Global distribution and conservation of marine mammals

Sandra Pompa[a,1], Paul R. Ehrlich[b], and Gerardo Ceballos[a,1]

[a]Instituto de Ecología, Universidad Nacional Autónoma de México, Distrito Federal, 04510, Mexico; and [b]Center for Conservation Biology, Biology Department, Stanford University, Stanford, CA, 94305

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We identified 20 global key conservation sites for all marine (123) and freshwater (6) mammal species based on their geographic ranges. We created geographic range maps for all 129 species and a Geographic Information System database for a 46,184 1° x 1° grid-cells, ∼10,000-km^2. Patterns of species richness, endemism, and risk were variable among all species and species groups. Interestingly, marine mammal species richness was correlated strongly with areas of human impact across the oceans. Key conservation sites in the global geographic grid were determined either by their species richness or by their irreplaceability or uniqueness, because of the presence of endemic species. Nine key conservation sites, comprising the 2.5% of the grid cells with the highest species richness, were found, mostly in temperate latitudes, and hold 84% of marine mammal species. In addition, we identified 11 irreplaceable key conservation sites, six of which were found in freshwater bodies and five in marine regions. These key conservation sites represent critical areas of conservation value at a global level and can serve as a first step for adopting global strategies with explicit geographic conservation targets for Marine Protected Areas.

biodiversity | conservation priorities | political endemism

The current loss of biological diversity is one of the most severe global environmental problems and probably is the only one that is truly irreversible. Recent studies show that anthropogenic factors are causing increasing rates of extinctions of both populations and species (1–3). Despite their immense value, marine ecosystems are deteriorating rapidly, especially because of habitat degradation, overexploitation, introduction of exotic species, pollution (including noise), acidification, and climate disruption (4, 5), in part because roughly 60% of the world's human population lives within 100 km of a coast, and 20% of ecosystems adjacent to oceans have been highly modified (6, 7). Because of those anthropogenic environmental changes, many species of marine animals have undergone local, regional, or global extinctions (8). Marine mammals provide some of the best-known cases of population and species extinction through overexploitation. Many species have experienced severe population depletion, and at least three [Caribbean monk seal (*Monachus tropicalis*), Atlantic gray whale (*Eschrichtius robustus*), and the Steller's sea cow (*Hydrodamalis gigas*)] became extinct because of hunting for their fur, blubber, and meat during the 19th and 20th centuries. The most recent extinction, caused by several human activities including illegal hunting for meat and body parts used in traditional medicine, is the baiji (*Lipotes vexillifer*) from the Yangtze River in China, which was declared extinct in 2008 (9).

Understanding geographical variation in species richness and other large-scale patterns can be especially valuable for the establishment of global conservation priorities (10–13). Those patterns, for example, allow assessment of what would be required to preserve all species in a given taxon and to determine critical sites for their conservation (14–16). Given that the distribution patterns of species richness usually are not closely related to those of endemism and extinction risk, conservation actions to minimize global species extinction necessarily involve a combined evaluation of patterns of richness, endemism, and endangerment (17, 18). Global distribution patterns have been determined for different vertebrate groups such as birds, amphibians, fish, and terrestrial mammals (19–22), but such large-scale analyses are lacking for marine/freshwater mammals (23).

Here we present a global analysis of distribution patterns for 129 marine mammals, focusing on the following goals: (*i*) describing their geographic ranges; (*ii*) assessing patterns of species richness and composition; and (*iii*) determining key conservation sites as a basis for understanding global conservation needs. We created a database with the geographic distribution of all 129 species of pinnipeds, cetaceans, sirenians, two species of otters, and the polar bear (24). We followed Reeves et al. (24) and Wilson and Reeder (25) for the basic taxonomic arrangement (*SI Appendix*). It is important to emphasize, however, that the taxonomy of many marine mammals is still confused. The oceans are the last remaining places where large, charismatic species doubtless remain to be described; new species have been found in the last 20 y. For example, *Mesoplodon perrini* (a 4-m beaked whale) (26) and *Orcaella heinsohni* (the 2-m Australian snubfin dolphin) (27) were scientifically described recently. The taxonomic position of many species is controversial and likely to change radically in the future when more data are available. For example, recent studies suggest that there are several species of orcas (28, 29), Bryde's whales (30), and Blue whales (31, 32). The taxonomy of dolphins also is complex. For example, some consider the Amazonian Tucuxi dolphin (*Sotalia fluviatilis*) to be two species (33, 34). Obviously, as taxonomic knowledge improves, one would expect changes in the overall distribution patterns we describe. We defined endemic species as those whose distribution is limited to a single country (political endemism), and the conservation status of all species follows that given by the International Union for the Conservation of Nature (*SI Appendix*) (35).

The lack of better distributional data precludes more sophisticated analysis, such as modeling standard habitat suitability, to predict ranges of the majority of marine mammal species on very large scales (36). Any comprehensive consideration of the distribution of cetaceans is hampered by the uneven sighting effort; range maps therefore must be interpreted with caution. To date, descriptive statistical techniques have been used to explore cetacean–habitat relationships for selected species in specific areas. There are fewer studies that examine patterns of species richness and geographic ranges using computationally intensive statistic modeling techniques. The development of models to test specific hypotheses about the ecological processes determining cetacean distributions has just begun (37). Marine spatial planning is clearly a way forward, particularly for the high seas, where nonspatial monitoring is difficult and where data gaps obstruct conventional management approaches (38).

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[1]To whom correspondence may be addressed. E-mail: sandra_pompa@ecologia.unam.mx or gceballo@ecologia.unam.mx.

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To make the data from different species as compatible as possible, we used the same source of distribution information for all species. Despite the limitations in present knowledge, it is imperative to evaluate and implement conservation measures in ways that attempt to compensate for the uncertainties. Spatial modeling incorporates data on the environment to generate a spatial prediction of relative density based on the preference for habitats defined by combinations of environmental covariates. The areas identified for the candidate Marine Protected Areas (MPAs) thus provide a good description of distribution available, as informed by features of the habitat that are shown to be important (39). Terrestrial mammal conservation faces similar uncertainties (40, 41), but significant progress has been made in identifying conservation sites critical for species richness, endemism, and endangerment, using data similar to those used in our study. Such knowledge has contributed to the steps that have been taken to protect many species (2, 15–18).

Results and Discussion

Marine mammals are a polyphyletic group that comprises 129 species grouped in three orders, Cetacea, Sirenia, and Carnivora (Table 1). The smallest marine mammal is the sea otter (1.15 m, 4.5 kg), and the biggest is the blue whale (30 m, 190 tons). Marine mammals show very complex, heterogeneous distributions throughout the oceans and also are found in a few freshwater lakes and rivers. The average geographic range for all species is 52 million km^2 (Fig. 1*A*). The most widely distributed species, with ranges exceeding 350 million km^2, are Bryde's (*Balaenoptera edeni*) and humpback (*Megaptera novaeangliae*) baleen whales. The marine species with the most restricted range is the vaquita (42) (*Phocoena sinus*), a porpoise species endemic to 4 000 km^2 in the upper northern Gulf of California, Mexico. However, most of the species with very restricted ranges, such as the Baikal seal (*Pusa sibirica)*, are freshwater species endemic to lakes. They probably have relict distributions, remnants of much larger ranges in geologic times (24). Both endemic and restricted-range species have high priority for conservation because they usually are more vulnerable to anthropogenic impacts (2, 10).

