressed as proportions of total (from Kaschner, 2004)[138]. The percentages of different food types in marine mammal consumption were computed based on diet composition standardised across species[96]. 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.*

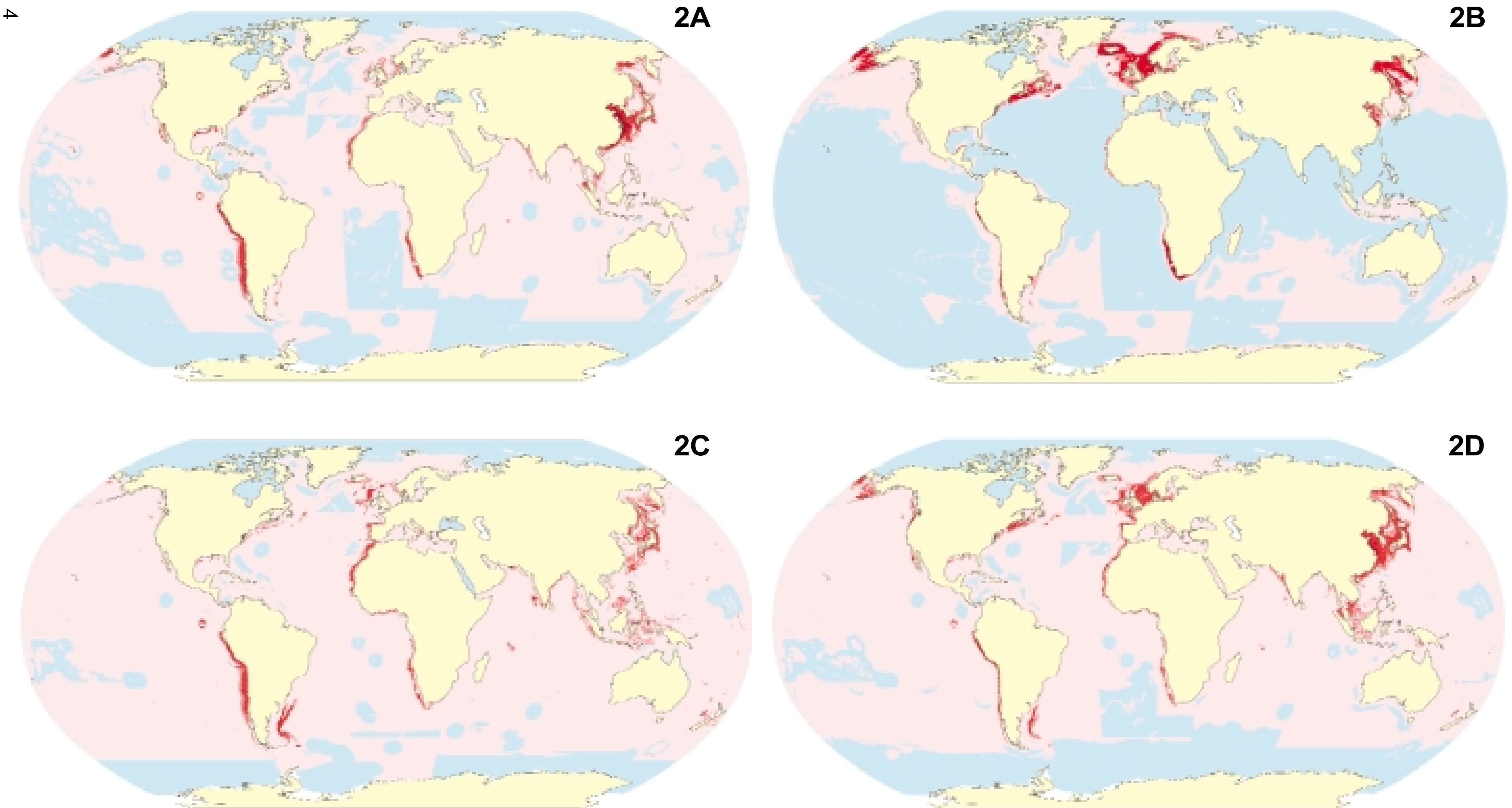
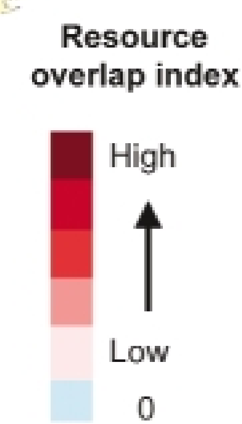


Figure 2. Where Do They Meet?
Maps of estimated spatially explicit resource overlap between baleen whales and fisheries (A), pinnipeds and fisheries (B), large toothed whales and fisheries (C), dolphins and fisheries (D) (from Kaschner, 2004). Maps were produced by computing a modified niche overlap index for each cell in the global grid (Sidebar 4). 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 and 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 and isolated "hotspots" 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. Note that predictions of high overlap in some areas, such as the northwestern Pacific for the baleen whales, are misleading as these are based on overestimates of marine mammal food consumption in these areas. Overestimates are due to a specific feature of our modelling approach that currently does not account for the effects of population structure and varying degrees of depletion of different populations of the same species (Kaschner, 2004).



to fisheries were it not for the marine mammals. This line of reasoning intuitively appeals to many people, as it is seemingly based on common sense. However, combined with references to hunger in poor countries, these arguments articulate a potentially dangerous and misleading view of the interactions between humans and marine mammals on the one hand and hunger and natural resources availability on the other.

The main problem is that the food consumption models underlying these arguments tend to be very simplistic and are regarded as inappropriate from a scientific viewpoint to adequately capture the complexity of competition in the ocean. However, sufficiently detailed models are currently lacking to deal with this issue and may never become available, largely due to the extensive requirements in terms of model complexity and field data. Therefore, we focus here on showing the flaws in the arguments that favour the resumption of whaling using these simple food consumption models—based on some further commonsense considerations and a few additional parameters.

We generated estimates of global food consumption by marine mammals for comparison with fisheries catches, using a similar type of simple model but one which also considers the compositions of diets and catches and spatial distribution of both marine mammals and fisheries. Results indeed indicate that the amounts taken by marine mammals exceed global fisheries catches. *However*, by incorporating information about the types of food taken by marine mammals, we show that most food consumed by marine mammals consists of prey types that fisheries do not target (Figure 1). By combining estimates of total food consumption with a new mapping approach, we further demonstrate that marine mammals consume most of their food in areas where humans do not fish (Figure 2) . The resulting maps show, for each major species group (baleen whales, pinnipeds, large toothed whales and dolphins), that overlap between marine mammal food consumption and fisheries is high only in some small isolated areas. Areas of overlap tend to be concentrated along the continental shelves of the Northern Hemisphere, where marine mammals take comparatively little of their food—in fact we demonstrate that less than 1 percent of all food consumed by any species group stems from areas of high overlap. Similarly, more than 85 percent of all fisheries operate in areas of low overlap. Consequently, while we acknowledge that local interactions between marine mammals and fisheries do occur, we show that the conflation of marine mammal food consumption and human food security does not at all take the form suggested by the proponents of marine mammal culls.

Moreover, this report shows, based on a review of the recent peer-reviewed ecological and modelling literature, that the very attempt to substitute predators such as marine mammals with fisheries leads to food web disruptions and adjustments that often preclude the harvesting of the former's prey by humans. Thus, the last decade, which has seen the "fishing down" of marine food webs, has not led to increased marine fisheries catches; indeed, global fisheries catches have been declining since the late 1980s despite the depletion of large predatory fish throughout the oceans by fisheries. Moreover, it is the continuation of present fisheries management approaches and the export of fisheries products from developing to developed countries—not marine mammals—that endanger human food security.

Solving the problems of global fisheries and human hunger are big challenges that will involve the best that humankind can contribute. These problems, however, will not be resolved by divisive, politically driven schemes such as the culling of marine mammals.

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Sharing One Planet

Marine mammals and humans have co-existed on this planet for several hundred thousand years (Figure 1). 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[1]. Not surprisingly, 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[2, 3]. In the past, the main threats were large-scale whaling[4] and sealing operations[5–7]. 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 abundances[8] or extirpated them completely, as with the now extinct Atlantic grey whale[9] or the Caribbean monk seal[10, 11]. Today, humans adversely impact marine mammals mainly through incidental entanglement in fishing gear[2, 3,12, 13], chemical[14–16] and acoustical pollution[17, 18], and in some cases, ship strikes[19, 20]—some populations close to the point of extinction are the vaquita[21], the Mediterranean[22–24] and Hawaiian monk seals[25] and western North Atlantic right whales[8, 26].

