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MARINE PROTECTED AREAS IN SOUTH AMERICA: SPATIAL ASSESSMENT OF CETACEAN DISTRIBUTION COVERAGE

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Recent attention to the great biological diversity of the world's oceans and the serious threats it currently faces has garnered support for the establishment of marine protected areas (MPAs) (Lovejoy, 2006), defined by the World Conservation Union (IUCN) as "any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Hoyt, 2005). Recent evidence suggests that MPAs can effectively contribute to the conservation of biological resources and the economic activities that depend on them (Behrens and Lafferty, 2004; Floeter *et al.*, 2006; Guidetti, 2007). Consequently, although the number of MPAs has increased dramatically in recent years, the creation of new ones is still considered a priority (Mora *et al.*, 2006; Remington *et al.*, 2007).

In the context of the expansion of national protected area networks, spatially explicit analyses of current coverage help identify major gaps and therefore to guide the establishment, design and management of new reserves. However, to date, most such analyses have been done for the terrestrial realm (Rodrigues and Gaston, 2001; Scott *et al.*, 2001; Sanderson *et al.*, 2002; Rodrigues *et al.*, 2004). Although MPAs worldwide have largely proven successful in protecting marine taxa and habitats (Guenette *et al.*, 1998; Halpern, 2003), the appropriateness of existing MPAs to adequately protect cetaceans may be limited (Reeves, 2000).

Typical MPAs are too small to offer adequate coverage for cetaceans, as these are species characterized by high dispersal capabilities (Hoelzel, 1994). As a consequence of their migratory behavior and complex habitat requirements, cetaceans have been proposed as 'umbrella species' that could be used to strategically create MPAs capable of offering coverage to both these marine mammals and a variety of other marine species with less extensive dispersal requirements (Hooker and Gerber, 2004). South America (SA) holds a significant fraction of the world's marine biological diversity, which includes at least 48 cetacean species (Table 1). Protected area systems in SA are extensive, but the degree to which they represent species and major terrestrial ecological units is varied and critical gaps still exist (Esty *et al.*, 2006; Soutullo and Gudynas, 2006). Here, we analyze the degree to which MPAs in SA cover the ranges of cetacean species.

Since conservation policy is normally planned and executed at the national level, and because legislation and enforcement are problematic in international waters, we limited our analysis to the exclusive economic zones (EEZ; 200 nautical miles from the shore, as defined by the United Nations Law of the Sea Convention) of all coastal countries in SA, namely: Argentina, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Uruguay and Venezuela. We collected distribution information for the 48 cetacean species present within these national waters. To minimize species distribution inaccuracies from particular sources, we integrated data from the Marine Mammals of the World section of the World Biodiversity Database (http://nlbif.eti.uva.nl/bis/index.php) and from three widely used marine mammal field guides (Carwardine, 1999; Reeves *et al.*, 2002; Reeves *et al.*, 2003). When a species' range differed among the different sources, we considered the broadest distribution limits as a conservative estimate. A potential caveat is that species occurrence data recorded in these sources may be incomplete and therefore fine-scale observations must also be considered when using analyses such as this one to delineate conservation strategies.

We compiled a list of MPAs in SA using the MPA Global database (http://www.mpaglobal.org, accessed 15 March 2007) and included in this analysis all MPAs present in its database regardless of their IUCN category and the completeness of the associated information, except when spatial coordinates or total area information were unavailable. Our initial database contained 166 MPAs. We then collated this list with the 2006 World Database on Protected Areas (UNEP-WCMC, 2006) and obtained boundary polygons when available. For those areas in which only point data were available, we drew a circular polygon on the appropriate area around the central coordinates. We calculated the area of each MPA situated over the water (*i.e.* beyond the continent coastline, including estuaries and deltas) and used this fraction to estimate the coverage provided to each species (percent coverage, Table 1).

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Table 1. Percent coverage provided to cetacean species in South America by the current marine protected area network. Fields marked by an asterisk (*) reflect pooled information for more than one species, subspecies or form, since exact distribution data are lacking. Minke whale's data reflect coverage for both subspecies (*B. bonaerensis* and *B. acutorostrata*). Common dolphin's coverage is pooled for both long-beaked common dolphin (*D. capensis*) and short-beaked common dolphin (*D. delphis*) data. Both the tucuxi and Guiana dolphin are pooled under *Sotalia* spp.

SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS[a]	% COVERAGE
Phocoena dioptrica	Spectacled porpoise	Data defficient	0.14
Balaenoptera bonaerensis (*)	Minke whale	Lower risk (LC)	1.93
Balaenoptera borealis	Sei whale	Endangered	1.93
Balaenoptera edeni	Bryde's whale	Data defficient	1.93
Balaenoptera musculus	Blue whale	Endangered	1.93
Balaenoptera physalus	Fin whale	Endangered	1.93
Berardius arnuxii	Arnoux's beaked whale	Lower risk (CD)	0.09
Caperea marginata	Pygmy right whale	Lower risk (LC)	0.09
Cephalorhynchus commersonii	Commerson's dolphin	Data defficient	0.10
Cephalorhynchus eutropia	Chilean dolphin	Data defficient	0.06
Delphinus spp. (*)	Common dolphin	Lower risk (LC)	1.93
Eubalaena australis	Southern right whale	Lower risk (CD)	0.25
Feresa attenuata	Pygmy killer whale	Data defficient	2.61
Globicephala macrorhynchus	Short-finned pilot whale	Lower risk (CD)	2.68
Globicephala melas	Long-finned pilot whale	Lower risk (LC)	0.09
Grampus griseus	Risso's dolphin	Data defficient	1.93
Hyperoodon planifrons	Southern bottlenose whale	Lower risk (CD)	0.08
Kogia breviceps	Pygmy sperm whale	Lower risk (LC)	2.48
Kogia sima	Dwarf sperm whale	Lower risk (LC)	3.05
Lagenodelphis hosei	Fraser's dolphin	Data defficient	3.79
Lagenorhynchus australis	Peale's dolphin	Data defficient	0.14
Lagenorhynchus cruciger	Hourglass dolphin	Lower risk (LC)	0.09
Lagenorhynchus obscurus	Dusky dolphin	Data defficient	0.11
Lissodelphis peronii	Southern right whale dolphin	Data defficient	0.10
Megaptera novaeangliae	Humpback whale	Vulnerable	1.93
Mesoplodon densirostris	Blainville's beaked whale	Data defficient	2.23
Mesoplodon europaeus	Gervais' beaked whale	Data defficient	0.98
Mesoplodon ginkgodens	Ginkgo-toothed beaked whale	Data defficient	9.85
Mesoplodon grayi	Gray's beaked whale	Data defficient	0.22
Mesoplodon hectori	Hector's beaked whale	Data defficient	0.15
Mesoplodon layardii	Strap-toothed whale	Data defficient	0.08
Mesoplodon peruvianus	Lesser beaked whale	Data defficient	3.73
Orcinus orca	Killer whale	Lower risk (CD)	1.93
Peponocephala electra	Melon-headed whale	Lower risk (LC)	3.89
Phocoena spinipinnis	Burmeister's porpoise	Data defficient	0.16
Physeter macrocephalus	Sperm whale	Vulnerable	1.93
Pontoporia blainvillei	Franciscana dolphin	Data defficient	0.53
Pseudorca crassidens	False killer whale	Lower risk (LC)	2.45
Sotalia spp. (*)	Tucuxi/Guiana dolphin	Data defficient	1.73
Stenella attenuata	Pantropical spotted dolphin	Lower risk (CD)	2.96
Stenella clymene	Clymene dolphin	Data defficient	1.23
Stenella coeruleoalba	Striped dolphin	Lower risk (CD)	2.89
Stenella frontalis	Atlantic spotted dolphin	Data defficient	1.29
Stenella longirostris	Spinner dolphin	Lower risk (CD)	3.71
Steno bredanensis	Rough-toothed dolphin	Data defficient	3.10
Tasmacetus shepherdi	Shepherd's beaked whale	Data defficient	0.14
Tursiops truncatus	Common bottlenose dolphin	Data defficient	3.23
Ziphius cavirostris	Cuvier's beaked whale	Data defficient	1.93

[a] Data from www.redlist.org, accessed March 15 2007. LC: Least concern, CD: Conservation dependent.

Our final database contained littoral and sublittoral components of 143 MPAs. To reduce the magnitude of spatial errors that might lead to overestimation, we removed all resulting polygons of less than 1km^2 (these polygons belonged to 24 MPAs or 16.7% of the MPAs in our final database). We then estimated the percentage of the range of each species that is included in a protected area.