In terms of richness, the analysis of our 46,184-cell, ∼10,000-km^2 global geographic quadrant grid (*Methods*) showed that the number of species per cell varied from 1 to 38, with an average of 17 species, across vast regions of the oceans. Interestingly, latitudinal gradients of species richness of marine and land mammals are very different. Marine mammals have undergone considerable anatomical modifications during their evolution. The unique characteristics of the marine ecosystems have resulted in the many different physiological and ecological responses that marine mammals have experienced. These modifications undoubtedly have resulted in energetic constraints. One of several complex structures of the marine environment is a more-or-less unpredictable, patchy distribution of food over large spatial and temporal scales; this patchy distribution almost certainly has contributed to the evolution of marine mammal energetics, especially through its effect upon energy storage and expenditure strategies. Species richness of land mammals increases sharply from temperate latitudes toward the equator. In contrast, species richness in marine mammals has a more northerly temperate component, showing a higher concentration of species (24 species average) between 30° N and 40° S (Figs. 1*B* and 2*A*). Other factors contributing to this pattern in marine mammals remain to be evaluated; nevertheless, the results of our richness-distribution patterns are consistent with other approaches analyzing marine mammal distribution patterns (36, 43).

Table 1. Variation in the number of cells and the area covered by different targets to select top-priority cells for marine mammal conservation

% Grid cells	# Grid cells evaluated	Extension (km^2)	Total species richness
1	462	4,620,000	91 (71%)
2.5	1,155	11,550,000	108 (84%)
5	2,309	23,090,000	127 (98%)
7.5	3,464	38,104,000	129 (100%)

Regions especially rich in marine species (Fig. 2*A*) were found along the coasts of North and South America, Africa, Asia, and Australia. Such patterns apparently are correlated with ocean currents and their dynamics, especially with nutrient flows connected to upwellings. For example, along the Pacific coast of the American continent, the highest species richness was found along the California, Baja California, and Peruvian coasts, where large upwelling systems maintain very productive fish communities (44). Interestingly, among higher taxa, patterns of species distribution in marine mammals differed strongly (Fig. 3 *A–C*). Pinniped (seal and sea lion) species richness was concentrated at the poles, especially near Antarctica, whereas Mysticetes (baleen whales) exhibited high species richness at 30° S latitude, and Odontocetes (toothed whales) were concentrated near tropical coasts. There also was variation in distribution at the family level within and among orders; for example, the two families in Sirenia had contrasting distributions: The Trichechidae (manatees) were found exclusively in the North and South Atlantic, whereas the Dugongidae (dugong) were restricted to the North Pacific and Indo-Pacific.

Political endemic species [i.e., species found in only one country, a restriction that may increase their vulnerability (2)] included seven species; the Baikal seal (*Pusa sibirica*), the Australian sea lion (*Neophoca cinerea*), the Galapagos fur seal (*Arctocephalus galapagoensis*), the Galapagos sea lion (*Zalophus wollebaeki*), the New Zealand dolphin (*Cephalorhynchus hectori*), the Hawaiian monk seal (*Monachus schauinslandi*), and the vaquita (*Phocoena* sinus) (45). Seven species, among them the New Zealand sea lion (*Phocarctos hookeri*) and the Australian Snubfin dolphin (*Orcaella heinsohni*), had restricted ranges. In terms of extinction risk, 10% of all marine mammals are considered vulnerable, 11% endangered, and 3% critically endangered (*SI Appendix*). Species at risk were found throughout the oceans but were concentrated at higher latitudes, especially near the Aleutian Islands and the Kamchatka Peninsula, where extensive exploitation of whales and seals occurred in the past (Fig. 4).

To assess the conservation challenges to marine mammals, we determined the area (i.e., the number of cells) required to incorporate different percentages (i.e., 10%, 15%, 20%, and 25%) of the geographic ranges of all species, using the Marxan optimization algorithm (*Methods*). Conserving at least 10% of all of the species' geographic range required *ca*. 45 million km^2 (5,700 grid cells), roughly equivalent to 12% of the world's ocean area (e.g., two times the extent of the Southern Ocean). This study provides grounds for future assessment of an area-explicit conservation parameter for marine mammals. The "target" of 10% was used so this work would be comparable to our previous papers on terrestrial mammals (15, 46); it also is one of the targets suggested by the Convention on Biological Diversity (47). This Convention has called for networks of protected areas, which, in addition to other conservation measures, are necessary components of sustainable use (39). Targeting 15%, 20%, and 25% of each marine mammal's distribution range considerably increased the area required to meet the targets (Fig. 5). Clearly, protecting larger targets must incorporate, by necessity, other conservation mechanisms in addition to reserves or MPA's (48, 49).

Our next step was to identify key conservation sites representing all marine mammal species in a geographically explicit way. We selected those sites using the grid cells with the greatest diversity followed by "irreplaceable" cells (i.e., cells with species represented nowhere else), using the Marxan optimization algorithm (*Methods*). We evaluated the representation of all marine mammal species in 1%, 2.5%, 5%, 7.5%, and 10% of the grid cells (Table 1). We chose 2.5% because these grid cells in-