On the other hand, there are examples of some marine mammals potentially adversely impacting fisheries. Controversial cases include the damaging of gear (e.g., harbour seals vs. fish farms)[27, 28], devaluation of catch through depredation (killer whales vs. long-line fisheries in Alaska)[28, 29], 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)[30–33].

Is Competition a Problem?

Competition between marine mammals and fisheries for available marine food resources has often been mentioned as another issue of concern[34–36]. This is understandable, since many marine mammal species, in common with humans, operate near or at the top of the marine food web[37]. In recent years, as the fisheries crisis has developed from a set of regional problems to a global concern[38, 39] and the animal protein that millions of people depend upon 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

Figure 1.
Co-existence of marine mammals and humans—not for very long, not always peaceful.

with other marine top predators, such as piscivorous fish. Moreover, some species—notably various species of fur seals[40, 41]—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[8, 40, 41]. For these reasons, whales, dolphins and pinnipeds lend themselves quite easily as culprits for 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"[42], 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 the issue of competition between marine mammals and fisheries on a global scale[43–45].

What Is Competition?

From an ecological perspective, competition is a situation where the simultaneous presence of two resource consumers is mutually disadvantageous[36]. A rarely acknowledged but implicit assumption is that the 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 importantly though, competition occurs only if the removal of either marine mammals or fisheries results in a direct increase of food available to the other[46, 47].

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[35, 48–54]. To address this question, various approaches have been applied to the problem of modelling marine mammal food consumption and the potential effects of this intake on fisheries yields, reviewed in detail elsewhere[46, 47, 55]. 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 between multiple species changing over time and in space[56–60]. The "who-eats-how-much" models are generally regarded as inadequate to investigate the issue of potential competition since they largely ignore important issues of uncertainty and food web interactions[47, 55]. However, the application of more complex models, such as those recommended by the United Nations Environment Programme to investigate proposals for marine mammal culls[61], is often hampered by the lack of availability of necessary data[47, 55, 62] 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 lay people[43]. 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.

As another side effect of their data requirements, most existing complex models focus on relatively small geographic areas[63–65]. 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, the 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 small part of a species' distributional range.

We propose to use 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[a] may be sufficient to counter claims that the culling of marine mammals will help us alleviate the major problems the world's fisheries are facing today, and even world hunger.

What We Will Do

In this report we will 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 importantly, however, we will 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 the 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[43–45]. These claims are based on very simplistic food consumption models—crude so-called "surplus yield" calculations[55]—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 3 to 6 times the global marine commercial fisheries catch[66, 67]. It is then often implied that a reduction in the predator population will translate directly into a corresponding increase in prey[67–70] 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[47]. 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 existing 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[53, 71]. 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 importantly, the naïve approach completely ignores the complex range of dynamic factors that affect how the removal of high-level predators impacts ecosystems[72], some of which we will discuss later in this report. 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...

As mentioned in the introduction, it may seem intuitive for many people 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 the 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 will instead show the flaws in the arguments that favour the 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 Sidebar 1, to estimate global annual food consumption of different groups of marine mammals to compare them with catches taken by world fisheries (Figure 2). Mean estimates for all groups are indeed almost as high or slightly higher than global reported fisheries catches (although it should be noted that total fisheries catches are likely underestimated[39]). 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 the baleen whales that are similar to those previously published[42, 67]. Although their abundance is comparatively low[b], 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 2; mostly small pelagics, benthic invertebrates and a group we have summarized as "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 is being eaten by baleen whales (as well as by toothed whales and pinnipeds) consists of food types that, for reasons of taste and accessibility, are of little interest to commercial fisheries. We will expand on this important consideration of ***what*** is being eaten in the next section.

Sidebar 1

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[51, q] 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 3,000 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[138]. 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 2) and averaged over the last decade. Note that this is an estimate only of the reported catches and that total takes by fisheries are probably closer to 150 million tonnes per year, if illegal, unreported or unregulated (IUU) catches are taken into account[39] (Figure 2).

The percentages of different food types in total marine mammal consumption were estimated based on the diet composition standardized across species, itself based on 200 published qualitative and quantitative studies of species-specific feeding habits[37]. 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), meso-pelagic fishes (MP), miscellaneous fishes (MF), higher vertebrates (HV) and an additional food type containing all catches of species only targeted by fisheries, such as large tuna, which we called non-marine mammal fishes (NM) (Figure 3).

Who Eats How Much of WHAT?

Different Species, Different Strokes

During their foraging dives, many marine mammal species regularly venture to depths of over a thousand meters[73–76] and far under the pack ice[77], 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[78, 79]. Along similar lines, at least some of our favourite 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 Sidebar 1, we specified the relative amount of 9 different food types consumed by major marine mammal groups and fisheries (Figure 3). 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, feeding predominately on large, deep-sea squid species not targeted by fisheries[80], shows the least similarity.

Size—among Other Things—Matters

Like all other parameters in the basic food consumption model, the determination of 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[81]. Diet composition estimates based on stomach content analyses tend to be biased towards cephalopods, as their hard parts are less readily digested than those of other prey groups[82]. Such biases may be addressed by applying correction factors that compensate for differential effects of digestion on different prey types[83, 84]. More serious biases are introduced by the predominance of stranded animals in the overall sample. Such

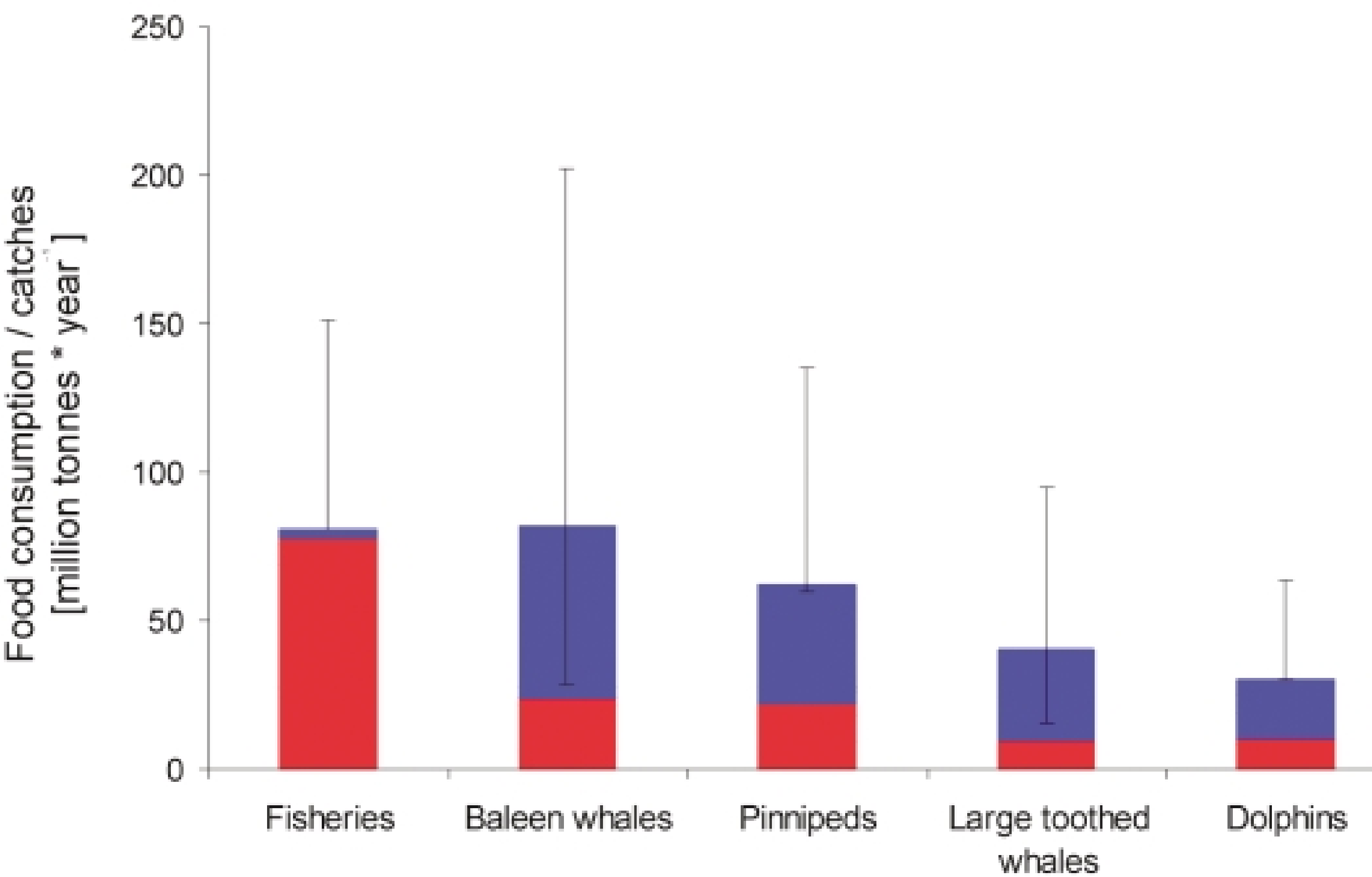


Figure 2. Who Eats How Much?
Estimated mean annual global catch/food consumption of fisheries and major marine mammal groups during the 1990s (modified from Kaschner, 2004)[138]. Error bars of marine mammal food consumption indicate minimum and maximum estimates based on different feeding rates[71]. Total fisheries catches are probably closer to 150 million tonnes per year if illegal, unreported and unregulated catches are taken into account[39]. The food intake by marine mammals 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 consumed by the various marine mammal groups are not targeted by fisheries.