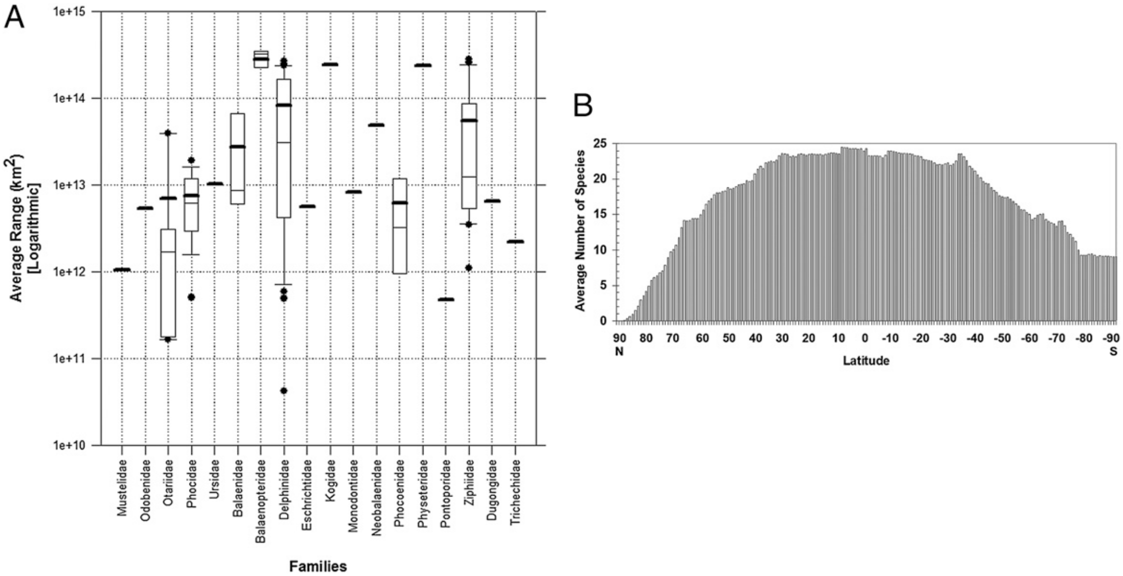

Fig. 1. Geographic distribution of marine mammals of the world. (*A*) Box plot with the conservative estimates of geographic range sizes by family. The thick black horizontal lines represent the average family range; the thin line inside the box marks the median family range; the top and bottom edges of the box are the first quartile (bottom edge) and the third quartile (upper edge) of the family range; bars derived from the box represent the maximum range value (upper bar) and the minimum range value (lower bar). Black dots represent outlier species. (*B*) Latitudinal trends in marine mammal species richness. Note that, as with terrestrial mammals, species richness is greater with decreasing latitude. However, in marine mammals the number of species is relatively similar from 30° N to 40° south, very different from the distribution of land mammal species.

cluded 108 (84%) of all species; the missing species were all the 10 endemic species and 11 additional species that have restricted distributions, so they were dispersed in a very large area. Selecting the top 5% of the grid cells would include an additional 19 species but would require more than twice the area required in the 2.5% scenario. Therefore we used Marxan to select in a more effective way the cells containing all missing species, optimizing the area required so that all marine mammals would be represented in our network of key conservation sites. Also, the 2.5% cutoff has been used in studies with land mammals, so using that cutoff allows comparison of terrestrial and marine conservation issues (17, 18).

We identified 20 key conservation sites (Fig. 2 *A* and *B*). These key sites can be the basis for identifying a comprehensive con-

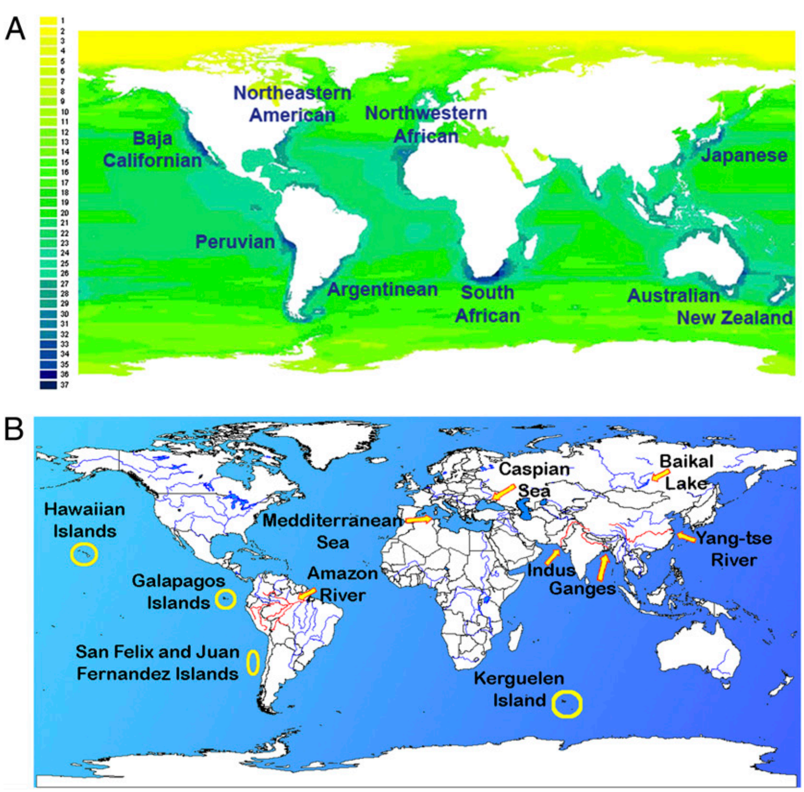

Fig. 2. Patterns of geographic distribution and key conservation sites for marine mammals. (*A*) The distribution of marine species richness is very heterogeneous. The most diverse 10,000-km^2 cells have 37 species. The number of species in each cell is shown in the column on the left. The map shows the nine key conservation sites selected as being among the top 2.5% of cells in species richness. These areas include strictly marine species exclusively. (*B*) Irreplaceable key conservation sites were selected so that all marine mammals are represented in a conservation network.

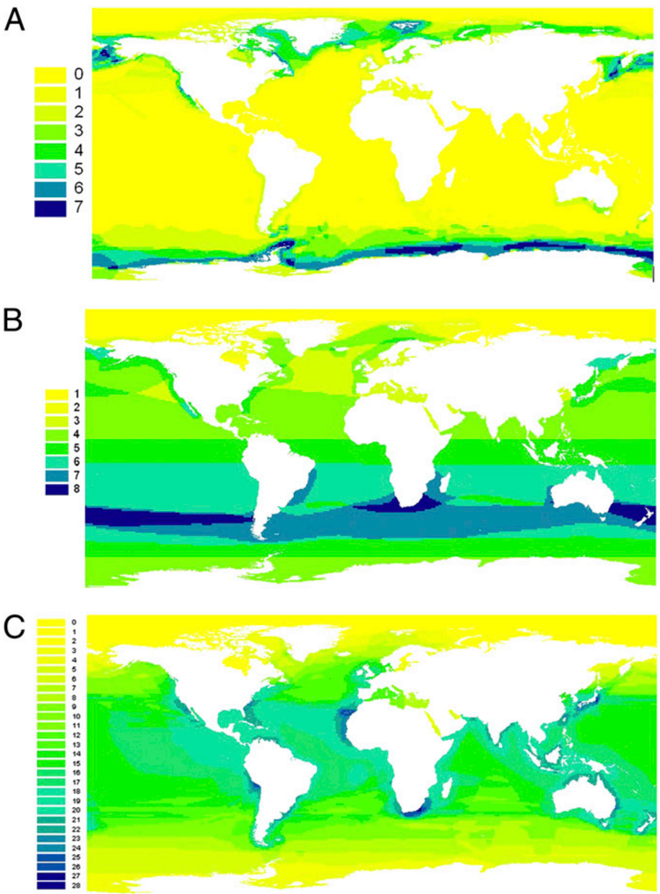

Fig. 3. Patterns of geographic distribution of species richness in different orders of marine mammals. (*A*) Pinnipeds (e.g., sea lions). (*B*) Mysticetes (e.g., blue whale). (*C*). Odontocetes (e.g., dolphins). Note the highly contrasting patterns and the higher species richness in Odontocetes. The number of species in each cell is shown in the column on the left.

servation strategy with MPAs representing all marine mammals, their ecological roles, and some threats (39, 50). The nine key conservation sites selected because of their species richness were along the coasts of Baja California, Northeastern America, Peru, Argentina, Northwestern Africa, South Africa, Japan, Australia, and New Zealand. These sites represent 108 species (84% of all marine mammal species), including five endemic species (Fig. 2). They are located in all continental waters except Europe and are mostly in temperate latitudes; only the key conservation site off Peru is located in tropical waters. They occur in five of the seven ocean regions (24), being absent from the polar regions, and include 11 (25%) of the 44 marine ecoregions (25). Not surprisingly, these key sites seem to be located in upwelling oceanic areas, where there is a confluence of cold and warm currents. These oceanographic circumstances favor zones of high primary production, which are good feeding areas for marine mammals (43). As expected, the areas of concentration of specific orders vary strongly across space (Fig. 3 *A*–*C*). The 11 key conservation sites that were deemed irreplaceable because the presence of endemic species were the Hawaiian Islands, Galapagos Islands, Amazon River, San Felix and Juan Fernández Islands, Mediterranean Sea, Caspian Sea, Lake Baikal, Yang-Tze River, Indus River, Ganges River, and the Kerguelen Islands (Fig. 2*B*). These sites had unique species, such as the Galapagos fur seal (*A. galapagoensis*) and the Mediterranean monk seal (*Monachus monachus*). Interestingly, six irreplaceable sites were continental (rivers and lakes), and five were marine.

We understand that grid cells are not all equally important for conservation aside from their species richness or endemic species (51, 52). In marine mammals, breeding and feeding grounds and migratory routes are especially important for conservation. Therefore, to identify the key conservation sites, special weight was given in the Marxan optimization algorithm (*Methods*) to grid cells found in calving/breeding/feeding grounds and to known migratory routes of several species. For example, the locations of the breeding grounds for humpback and right whales are well known and often are relatively concentrated, as are all or part of the migratory corridors for some populations. However, such information is not available for many species. Giving more weight to breeding/feeding areas of migratory routes is very important for marine mammals that are highly mobile.

We analyzed the relationship of three human impacts—climate disruption, ocean-based pollution, and commercial shipping (53)—with grid-cell species richness, using a Spearman rank correlation. As we expected, the three impacts have a significant correlation with species richness ($rs = 0.693$, $n = 46{,}164$, $P < 0.01$ for climate disruption; $rs = 0.666$, $n = 46{,}164$, $P < 0.01$ for pollution; and $rs = 0.678$, $n = 46{,}164$, $P < 0.01$ for shipping). Our results indicate the widespread impact of human activities on marine ecosystems and their potential for negatively impacting key marine mammal conservation sites. Around 70% of the highest values for the three impacts were located within or near one of our key conservation sites. Adding other human impacts such as commercial fishing probably will show even stronger impacts of human activities on marine mammal conservation.

Areas of overlap between fisheries and marine mammal groups are concentrated mostly in the Northern Hemisphere and appear to occur primarily between pinnipeds and fisheries. Partly because of the comparatively low total food intake of dolphins, the overlap between dolphins and fisheries is quite low and, again, is concentrated mostly in the Northern Hemisphere. Not surprisingly, the lowest overlap occurs between fisheries and deep-diving large-toothed whales, whose diets consist primarily of large squid species and mesopelagic fish not currently exploited by fisheries (54). Narrow coastal fringes are the location of nine of our key conservation sites identified by their species richness. The Japanese and Peruvian richness sites are located within the Northwest and Southeastern Pacific zones, respectively; these two zones have the highest fisheries catch of the major fishing areas in the world (55). The Australian key conservation site, the one with the highest species richness, is in the East Indian Ocean and the Southwest Pacific zones, which are ranked sixth and 18th, respectively, by catch intake (55). The Japanese richness site also is located within Chinese waters (China is top fish-harvesting nation in the world), where 17 million tons of fish are captured annually and where at least 30 marine mammal species live (55). In addition, at least five of the key conservation sites overlap with highly impacted ocean areas where high bycatch fishing occurs (53).

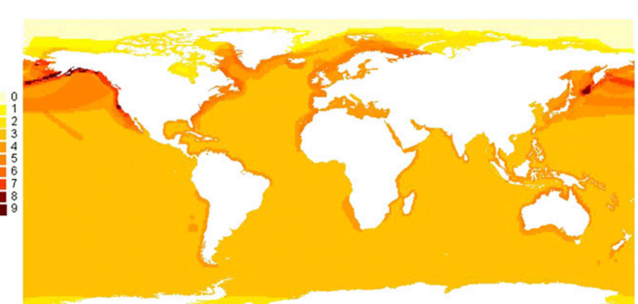

Fig. 4. Patterns of geographic distribution of marine mammal species that are at risk for extinction. The species included are those considered vulnerable, endangered, or critically endangered by the International Union for the Conservation of Nature (25). The number of species in each cell is shown in the column on the left.

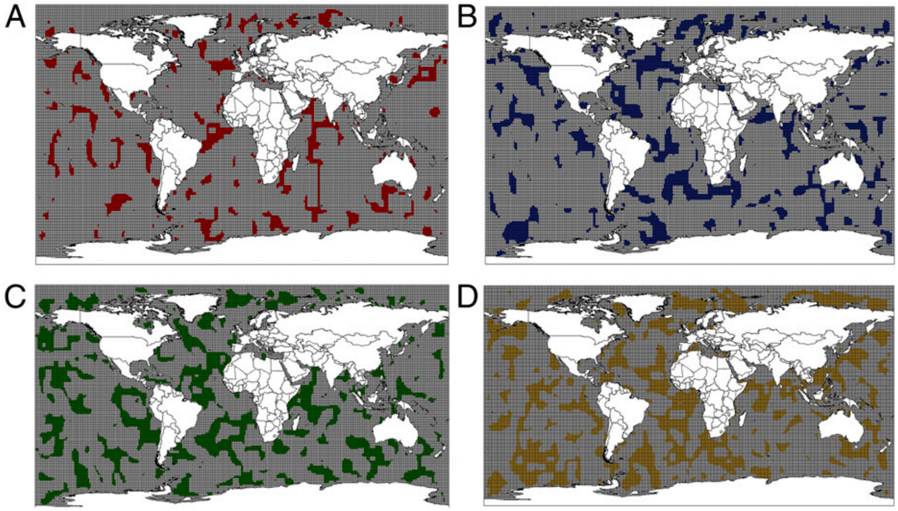

Fig. 5. Conservation targets covering (*A*) 10%, (*B*) 15%, (*C*) 20%, and (*D*) 25% of the marine mammal distributions using the Marxan optimization algorithm to optimize the number of grid cells and its geographic location.