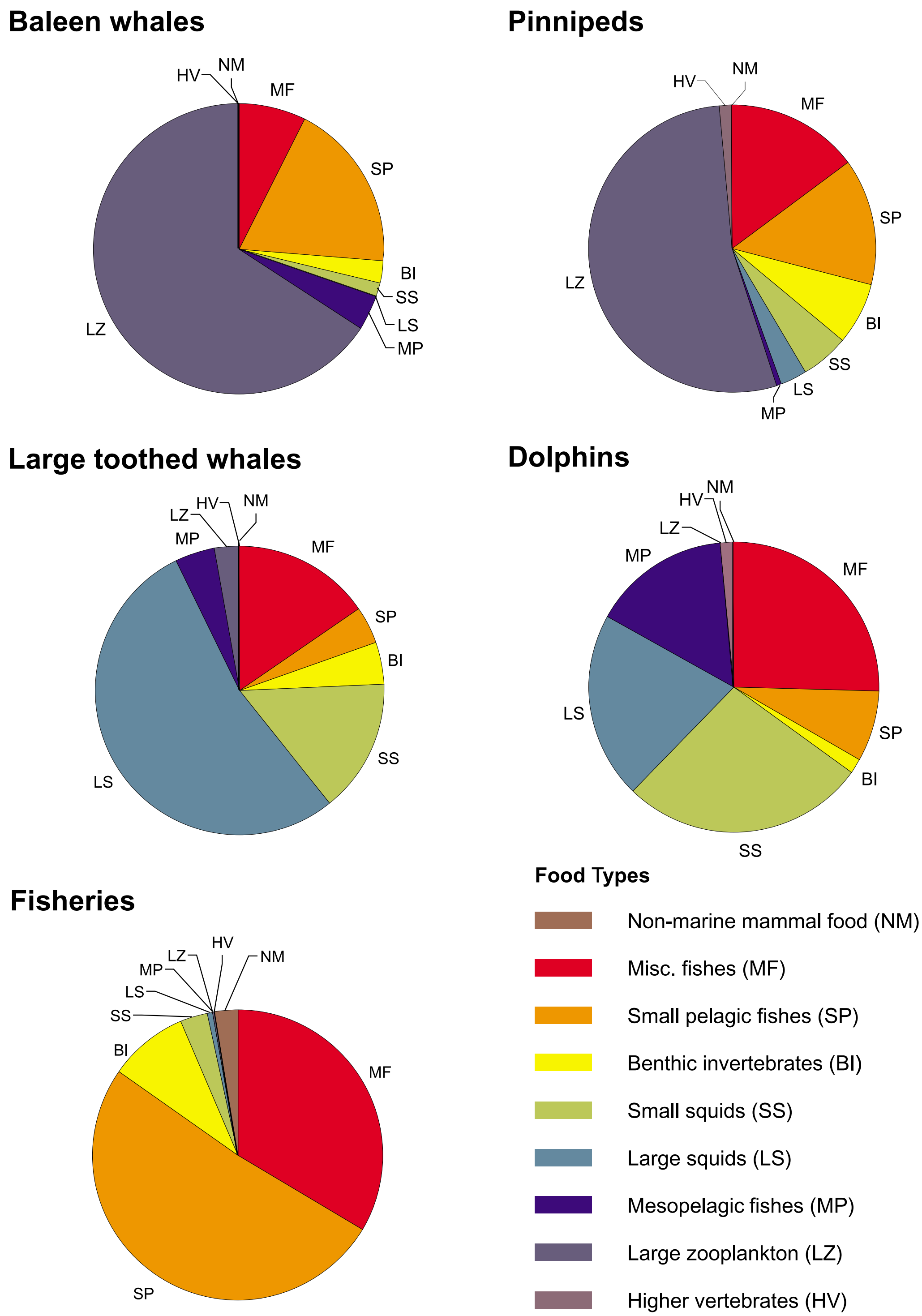


Figure 3. Who Eats How Much of WHAT?
Estimated mean annual global catch/food consumption of marine mammals and fisheries by 9 major food types during an average year in the 1990s expressed as proportions of total (from Kaschner, 2004)[138]. The percentages of different food types in marine mammal consumption were computed based on diet composition standardised across species[96]. 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.

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[81]. Other, newer molecular methods, including stable isotope[85–87] and fatty acid[86, 88–90] analyses, also have biases[91]. Finally, there is substantial geographical and seasonal variation in the diet composition of marine mammal species[92–94].

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

Who Eats How Much of What WHERE?

As mentioned in the introduction, the spatial overlap of resource exploitation is a pre-requisite for competition to occur. In this section, we will 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 5)— a modelling process briefly described in Sidebar 2[141]. 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 or North Sea, 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 offshore, 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[95]. 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[96].

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, marine mammals are not restricted in their distribution by the distance to the nearest landmass or the climatic conditions that largely

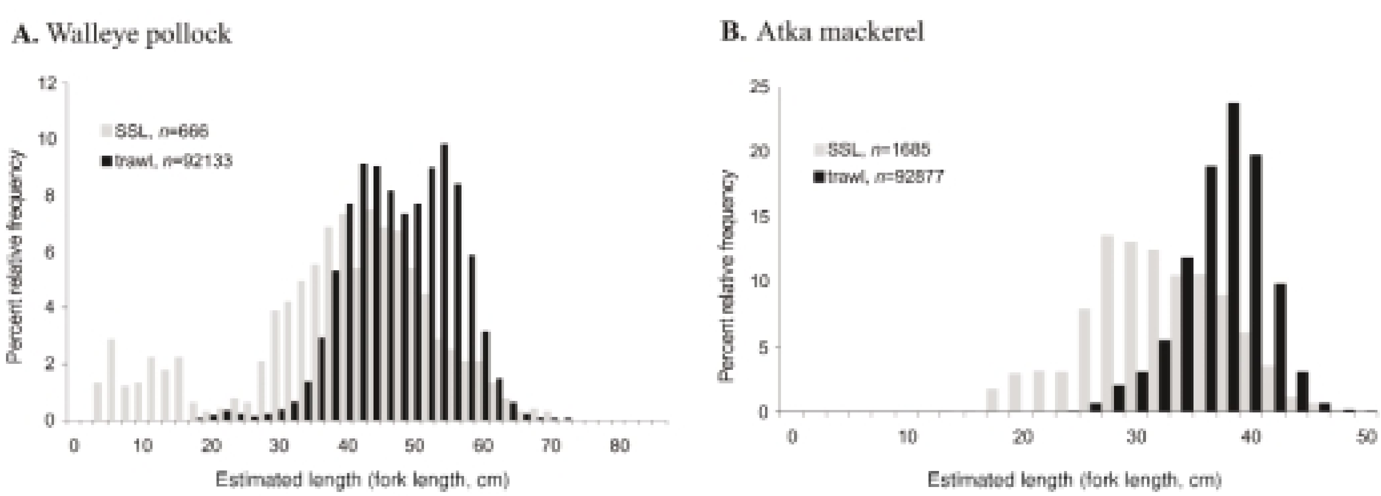


Figure 4. Size—among Other Things—Matters
Example of differences in prey size targeted by marine mammals and fisheries: Relative frequency histograms of the estimated fork length of walleye pollock and Atka mackerel consumed by Steller sea lions in Alaska compared with relative frequency histograms of fish caught by the walleye pollock and Atka mackerel commercial trawl fishery in the same areas. Estimates of prey sizes taken by sea lions are based on analysis of bones found in Steller sea lion scat, with correction factors applied to account for differential impacts of digestion on different bones (reproduced with permission from Zepplin et al., 2004)[82]. Note that Steller sea lions frequently target much smaller prey sizes than those taken by the fisheries.