Many marine species and populations [e.g., North Atlantic right whale (*Eubalaena glacialis*) and the Sei whale (*Balaenoptera borealis*)] are at the brink of extinction from overharvesting, pollution, bycatch, and exhaustion of prey-species populations (24, 25, 56–58), and their long-term survival depends on sound management that addresses the factors causing their decline. The baiji dolphin, once endemic to the Yang-Tze River in China, is a disturbing example of the plight of marine mammals impacted by human activities (9). The next candidate to become extinct if no solid conservation and management strategies are implemented is the Mexican vaquita. Endemic to the Gulf of Baja California, the species has been declining sharply for at least 2 decades; one fifth of the population is killed in gillnets every year, and there now are only an estimated 150–300 individuals (59). Indeed, more than 650,000 marine mammals die from entanglement in fishing nets each year (60), making bycatch the single largest cause of mortality for small cetaceans and pushing several species to the verge of extinction.

Conservation strategies also should take into account the possible impacts of anthropogenic climate disruption (61, 62) on the distribution of these mammals and its repercussions on the establishment of connective corridor systems between protected areas (61) and on management plans. Finally, management interventions must be evaluated critically with regard to ecological viability and benefits vs. costs (61).

By selecting the smallest area of reserves using an optimization algorithm, the opportunity conservation cost would be generally lower, but this approach will depend on the distribution of other potential economic activities (63). For instance, an evaluation of fisheries values could provide a feasible first cut at calculating those costs. Given the distribution patterns of marine mammals, the increasing pressures of human activities in the oceans, and the threat of climate disruption, the conservation of marine mammals is a daunting problem. Saving one or two populations of most species will not be enough (2) because of the role that such charismatic mammals play in the ecological dynamics of marine and freshwater ecosystems and in the provision of ecosystem services. As many scientists have emphasized in other forums, especially in connection with whaling (64), the complexity and scale of the problem requires an unprecedented international effort with the development of both new attitudes and institutions (65). The main objectives of selection criteria for MPAs are to identify potential MPAs for highly mobile and temporally variable pelagic species, including high-density areas, feeding or breeding grounds, and migratory routes; to provide a transparent and systematic approach to selection; and to help determine priorities for action (39).

Uncertainty will always be a factor in research on pelagic organisms and their environment. Empirical data point to dramatic declines and changes in marine systems, and ongoing research continues to provide techniques to incorporate and contend with uncertainty. The challenge is to produce timely and scientifically defensible research based on available data to address this conservation crisis now (56). The future of marine mammals in particular and biodiversity in general will depend on the actions we take.

Methods

We compiled and digitized the geographic range maps from published sources for all 129 species and created a Geographic Information System database for 46,184 1° x 1° grid-cells, ~10,000-km^2. We then conducted a presence/absence analysis to determine the number of species in each grid cell and the number of cells in which each species was recorded. We created maps of global species richness, irreplaceable sites, endemism, and threatened species. Key conservation sites for species richness were determined either as the 2.5% of the cells with the highest species richness or as irreplaceable sites, defined as regions containing species not represented in any other part of the world (17, 18). Additionally, we used optimization algorithms, i.e., ResNet (66) and Marxan (67, 68 69), to determine the number of cells required to cover 10%, 15%, 20%, and 25% of the geographic ranges of all species and the area of the ocean covered by each percentage.

Marxan is software that delivers decision support for reserve system design intended to solve a particular class of reserve design problem in which the goal is to achieve some minimum representation of biodiversity features for the smallest possible cost. Given reasonably comprehensive data on species, habitats, and/or other relevant biodiversity features, Marxan aims to identify the reserve system (a combination of planning units) that will meet user-defined biodiversity targets for the minimum cost. In this particular case, Marxan selected planning units (here, grid cells) to meet the targets (10%, 15%, 20%, and 25% of the geographic ranges of all 129 species) and also considered the following factors. Each grid cell is assigned a "cost" depending on the target (e.g., area, number of species, threat), and Marxan minimizes the combined grid-cell cost of the conservation network, still selecting expensive grid cells if they are needed to meet the targets. This cost can be a measure of any aspect of the planning unit (25, 69, 70); in this case, it was species richness plus cells weighted for breeding/feeding ground or migratory route. We set Marxan to select adjacent planning units preferentially rather than a series of unconnected units, which would be less ecologically viable and more difficult to manage. Then Marxan identified a set of grid cells each time it was run: 100 runs generated 100 different grid-cell networks (67). Units that appeared in every network were considered irreplaceable, because they always would be needed to meet the targets, whereas other units could be swapped with similar units, and the targets still would be met. Fig. 5 was achieved using these methods.

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SUPPLEMENTARY INFORMATION

I. TAXONOMIC DECISIONS

In this work we followed Wilson and Reeder (2005) and Reeves, Stewart, and Clapham's (2002) taxonomy. In the last 20 years several new species have been described such as *Mesoplodon perrini* (Dalebout 2002), *Orcaella heinsohni* (Beasley 2005), and the recognition of several species have been proposed for orcas (Perrin 1982, Pitman *et al*. 2007), Bryde's whales (Kanda *et al.* 2007), Blue whales (Garrigue *et al*. 2003, Ichihara 1996), Tucuxi dolphin (Cunha *et al*. 2005, Caballero *et al*. 2008), and other marine mammals. Since we used the conservation status of all species following IUCN (2011), this work is based on species recognized by this IUCN to keep a standardized baseline.

II. SPECIES LIST

List of the species included in this paper, indicating their conservation status according to IUCN (2010.4) and its range area.

Order	Family	Species	IUCN 2010	Freshwater	Range area km^2
Carnivora	Mustelidae	*Enhydra lutris*	EN A2abe		1,084,750,000,000
		Lontra felina	EN A3cd		996,197,000,000
	Odobenidae	*Odobenus rosmarus*	DD		5,367,060,000,000
	Otariidae	*Arctocephalus australis*	LC		1,674,290,000,000
		Arctocephalus forsteri	LC		1,823,240,000,000
		Arctocephalus galapagoensis	EN A2a		167,512,000,000
		Arctocephalus gazella	LC		39,155,300,000,000
		Arctocephalus philippii	NT		163,932,000,000
		Arctocephalus pusillus	LC		1,705,430,000,000
		Arctocephalus townsendi	NT		1,045,950,000,000
		Arctocephalus tropicalis	LC		39,249,100,000,000
		Callorhinus ursinus	VU A2b		12,935,900,000,000
		Eumetopias jubatus	EN A2a		3,051,310,000,000
		Neophoca cinerea	EN A2bd+3d		1,347,900,000,000
		Otaria flavescens	LC		2,371,930,000,000
		Phocarctos hookeri	VU A3b		171,500,000,000
		Zalophus californianus	LC		966,957,000,000
		Zalophus wollebaeki	EN A2a		175,487,000,000
	Phocidae	*Cystophora cristata*	VU A2b		5,167,870,000,000
		Erignathus barbatus	LC		12,550,800,000,000

		Halichoerus grypus	LC		2,443,290,000,000
		Histriophoca fasciata	DD		3,625,450,000,000
		Hydrurga leptonyx	LC		9,900,130,000,000
		Leptonychotes weddellii	LC		7,146,790,000,000
		Lobodon carcinophaga	LC		18,961,100,000,000
		Mirounga angustirostris	LC		2,054,680,000,000
		Mirounga leonina	LC		8,976,400,000,000
		Monachus monachus	CR A2abc; C2a(i); E		2,730,360,000,000
		Monachus schauinslandi	CR A3ce+4ce		503,740,000,000
		Ommatophoca rossii	LC		12,649,700,000,000
		Pagophilus groenlandicus	LC		8,352,950,000,000
		Phoca largha	DD		5,173,220,000,000
		Phoca vitulina	LC		4,233,030,000,000
		Pusa caspica	EN A2abd+3bd+4abd		-
		Pusa hispida	LC		14,792,000,000,000
		Pusa sibirica	LC	FW	-
	Ursidae	*Ursus maritimus*	VU A3c		10,273,300,000,000
Cetacea	Balaenidae	*Balaena mysticetus*	LC		8,735,490,000,000
		Eubalaena australis	LC		66,669,400,000,000
		Eubalaena glacialis	EN D		-
		Eubalaena japonica	EN D		5,995,590,000,000
	Balaenopteridae	*Balaenoptera acutorostrata*	LC		138,899,000,000,000
		Balaenoptera acutorostrata subsp.	LC		-
		Balaenoptera bonaerensis	DD		235,109,000,000,000
		Balaenoptera borealis	EN A1ad		325,876,000,000,000
		Balaenoptera edeni	DD		225,248,000,000,000
		Balaenoptera musculus	EN A1abd		349,620,000,000,000
		Balaenoptera omurai	DD		-
		Balaenoptera physalus	EN A1d		348,861,000,000,000
		Megaptera novaeangliae	LC		349,580,000,000,000
	Delphinidae	*Cephalorhynchus commersonii*	DD		1,780,950,000,000
		Cephalorhynchus eutropia	NT		493,046,000,000
		Cephalorhynchus heavisidii	DD		802,273,000,000
		Cephalorhynchus hectori	EN A4d		42,555,300,000
		Delphinus capensis	DD		9,313,700,000,000
		Delphinus delphis	LC		31,026,900,000,000
		Feresa attenuata	DD		198,729,000,000,000
		Globicephala macrorhynchus	DD		238,501,000,000,000
		Globicephala melas	DD		104,690,000,000,000
		Grampus griseus	LC		265,158,000,000,000

		Lagenodelphis hosei	LC		165,128,000,000,000
		Lagenorhynchus acutus	LC		8,519,550,000,000
		Lagenorhynchus albirostris	LC		10,168,600,000,000
		Lagenorhynchus australis	DD		590,641,000,000
		Lagenorhynchus cruciger	LC		61,848,200,000,000
		Lagenorhynchus obliquidens	LC		20,853,700,000,000
		Lagenorhynchus obscurus	DD		6,186,320,000,000
		Lissodelphis borealis	LC		12,737,400,000,000
		Lissodelphis peronii	DD		78,075,800,000,000
		Orcinus orca	DD		159,671,000,000,000
		Orcaella brevirostris	VU A4cd		4,252,570,000,000
		Orcaella heinsohni	NT		1,264,170,000,000
		Peponocephala electra	LC		167,492,000,000,000
		Pseudorca crassidens	DD		115,652,000,000,000
		Sotalia fluviatilis	DD		2,115,420,000,000
		Sotalia guianensis	DD		-
		Sousa chinensis	NT		15,839,700,000,000
		Sousa teuszii	VU C2a(i)		1,554,490,000,000
		Stenella attenuata	LC		185,346,000,000,000
		Stenella clymene	DD		40,843,500,000,000
		Stenella coeruleoalba	LC		247,740,000,000,000
		Stenella frontalis	DD		45,684,100,000,000
		Stenella longirostris	DD		197,320,000,000,000
		Steno bredanensis	LC		220,032,000,000,000
		Tursiops aduncus	DD		26,634,700,000,000
		Tursiops truncatus	LC		232,786,000,000,000
	Eschrichtiidae	*Eschrichtius robustus*	LC		5,640,160,000,000
	Iniidae	*Inia geoffrensis*	DD	FW	-
	Kogidae	*Kogia breviceps*	DD		251,271,000,000,000
		Kogia sima	DD		235,194,000,000,000
	Lipotidae	*Lipotes vexillifer*	CR C2a(ii), D	FW	-
	Monodontidae	*Delphinapterus leucas*	NT		10,167,800,000,000
		Monodon monoceros	NT		6,370,340,000,000
	Neobalaenidae	*Caperea marginata*	DD		49,073,400,000,000
	Phocoenidae	*Neophocaena phocaenoides*	VU A2cde		4,086,040,000,000
		Phocoena dioptrica	DD		2,431,640,000,000
		Phocoena phocoena	LC		9,201,080,000,000
		Phocoena sinus	CR A4d; C2a(ii)		18,195,900,000
		Phocoena spinipinnis	DD		1,274,860,000,000
		Phocoenoides dalli	LC		19,888,000,000,000

	Physeteridae	*Physeter macrocephalus*	VU A1d		239,682,000,000,000
	Platanistidae	*Platanista gangetica*	EN A2abcde	FW	-
		Platanista minor	-	FW	-
	Pontoporidae	*Pontoporia blainvillei*	VU A3d		480,376,000,000
	Ziphiidae	*Berardius arnuxii*	DD		101,075,000,000,000
		Berardius bairdii	DD		23,620,500,000,000
		Hyperoodon ampullatus	DD		12,598,000,000,000
		Hyperoodon planifrons	LC		86,815,900,000,000
		Indopacetus pacificus	DD		106,594,000,000,000
		Mesoplodon bidens	DD		13,884,300,000,000
		Mesoplodon bowdoini	DD		4,419,570,000,000
		Mesoplodon carlhubbsi	DD		1,096,570,000,000
		Mesoplodon densirostris	DD		257,754,000,000,000
		Mesoplodon europaeus	DD		12,338,600,000,000
		Mesoplodon ginkgodens	DD		3,486,050,000,000
		Mesoplodon grayi	DD		66,140,000,000,000
		Mesoplodon hectori	DD		5,066,070,000,000
		Mesoplodon layardii	DD		83,734,500,000,000
		Mesoplodon mirus	DD		6,300,090,000,000
		Mesoplodon perrini	DD		8,015,760,000,000
		Mesoplodon peruvianus	DD		12,321,700,000,000
		Mesoplodon stejnegeri	DD		6,809,010,000,000
		Mesoplodon travsersii	DD		-
		Tasmacetus shepherdi	DD		4,419,310,000,000
		Ziphius cavirostris	LC		280,013,000,000,000
Sirenia	Dugongidae	*Dugong dugon*	VU A2bcd		6,586,460,000,000
	Trichechidae	*Trichechus inunguis*	VU A3cd	FW	-
		Trichechus manatus	VU C1		2,189,720,000,000
		Trichechus senegalensis	VU A3cd, C1		-