Sidebar 2

Modelling and Mapping of Global Fisheries Catches—You Couldn't Have Caught That There![141]

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), these statistics 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. Information about species distributions and fishing access agreements can therefore serve as constraints 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, the documented history of fishing prior to 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.seaaroundus.org*, and average catch distribution for the 1990s is shown in Figure 5.

influence the locations of fishing grounds and major human settlements. Conversely, many species occur predominately 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 predominately 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 Sidebar 3, 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 (Figure 6). Often cosmopolitan in their distributions, the baleen and large toothed whale species, for example, are likely 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 homogenous across large areas (Figure 6 A & C). Food intake of the smaller dolphin species is even lower and appears to be concentrated in temperate waters (Figure 6 D). Pinniped food consumption, in contrast, tends to be more closely associated 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 (Figure 6 B).

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 the 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 modelling 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[e].

Sidebar 3

Modelling and Mapping Large-Scale Marine Mammal Distributions—We May Know More Than We Think We Know…

The 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 through the 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 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 that 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[138]. Within a global grid (described in Sidebar 2) we used our model to quantitatively relate 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 defines rigorously the geographic regions that experts describe essentially 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[139, 140]. The predicted distributions for the 115 marine mammal species considered here can be viewed online at *www.seaaroundus.org*.

Where They Meet

Using the predicted geographic distributions of marine mammal food consumption and fisheries catches, we can 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 7 A–D), 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 4). 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 predicted hotspots in the western North Pacific are largely due to the biases associated with determining food consumption discussed in the previous section. Partially due to the comparatively low total food intake of dolphins, the overlap between fisheries and this group is quite low and again mostly concentrated in the Northern Hemisphere. Not surprisingly, the lowest overlap occurs between fisheries and deep-diving large toothed whales, whose diets primarily consist of large squid species and meso-pelagic fish, not currently exploited by fisheries.

And How Big a Problem Is That?

The maps illustrate clearly that overlap between marine mammal groups and fisheries is probably not a global issue, but rather one restricted to a few relatively small geographic regions and concerning a few species.

Looking at our maps, the skewed perception of this problem by nations in close vicinity to these hotspots 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 8). 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 co-exist quite peacefully in most of the world's oceans[f].

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 represent an over- rather than an underestimation of overlap for the reasons outlined in the previous sections. Moreover, as shown by comparison of the maps of food consumption and fisheries catches, areas of high overlap appear to be largely associated with areas of extreme concentrations of fisheries extractions, rather than locally concentrated food intake by marine mammals. It is therefore more

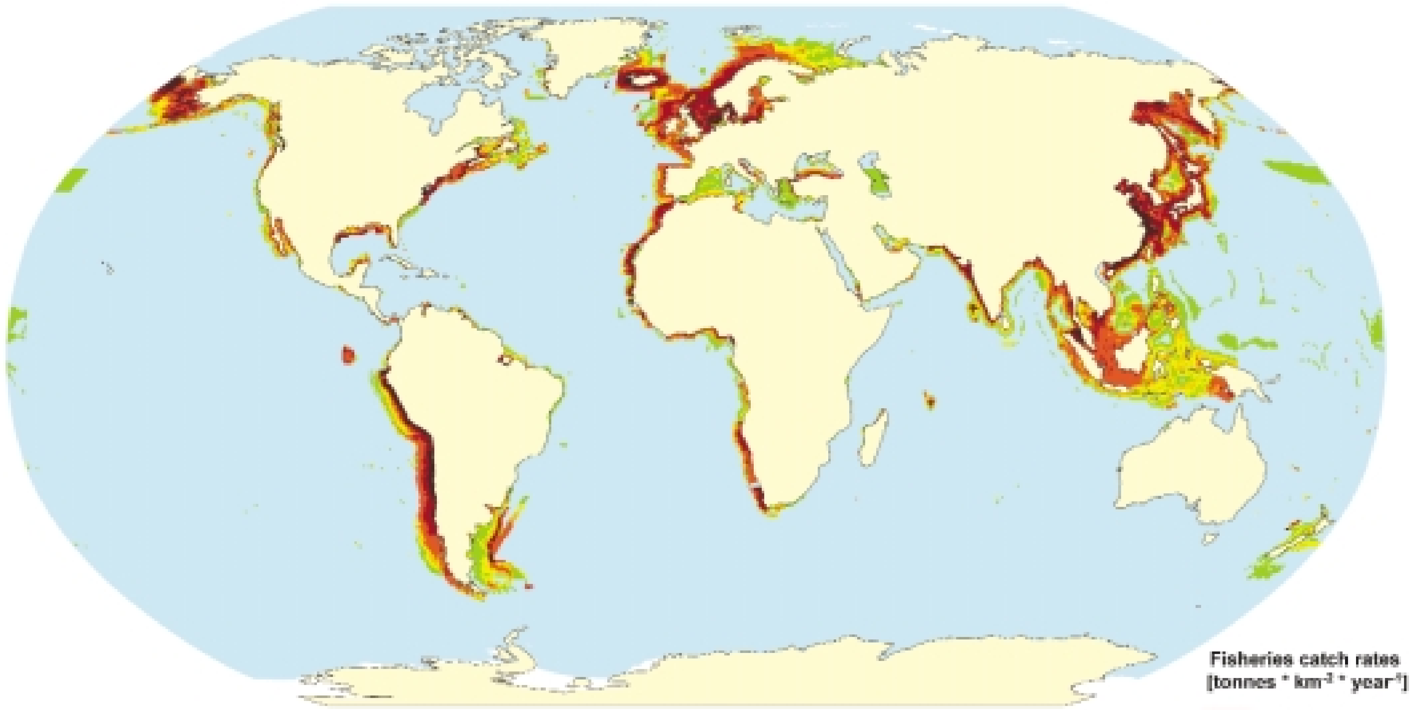


Figure 5. Where Are Fisheries?
Map of predicted spatially explicit global fisheries catch rates during an average year in the 1990s, generated through spatial-disaggregation of reported annual catches in a global grid of 0.5° latitude by 0.5° longitude cell dimensions using a rule-based approach (Sidebar 2) (based on data from Watson et al., 2004[141], with catches averaged over the last decade). Non-regular colour-coded scale, described in the legend, is the same as in Figure 6, except for the lowest category, which combines three of the marine mammal categories. 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 1,000 tonnes per km^2 per year—more than 100 times as much as the maximum marine mammal food consumption rates predicted anywhere in the world[138].

likely for fisheries to adversely impact marine mammal species in these areas of intense fishing than *vice versa*, as has already been suggested elsewhere[97]. 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 the issue of potential competition may better be addressed at a local level. We also note that most of the potential "hotspots" highlighted by our approach are in areas that have been the focal points of much debate about marine mammal-fisheries interactions, such as in the Bering Sea with the potential negative impacts of the U.S. groundfish fisheries on the endangered western population of Steller sea lions[98, 99], or the Benguela system off southwest Africa with the potential impacts of the increasing population of South African fur seals on the hake stocks in this area[100, 101]. These and other hotspots will require much more detailed investigation to establish the true extent of the problem at hand.

Some Biological Complications

As mentioned earlier, it is generally agreed that far more complex models are needed, incorporating many additional parameters and requiring more, often still unavailable data[47, 97, 102] to adequately address the issue of interactions between marine mammals and fisheries—and the potential far-reaching effects of the removal of top predators from marine ecosystems[72, 97, 103, 104] in those areas where competition may occur. The assumptions, structures and data needed for such models have been extensively reviewed elsewhere[47, 97, 102]. However, here we will highlight the problems associated with attempts to increase fisheries catches through the culling of marine mammals in those areas where the existence of competition is agreed to be 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, it is of "food webs" that we should speak[g]. 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 instead diverted into