III. AREA CALCULATIONS (Goodes Homolosine Projection)

The Goode homolosine projection (or interrupted Goode homolosine projection) is an interrupted, pseudocylindrical, equal-area, composite map projection used for world maps. Its equal-area property makes it useful for raster data representation. The projection is composed of twelve regions that form six interrupted lobes. The lobes are the top sections of a Mollweide projection, and are carefully grafted on to six interior regions along the equator that are subject to a sinusoidal projection. Because the Mollweide is sometimes referred to as the "homolographic projection," the two names "homolographic" and "sinusoidal" are fused in the name "homolosine," which Goode applied to this projection. If one looks carefully along the edges of the lobes, one can see a subtle discontinuity at approximately the 41st parallels. The equal-area nature of the Goode follows from the fact that its source projections are themselves both equal-area.

The projection was developed in 1923 by John Paul Goode to provide an effective alternative to portraying global areal relationships on the Mercator map.

This projection was quite common in the 1960's, when it gained the nickname "the orange-peel map" from its resemblance to a flattened, hand-peeled rind of that fruit. Since then the Peters projection, which distorts the shapes of the continents, has gained usage. (ESRI 2010).

IV. SPECIES IN KEY CONSERVATION SITES AND IRREPLACEABLE SITES

Global priority key conservation area indicating their species richness, endemism, endangerment, ecoregion where they are located, and ecoregion's threat[37]. Irreplaceable areas (i.e. containing species found nowhere else) are indicated with an asterik; such areas usually have only one species.

	Key conservation sites	**Number Species**	**Endemic/ Small-Range**	**Risk Category for each ecoregion***	**Number and Name of the ecoregion***	**Estimated conservation status of the ecoregion***
Highest Richness	South African	16	4	VU, EN	209: Benguela Current 211: Agulhas Current	V RS
	Argentinean	15	4	VU, EN	205: Patagonian Southwest Atlantic	V
	Australian	14	4	VU, EN	206: Southern Australian 222: Great Barrier	RS RS
	Baja Californian	25	7	VU, EN, CR	214: Gulf of California	CE
	Peruvian	19	5	VU, EN	210: Humboldt Current	V
	Japanese	25	7	VU, EN, LR	217: Nansei Shoto	CE
	New Zealand	13	2	VU, EN, LR	207: New Zealand	V
	Northwestern African	25	7	VU, EN, LR	216: Canary Current	CE
	Northeastern American	25	7	VU, EN, LR	202: Chesapeake Bay	V
Irreplaceable	Hawaiian Islands	1[1]	1	EN	227: Hawaiian Marine	V
	Galapagos Islands	1[2]	1	VU	215: Galapagos Marine	V
	San Félix and Juan Fernández Islands	1[3]	1	VU	210: Humboldt Current	V
	Amazon River	2[4]	1	VU	147: Amazon River And Flooded Forests	RS
	Mediterranean	1[5]	1	CR	199: Mediterranean Sea	CE

	Sea					
	Indus River	1[6]	1	Not Listed	Not Listed	Not Listed
	Ganges River	1[7]	1	EN	Not Listed	Not Listed
	Yang-tse River	1[8]	1	EX	149: Yang-Tse River And Lakes	CE
	Baikal Lake	1[9]	1	LR	184: Lake Baikal	V
	Caspian Sea	1[10]	1	VU	Not Listed	Not Listed
	Kerguelen Islands	1[11]	1	Not Listed	Not Listed	Not Listed

[1]*Monachus schauinslandi*, [2]*Arctocephalus galapagoensis*, [3]*A. philippii*, [4]*Inia geoffrensis*,*Trichechus inunguis* (both freshwater), and *Sotalia fluviatilis*, [5]*Monachus monachus*, [6]*Platanista minor* (freshwater), [7]*Platanista gangetica* (freshwater), [8]*Lipotes vexillifer* (freshwater), [9]*Pusa sibirica* (freshwater), [10]*Pusa caspica*, [11]*Cephalorhynchus commersonii* and *A gazella.*
* VU=Vulnerable, EN= Endangered, CR= Critically Endangered, LR= Lesser Risk, EX= Extinct, CE: Critically Endangered, V: Vulnerable, RS: Relatively Stable or Intact. Data from Olson and Dinerstein (2002).

V. ESTABLISHED PROTECTED AREAS AND THREAT IN THE KEY CONSERVATION AREAS DEIFINED IN THIS PAPER

In the following table the proposed or established marine protected area (MPA) or sanctuary (SAC) in each Key Conservation Site are mentioned as an indication of their protection and management to reduce impacts of human activities. The species present are also recorded for each site, as well as threats such as overfishing and pollution (Data modified from Hoyt, 2005).

World Commission on Protected Areas (WCPA) - IUCN Region	SACs and MPAs with location and size* included in the Key Conservation Site (*only water)	Marine mammals present, including endangered species	Threats detected	Endangered marine mammals included
Northeast Pacific (15)	**Baja Californian Key Conservation Site**			
	El Vizcaino Biosphere Reserve (5 km, includes lagoons of Ojo de Liebre, San Ignacio and Guerrero Negro)	Shared habitat for large whales and dolphins, frequented by migrating cetaneans, serves as mating and breeding grounds, and for some species feeding ground. Spot or annual gray whale migration. Laguna San Ignacio is the only primary gray whale breeding/calving area in Mexico that remains unaltered by industrial development. Sei, Minke, Blue, Bryde, Fin and Sperm whales	Ecosystmic damage by saltworks, dump and noise pollution	
	Revillagigedo Archipelago Biosphere Reserve (6,193 km^2)	One of the key humpback whale breeding grounds in the North Pacific. Management plan under review	Ilegal fishing	
	Islas Marias Biosphere Reserve (4,052 km^2)	Humpback whale breeding ground, management plan under review	Ilegal fishing	
	Loreto Bay National Park (1,820 km^2)	May not include extensive cetacean critical habitat *per se*, but the park does benefit feeding grounds		
	Upper Gulf of California and Colorado River Delta Biosphere Reserve (9,600 km^2)	Protects the endangered Vaquita and the Colorado River Delta wetlands. Vaquita	Bycatch	Vaquita