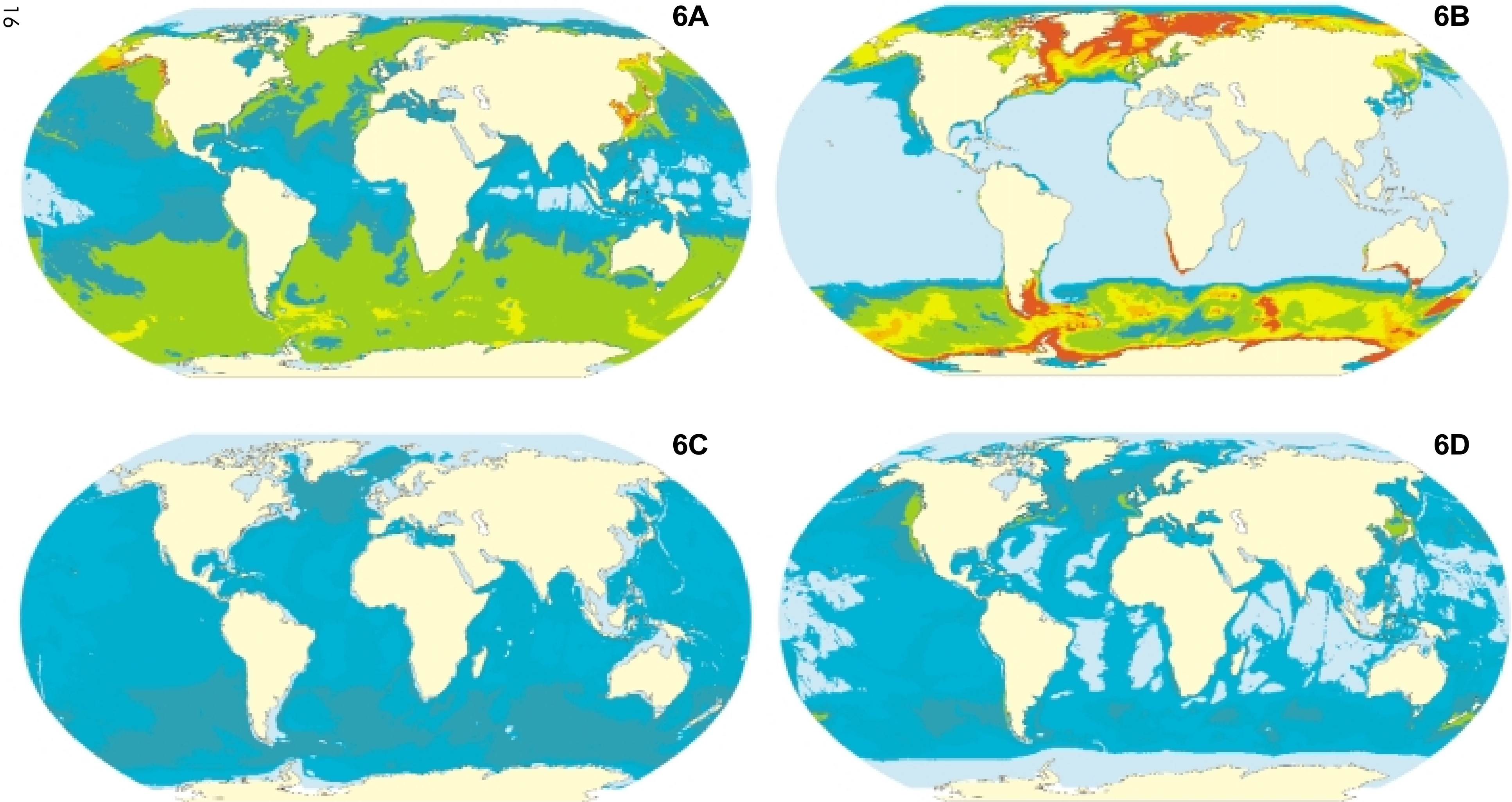
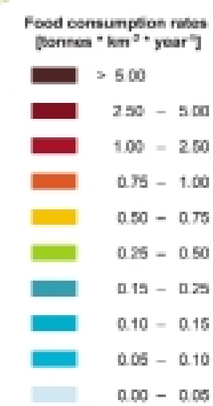
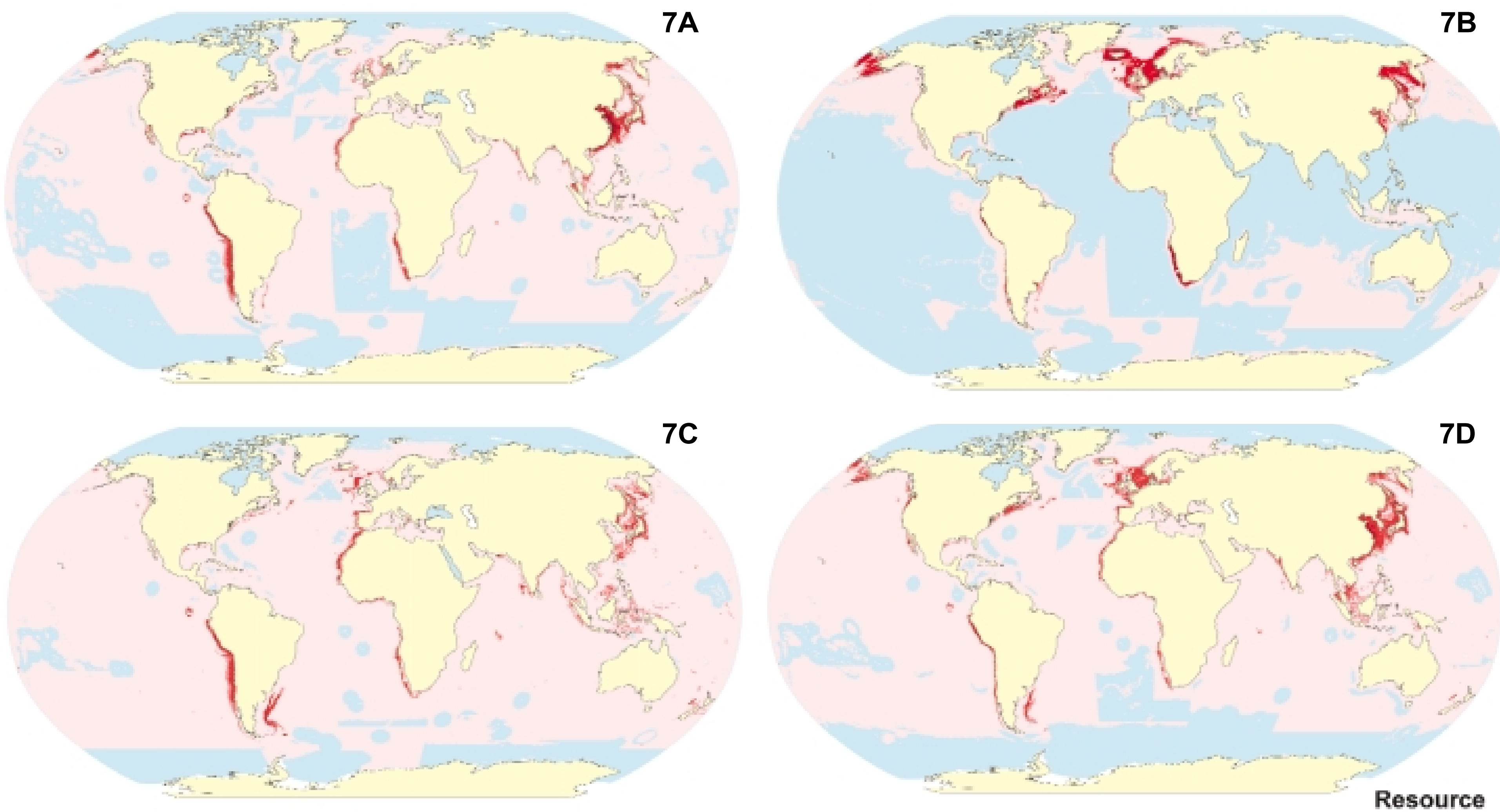


Figure 6. Where Are Marine Mammals?
Maps of predicted spatially explicit global food consumption rates of marine mammal groups during an average year in the 1990s (from Kaschner, 2004)[138]. Spatially explicit estimates of food consumption rates for baleen whales (A), pinnipeds (B), large toothed whales (C) and dolphins (D) are shown. These were produced by linking species-specific food consumption estimates to predicted species distributions generated by an environmental suitability model in a global grid of 0.5° latitude by 0.5° longitude cell dimensions (Sidebar 3) and then summing rates across all species within one taxonomic group. Non-regular colour-coded scale, described in the legend, is the same as in Figure 5, except for three added low-density categories needed to make patterns visible for all species groups. Food consumption is much more homogenously distributed than fisheries catches (compare Figure 5). Areas of highest concentrations vary for different species groups, but are generally located in regions further offshore or in higher latitudes seldom visited by fisheries. Note open-ended scale of legend and that maximum food consumed (dark red) by any species group does not exceed 10 tonnes per km² per year anywhere in the oceans—100 times less than top fisheries extraction rates. Please also note 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 artefacts of a specific feature of our modelling approach[e]. Overall, close to 70 percent of all marine mammal food consumption is taken in the Southern Hemisphere, and most of this is consumed south of 40–50° latitude south, where only 6 percent of all fisheries catches are taken[138].





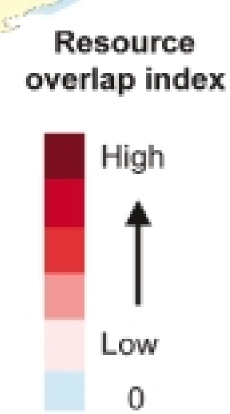


Figure 7. Where Do They Meet?

Maps of estimated spatially explicit resource overlap between baleen whales and fisheries (A), pinnipeds and fisheries (B), large toothed whales and fisheries (C), dolphins and fisheries (D) (from Kaschner, 2004)[138]. Maps were produced by computing a modified niche overlap index for each cell in the global grid (Sidebar 4). 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 and 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 and isolated "hotspots" 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. Note that predictions of high overlap in some areas, such as the northwestern Pacific for the baleen whales, are misleading as these are based on overestimates of food consumption in these areas. Overestimates are due to a specific feature of our modelling approach that currently does not account for the effects of population structure and varying degrees of depletion of different populations of the same species (Kaschner, 2004)[138].

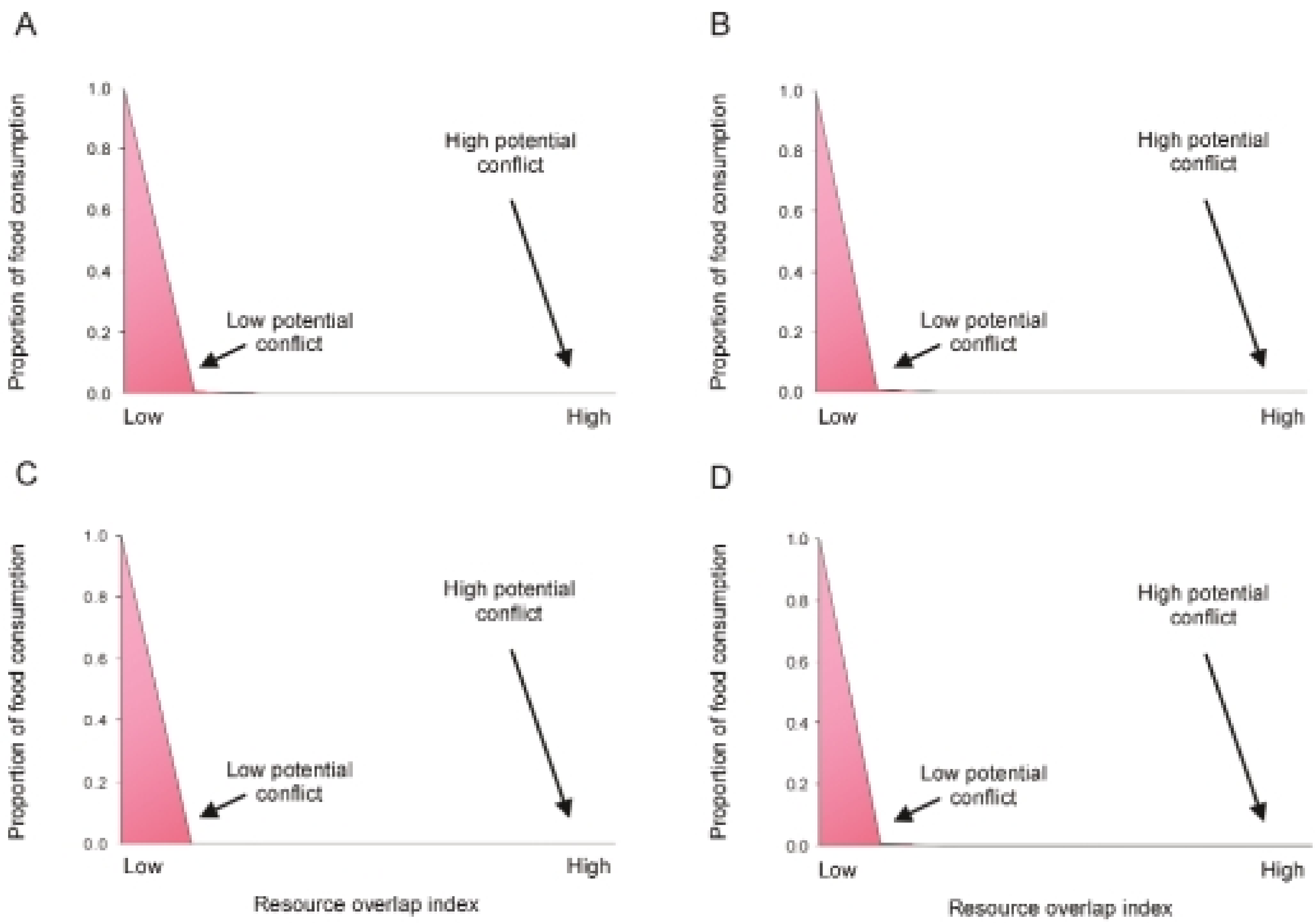


Figure 8. And How Big a Problem Is That?
Proportion of mean annual global catch/food consumption taken by baleen whales (A), pinnipeds (B), large toothed whales (C), and dolphins (D) in the 1990s in areas of predicted high or low resource overlap, respectively (from Kaschner, 2004)[138]. Note that in 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)[138].

unproductive pathways, notably the so-called "microbial loop". On the other hand, this diversity of pathways protects predators against the disappearance of one or another of their favourite prey species[105]. It is therefore not surprising that higher-level predators, such as sharks or dolphins, 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[46, 72]. Basically, predators not only consume their favourite prey, but also the competitors and, in many cases, the predators of their prey[46, 72, 101]. This is illustrated schematically in Figure 9 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[106]. 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 also have to cull B, and so on *ad infinitum*. It is this conundrum that 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 being composed of interlinked sets of feeding triangles shown schematically in Figure 9. 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 centimetre fish so that he can catch more 5 centimetre 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 modelling approaches[50, 63, 72, 101, 107–112, h]. 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, which 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[107, 113].

How Much Culling—If Ever—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[i], other factors, such as the vulnerability of prey species to predation[114], the ability of the predator to switch between prey species, and movements of animals between different areas, will greatly influence how much is eaten by a given species 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[46]. 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 the culling of marine mammals and the subsequent targeting of their prey[j].

Though an estimated 950 million people worldwide currently rely on fish and shellfish for more than one third of their animal protein[36], the per capita supply of wild caught fish for human consumption has been declining since the mid-1980s, particularly in the developing countries of the world[k]. This is due in part to overfishing, which has led to the decline of global catches since the late 1980s[38, 39, 115], but also to human

Sidebar 4

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

In the context of 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. However, this question could not be addressed—at least not on a large scale—prior to the development of mapping techniques for marine mammal distributions and fisheries catches such as described in Sidebars 2 and 3.

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 3) to the outputs from the basic food consumption model (Sidebar 1). The food consumption maps for groups of species shown in Figure 6 were then generated, by summing 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[142], 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[51, 138, 142, r]. The resulting maps (Figure 7) represent the area where conflicts between specific groups of marine mammals and fisheries *may* occur, i.e., both players are potentially taking comparatively large amounts of similar food types in the same geographic region.

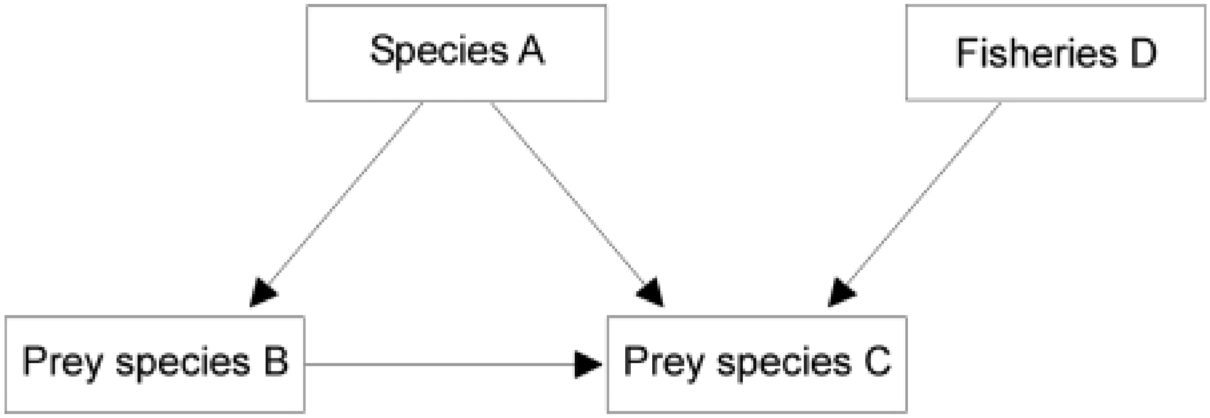


Figure 9. We May Be in for Surprises
Schematic representation of beneficial predation: Whale species A feeds on both prey species B and on prey species C, the latter a commercially harvested species. In addition, prey species B also feeds on prey species C. This means that a decrease in whale species A may actually 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 the predators will not necessarily result in an increase in a particular prey species.

population growth. Indeed, no natural resource, including wild caught fish, could ever meet our ever-growing demand. We shall abstain from elaborating on the fact that of the 120–150 million or so tonnes of fish and invertebrates killed annually by fisheries, only about half is actually eaten by people: about 30 million tonnes of bycatch are discarded or killed by lost gear ("ghost fishing"), while a huge amount is lost to spoilage[116] and during processing (e.g., gutting, filleting)[117], or left uneaten, in richer countries, at the edge of consumers' plates. Another 30 million tonnes, however, are fed to various livestock[39] 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 (Figure 10)[118, 119].