	Bahía Magdalena National Gray Whale Refuge	Proposed MPA to protect gray whale breeding and calving habitat		
	Monterrey Bay National Marine Sanctuary (13,802 km^2)	Abundant cetaceans and other marine mammals. Sea otter, Steller Sea Lion	Oil and gas exploration, waste dumping and other discharges, fisheries	
	Gulf of the Farallones National Marine Sanctuary (3251 km^2)			
	Cordell Bank National Marine Sanctuary (1,363 km^2)	Critical habitat for marine mammals and seabirds	Frequent naval oprerations	
	Channel Islands National Marine Sanctuary (4,295 km^2)	Protects key habitats for marine mammals including cetaceans, extensive pinniped rookeries and seabirds	Oil and gas exploration, waste dumping and other discharges, fisheries	
Southeast Pacific (17)	**Peruvian Key Conservation Site**			
	Paracas National Reserve (2,177 km^2)	Little research into cetaceans in the MPS except for the resident bottlenosed dolphins and small cetacean-fisheries interactions. Marine otter, South American sea lion and fur seal		Marine otter, South American sea lion and fur seal
	Galapagos Islands Key Conservation Site			
	Galapagos Marine Resources Reserve and Whale Sanctuary (158,000 km^2)	Endemic Galapagos fur seal and sea lion; cetaean mating and breeding area and frequented by migrating cetaceans	Shipping, comercial fishing and tourism	
	San Félix & Juan Fernández Islands Key Conservation Site			
	Caldera MPA	Proposed and in process. Contains 43% of the cetacean diversity recorded for Chile. Sei, Antartic Minke, Blue, Bryde and Fin whales	Comercial fishing, ilegal dolphin hunt, poor management	

	Humboldt Penguin National Reserve (8.6 km^2)	Proposed for expansion al Los Choros MPA. Sperm whale	Uncontrolled dolphin watching activities, dolphin killing	
Northwest Atlantic (4)	**Northeastern American Key Conservation Site**			
	Monitor National Marine Sanctuary (3.4 km^2)	The sanctuary itself is too small to afford real protection without considerable expansion of its size and effective mandate. North Atlantic Right, Sei, Minke, Blue, Bryde and Fin whales; Sperm whale; Manatee	Whale watching industry, toxic waste dumpling, vessel colitions with cetaceans	North Atlantic Right Whale
South Atlantic (9)	**Argentinean Key Conservation Site**			
	South Atlantic Sanctuary	Proposed MPA	Commercial whaling	
	Bahia Anegada Nature Reserve (73.86 km^2)	Breeding areas for South American sea lion and important research site of Franciscana; no management plan. Franciscana.		Franciscana
	Golfo San José Provincial Marine Park	Critical breeding area for Southern Right Whales	Whale watching industry	
	Punta Loma Faunal Reserve (17.1 km^2)	Sei, Antartic Minke, Blue, Bryde and Fin whales	Water contamination, shipping traffic and increasing fishing activity in the area	
	Punta Norte Provincial Faunal Reserve (0.06 km^2)	Sperm Whale	Fisheries	
	Punta Pirámide Nature Reserve (1.32 km^2)			
	Península Valdés Nature Reserve (3,600 km^2 mostly including land)			
West Africa (8)	**Northwestern African Key Conservation Site**			
	South Atlantic Sanctuary	Proposed MPA	Comercial whaling	

	Canary Islands Cetacean Marine Sanctuary	Proposed MPA containing at least 26 cetacean species. Sei, Minke, Blue, Bryde and Fin whales; Atlantic Humpback dolphin	Noise pollution and frequent naval operations, fisheries, pollution, oil, gas, and human development	
	Chinijo Archipelago Natural Park (91 km^2)	Sperm Whale		
	Natural Marine Park of the Whales and Franja Marina Teno Rasca SAC (695 km^2)			
	Franja Marina Santiago - Valle Gran Rey SAC (131.4 km^2)			
	Sebadales de La Graciosa SAC (11.9 km^2)			
	Mar de las Calmas SAC (99 km^2)			
	Sebadales de Corralejo SAC (19.4 km^2)			
	South African Key Conservation Site			
	Dwesa-Cwebe MPA (176 km^2)	No management or zoning plan	Fisheries, bycatch, pollution and human development, illegal dolphin hunt	
	Mkambati MPA (130 km^2)	No management or zoning plan		
	Hluleka MPA	No management or zoning plan		
	Trafalgar MPA (2.5 km^2)	Very limited management		
Northwest Pacific (16)	**Japanese Key Conservation Site**			
	Finless Porpoise Gathering Area National Monument (1.5 km)	Sperm whale, Finless porpoise	Fisheries, bycatch, pollution and human development, illegal dolphin hunt, shipping traffic, poaching, gold mine excavations	
	Seto-naikai National Park (628 km^2)	North Pacific Right, Sei, Minke		
	Kurilskiy Nature Reserve (2 km)	Blue, Bryde and Fin whales		
	Poronayskiy Nature Reserve (567 km^2 including many land areas)			
Australia - New	**Australian Key Conservation Site**			

Zealand (18)	Solitary Islands Marine Reserve and Marine Park (710 km^2)	Management plan has key habitat provisions for cetaceans	Recreational and comercial boating traffic, entanglement, noise, and depletion of prey	
	Cape Byron Marine Park (227 km^2)	11 cetacean species. Important long-term monitoring of migrating humpback whales, as well as a refuge area for humpback mothers and calves on migration. Sei, Antartic Minke, Blue, Bryde and Fin whales; Irrawady dolphin; Dugong	Fishing, entanglement, jet-skis and comercial shipping	
	Jervis Bay Marine Park (220 km^2)	Sperm whale	Whale watching industry	
	Port Stephens Marine Park (140 km^2 aprox.)	May be proposed	Dolphin watching	
	New Zealand Key Conservation Site			
	Banks Peninsulsa Marine Mammal Sanctuary and *proposed* extension (1,140 km^2)	Sei, Antartic Minke, Blue, Bryde and Fin whales	Dolphin entanglement, fisheries	
	Akaroa Harbour Marine Reserve	Proposed		Hector's Dolphin
	Doubtful Sound Marine Sanctuary	Proposed	Dolphin watching	
South Pacific (14)	**Hawaiian Islands Key Conservation Site**			
	Hawaiian Islands Humpback Whale National Marine Sanctuary (3,368 km^2)	Key Humpback whale winter breeding, singing, calving, and nursing habitat. Hawaiian Monk Seal, Sei, Minke, Blue, Bryde and Fin whales; Sperm whale	Fisheries, fishing, military activities.	Hawaiian Monk Seal
Mediterranean	**Mediterranean Sea Key Conservation Site**			

(3)	59 MPA or SCA contained (at least 91,568 km^2)	14 species with applicable appendices of international conventions, directives and agreements; declining population of common dolphins (>100). Mediterranean Monk Seal	High contaminant levels and fishing	Mediterranean Monk Seal
Antarctic (1)	**Kerguelen Islands Key Conservation Site**			
	Heard & McDonald Islands (65,000 km^2)	Not designed specifically around cetacean habitat, but because of its size it almost certainly contains some significant cetacean habitat. Sei, Minke, Blue, Bryde and Fin whales; Sperm whale		

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