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 lacking 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[118, l]. 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 presently exported from countries where people "do not have adequate food"[66]. Indeed, it is precisely the low purchasing power of the people within these countries that prevents them from successfully competing 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 and have therefore generated widespread calls for mitigation[120]. Particularly, people have noted that fisheries management has so far tended to focus on single stocks, thus neglecting feeding and other interactions between 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"[m]. 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[n]. This includes the challenge of achieving set conservation objectives for predators of species targeted by fisheries[121].

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 upon 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."[66]

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

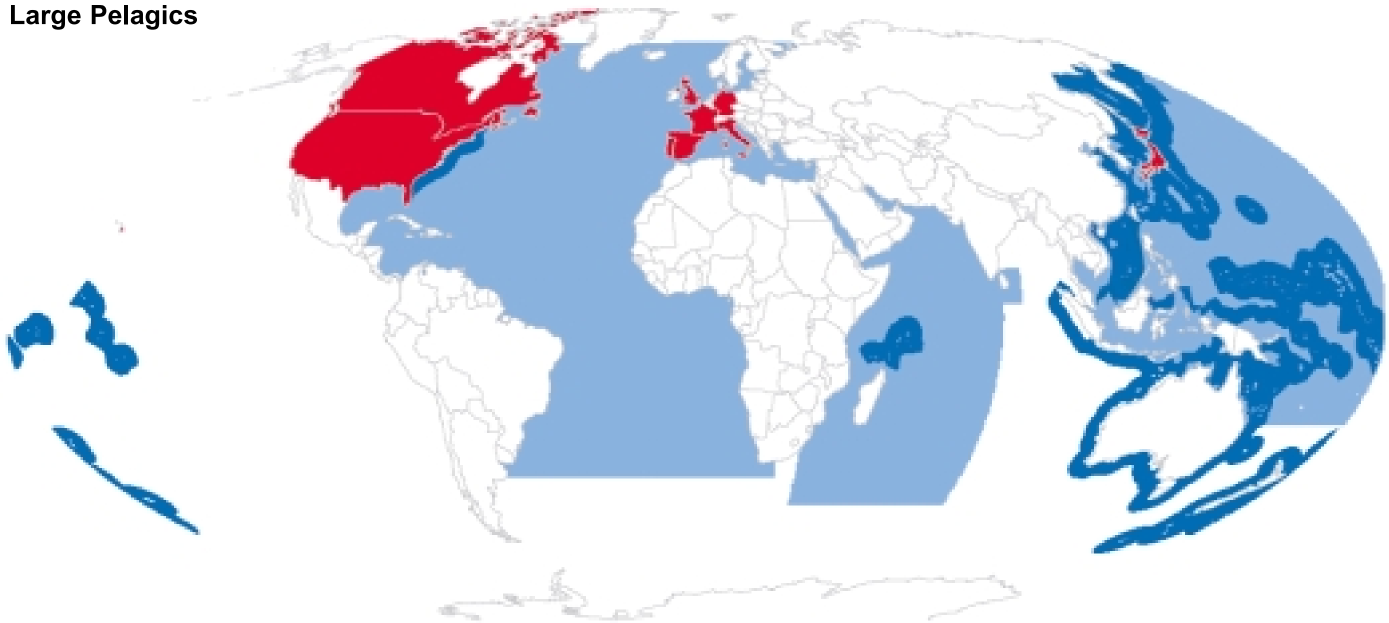


Figure 10. The Problem of World Hunger—Are We Simply Looking for Scapegoats?
Map of fish producers and consumer countries showing major importing (red) countries and the Exclusive Economic Zones (blue), where the majority of exports were sourced for large pelagic fish from 1976–2000. This provides an illustration that the majority of catches from developing countries are being consumed in developed countries[s]. Given such trading patterns, it is doubtful that an increase in global fisheries production would translate into a decrease in world hunger (reproduced with permission from Alder et al.)[119].

the fish been overexploited, but so have the marine mammals. Given reduced fishing pressure, fish can be expected to recover faster[o] than marine mammals[122, 123], given their respective reproductive abilities. Indeed, all recent evidence confirms that baleen whales are far less abundant than they were historically[4, 8, 19, 124, 125]. Re-establishing the disrupted balance of ecosystems is therefore hardly a simple matter of reducing whale numbers.

Clearly what we have is an attempt at finding a convenient scapegoat for the mismanagement of fisheries[43] and the reduction of catches caused by excess fishing effort throughout the world. This puts the following quote 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."[42]

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[2, 126, 127], discarding[127], ghost fishing[128]), and pathological management structures (e.g., excess fishing capacity[129], subsidies[130]), 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?

Interestingly, nobody has proposed (so far!) to kill all seabirds to increase fish available for human consumption. There are millions of seabirds in the world, consuming massive amounts of fish, squids and other valuable invertebrates. Although they individually tend to weigh little, the high metabolic rate of birds leads to very high food consumption rates[131]. Thus, in the aggregate, seabirds have been estimated to consume 50–80 millions tonnes of fish and invertebrates per year[132], at least half of what humans kill annually. Yet no one has proposed that seabirds should 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 should also propose that we go after the seabirds. More importantly, 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[51, 133]. Indeed, the greatest predators of fish are other fish[51, 134]. But then again, we are in fact eliminating large predatory fish anyway, as we fish down marine food webs, reducing high-level predator biomasses as we go along[103, 135, 136]. Nevertheless, overall catches are decreasing[p], 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[97, 137, 138].

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, however, spend some time thinking about the fact that marine mammals—and other top predators—have been "successfully managing" marine resources, 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. Maybe we could learn something from them. It's food for thought.

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a. Granted, in combination with some fairly sophisticated spatial modeling techniques.[138–141]

b. We estimated only about one million baleen whales worldwide, versus about 35 million pinnipeds and 16 million dolphins.[138]

c. That is, the effects of a species switching between feeding on 50 percent herring and feeding on 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.

d. 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 than those consumed by the marine mammal.

e. As a result, in the North Pacific, for example, the healthy and growing Eastern subpopulation of 18,000–20,000 grey whales that feed and breed along the Pacific coast of North America[143–145] effectively "subsidizes" the highly depleted Western subpopulation. This latter subpopulation historically occurred all along the coasts of Russia, 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[146, 147].

f. 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 hotspots on our maps[138].

g. 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.

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

i. That is, many whales will eat more than no whales at all.

j. 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."[42]

k. *www.fao.org/fi/statist/nature_china/30jan02.asp.*

l. Another example: Chilean sardine, once a staple food, is now scarce on Chilean markets, as most of the catch is ground up into fish meal to feed an export-orientated 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[148]. 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[150].

m. 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*).

n. For example, at the "Quantitative Ecosystem Indicators for Fisheries Management" symposium, Paris, 2004, organized by the IOC at the HQ of Unesco (*www.ecosystemindicators.org*).

o. As they did, for example, during World War II in the North Sea, which was mined and too dangerous to fish[149].

p. Given that biological production is higher 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)[103]. 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[151]) 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

$$FiB_y = \log\{[Y_y \cdot (1/TE)^{TL_y}] / [Y_o \cdot (1/TE)^{TL_o}]\}$$

where Y_y is the catch at year y; TL_y is the mean trophic level of the catch at year y; Y_o is the catch and TL_o is the mean trophic level of the catch at the start of the series being analysed[103]. Note that the FiB index is designed such that it does not vary during those periods when changes in TL are matched by catch changes in the opposite direction, i.e., 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[103]. 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, and hence removing top predators from marine food webs appears, based on the FiB index as well, not to be an efficient strategy for increasing fisheries catches in a sustainable fashion.

q. $Qi = \sum N_{is} * W_{is} * R_{is}$, 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.[51]

r. $$a_{jl} = \left(\frac{2\sum_k p_{lk} p_{jk}}{\sum_k p_{lk}^2 + p_{jk}^2} \right) * (pQ_l * pC_j),$$ 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.[51, 138, 142]

s. Similar patterns prevail for demersal and small pelagic fishes and invertebrates.[119]

Kristin Kaschner

MMRU, Fisheries Centre

UBC, Vancouver, Canada

Kristin Kaschner grew up in Bremen, Germany and received her "Diplom" (MSc)—with a specialization in bioacoustics—from the Biology Department of the Albert-Ludwigs-Universität of Freiburg, Germany, in 1997. For her Master's thesis research, she participated in CETASEL, an EC funded research collaboration aiming to reduce the bycatch of small cetaceans in pelagic trawl gear by technical means. As a project collaborator based at the Underwater Acoustics Group at Loughborough University, Leichestershire, UK, she developed an acoustic analysis technique to study the behaviour of small cetaceans around midwater trawl nets. Joining the Marine Mammal Research Unit at the Fisheries Centre at the University of British Columbia in late 1998 to work on her Ph.D., she has been a member of the Sea Around Us team since 1999. In addition to being in charge of coordinating the German fisheries data acquisition and compilation, her main research focus is the investigation of the potential impact that fisheries may have on marine mammal populations using spatial modelling approaches. Under the supervision of Daniel Pauly and Andrew Trites, her dissertation work focuses on the development of a large-scale model simulating geographical and seasonal changes in marine mammal distribution, abundance and food consumption to assess the degree of trophic overlap with fisheries on a global scale. Part of this work included the development of a global marine mammal database—containing information on distribution, migration and feeding patterns, habitat preferences, abundances estimates, mean body weights, diet composition and feeding rates—that will be made available online through the Sea Around Us website (*www.seaaroundus.org*) within the next year.

In addition to her academic work, Ms. Kaschner has been involved in a number of international projects working for various conservation-oriented NGO's, including the BUND Germany, Greenpeace Australia & Denmark, WWF Germany & US as well as assorted research institutes in Denmark, Sweden, the Netherlands, the UK, Australia, US, Canada and Germany. Most of this work has focused on studying general cetacean biology and more specifically impacts of human activities on marine mammal populations over the past 10 years. Most recently, she was contracted by the ASCOBANS scientific advisory committee to conduct an extensive review of small cetacean bycatch in the ASCOBANS area and adjacent waters, which was presented at the fourth meeting of ASCOBANS parties in the summer of 2003. Ms. Kaschner was an invited participant at the International Whaling Commision Scientific Committee workshop on bycatch mitigation and acoustic deterrents in 1999 and is a member of the Cetacean Bycatch Task Force. She also has been a FishBase collaborator since 2000, compiling information about the acoustical behaviour of fish. In addition, she is a contact person for the Northwest Student Chapter of the Society of Marine Mammalogy (NWSSMM).

Daniel Pauly

Dr. Daniel Pauly is a French citizen, born in May 1946 in Paris, France. He acquired a "Diplom" (= MSc) in 1974 in Germany and a Doctorate degree in Fisheries Biology in 1979 at the University of Kiel. He joined the International Center for Living Aquatic Resources Management (ICLARM), in Manila, Philippines, in July 1979 as a Postdoctoral Fellow, and gradually took increasing responsibilities as Associate and Senior Scientist, then Program and Division Director. He became an adjunct Professor at the University of the Philippines, where he taught fisheries sciences, and acted as thesis advisor to more than 20 MSc and PhD students. After a study leave at Kiel University (1985), he directed the doctoral theses of a number of students at the Institut für Meereskunde, where, as "Privatdozent," he also taught several courses in fish population dynamics.

In October 1994, he joined the Fisheries Centre, University of British Columbia (UBC), in Vancouver, Canada, as a tenured full Professor, while remaining ICLARM's Principal Science Advisor until Dec. 1997, and the Science Advisor of its FishBase project until 2000.

Since 1999, Dr. Pauly has acted as Principal Investigator of the Sea Around Us Project, based at the Fisheries Centre, UBC, funded by the Pew Charitable Trusts, Philadelphia, PA, and devoted to studying the impact of fisheries on the world's marine ecosystems. His scientific output, mainly dedicated to the management of fisheries and to ecosystem modelling, comprises authored and edited books, scientific papers and reports (a total of more than 500 items), and the concepts, methods and software he (co-) developed are in use throughout the world. This applies notably to the Ecopath modelling approach and software (see *www.ecopath.org*) and to FishBase, the online encyclopedia of fishes (see *www.fishbase.org*).

In 2001 he was awarded both the Murray Newman Award for Excellence in Marine Conservation Research, sponsored by the Vancouver Aquarium, and the Oscar E. Sette Award of the Marine Fisheries Section, American Fisheries Society. He was named an "Honorarprofessor" at Kiel University, Germany, in late 2002, and elected a Fellow of the Royal Society of Canada (Academy of Science) in early 2003. Profiles of Dr. Pauly were published in *Science* on April 19, 2002, *Nature* on Jan. 2, 2003, and the *New York Times* on Jan. 21, 2003.

Positions Held

1974 to 1976: "Projektassistent", German Society for Technical Cooperation (GTZ), assigned to the Indonesian-German Demersal Fisheries Project, Jakarta and Semarang, Indonesia.

1977 to 1979: Doctoral student and research assistant, Department of Fishery Biology, Institute for Marine Sciences, Kiel, Germany.

1979 to 1994: increasing responsibilities as staff member of the International Center for Living Aquatic Resources Management (ICLARM, Manila, Philippines): 1979-80: Post-Doctoral Fellow; 1980–85: Associate Scientist; 1985-94: Senior Scientist; 1986-93: Director, Resources Assessment and Management Program (and of successor Programs and Division); 1994-97: Principal Scientific Advisor, ICLARM; 1994-2000: Senior Scientific Advisor, FishBase Project, ICLARM.

1994 to present: Professor of Fisheries, Fisheries Centre, University of British Columbia, Vancouver, Canada.

Membership in Scientific Societies and Panels

Asian Fisheries Society, 1984 to 1993; Fisheries Society of the British Isles, 1987 to present; American Fisheries Society, 1981 to 1987 and 1995 to present; Network of Tropical Fisheries Scientists, 1982 to 1997; Network of Tropical Aquaculture Scientists, 1987 to 1997; Common Property Resource Network, 1986 to 1997; Deutsche Gesellschaft für Meeresforschung, 1982 to 1994; Philippine Fisheries Research Society, 1980 to 1989; British Sub-Aqua Club/Philippine Sub-Aqua Club, 1988 to 1997; Sociedad Mexicana de Historia Natural, 1987 to 1989; IOC/FAO Guiding Group of Experts of the Ocean Science and Living Resources Program, 1984 to 1989; Biological Rapporteur, IOC/SCOR Committee on Climate Changes and the Oceans, 1987 to 1988; Scientific Advisor, Asian Fisheries Society Research Fellowship Award Scheme, 1988 to 1993; Committee on Marine Science, Pacific Science Association, 1986 to 1988; Committee on Ecosystem Management for Sustainable Marine Fisheries, (U.S.) National Research Council (Washington, D.C.), September 1995 to 1998; International Foundation for Science, Scientific Advisor, 1995 to 1998; Working Group 105 on "The Impact on Fisheries Harvest on the Stability and Diversity of Marine Ecosystems" of the Scientific Committee on Oceanic Research, March 1996 to March 1999. Coordinating Lead Author for "Marine Systems," Millennium Ecosystem Assessment (2002–2005); Fellow, Royal Society of Canada (Academy of Science, from 2003).

Editorial Boards

J. Applied Ichthyol., Subject Editor for Fisheries in Developing Countries, 1985 to 1994; *Asian Fisheries Science*. Editorial Board Member, 1987 to 1993; *Fishbyte* (Newsletter of the Network of Tropical Fisheries Scientists). Editor, 1988 to 1991; and Editor, *Fishbyte Section of Naga, the ICLARM Quarterly*, 1992 to 1996; *Reviews in Fish Biology and Fisheries*, Editorial Board Member, 1991 to 1999; *Boletim, Instituto Português de Investigação Maritima*. Editorial Board Member, 1995 to present; *African Journal of Tropical Hydrobiology and Fisheries*. Editorial Board Member, 1995 to present; *Marine and Freshwater Research* (Formerly *Austr. J. Mar. Freshwater. Res.*), 1997 to present; *Fish and Fisheries*, Associate Editor, 1999 to present.

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