We found that a significant fraction of the areas listed in the MPA database we consulted had no jurisdiction beyond the intertidal zone. MPAs in our database generally included small areas that in total covered less than 3.5% of the EEZs in SA. Only three MPAs included ocean areas larger than 10000km^2 whereas 40% had areas of less than 10km^2. Finally, although management and enforcement in the open ocean are essential given the high connectivity in marine systems (Cawardine, 2002; Hoyt, 2005; Norse, 2005), in this case exemplified by inshore and offshore cetacean stocks or populations (Palumbi, 2003; Norse, 2005), there were currently no established high-seas MPAs in the region (*i.e.* protected areas that do not share a border with a terrestrial component, whether continental or insular).

Not surprisingly, cetacean distribution ranges were minimally covered by MPAs in SA. Across all species, the average percentage of the cetacean range included in a MPA was 1.7% (range 0.06-9.8%). A total of 19 species had less than 1% of their range covered in the current MPA system, including nine species whose ranges have less than 0.1% coverage (Table 1). Further, we found that the average range coverage for endemic species (0.45%) was lower than the average for all species and was independent of conservation status (Table 1). It is important to note that the overall inclusion levels (*e.g.* the total percentage of the range that is included in a MPA) reported here do not explicitly account for the number of individual polygons that contribute to the total area under protection. Given the small size of most oceanic polygons in MPAs in SA (as above, the protected fractions that extend beyond the shore), the percentage of inclusion of a species' range is overwhelmingly represented by the sum of several small areas. This fragmentation of protected areas can further limit their conservation potential for cetaceans. Taken together, these results indicate that cetaceans are inadequately represented in MPA networks in SA. Those species that are considered as endangered, vulnerable or data deficient, as well as the endemic species (Table 1) could serve as a starting point in identifying candidates for conservation priorities in the region.

Mapped boundaries were absent in a large fraction (48.5%) of the MPAs included in this analysis, as was information about management, regulation and zoning. Zoning regimes delineate different conservation goals and regulations within the boundaries of some protected areas, resulting in different levels of protection afforded to cetacean species and their habitats within each of our mapped polygons. Since we treated all polygons in this analysis as a uniform conservation unit, strict protection of cetacean ranges is overestimated in our results. Although we do not expect any significant effect on our results given the low coverage afforded to cetaceans, any bias introduced by such overestimation would be small and would only reinforce our conclusions. However, species' distributions are not uniform throughout their ranges and MPAs in the region may contain critical areas (*e.g.* feeding or mating grounds), which would increase their conservation value in spite of a relatively small area protected. In the absence of more detailed spatially defined datasets, analyses such as this one necessarily incorporate errors, both of omission and commission; we hope that in the future national environmental authorities will refine and update their datasets, but suggest that qualitatively our conclusions remain valid.

Given the multi-factorial nature of the current threats faced by cetaceans, MPAs represent only one approach to cetacean conservation. For instance, the most recent assessment of South American small cetacean species by the International Whaling Commission (IWC) highlighted the need for information on abundance, distribution, population structure, life history and habitat of these taxa (IWC, 2009). The theory underlying the design of MPAs is in its infancy and remains context dependent (Botsford *et al.*, 2003; Gerber *et al.*, 2003; IWC, 2009); moreover, with few exceptions, most MPAs are not typically designed to protect cetaceans specifically (Hoyt, 2005). In any plan to expand current levels of protection, it is necessary to carefully balance the need for larger areas under protection with actual capacity for enforcement, and consideration to whether increasing the number of MPAs and the total area under protection provides added benefits to the protection granted by other means. At a local scale, future MPAs aimed at conserving cetaceans would benefit from cetacean habitat preference assessments and modeling efforts that identify potential areas of higher occurrence and abundance (Reilly, 1990; Reilly and Fiedler, 1994; Baumgartner *et al.*, 2001; Davis *et al.*, 2002; Redfern *et al.*, 2006). Important issues related to cetacean demography in the context of a complex and dynamic environment could be best approached by integrating data across disciplines (Palumbi, 2003; Palumbi *et al.*, 2003). For instance, in cetaceans, genetic approaches offer high resolution to characterize population structure, connectivity, and identify management units (Hoelzel, 1998; DeSalle, 2004), which could be further enhanced by detailed oceanographic information to contextualize such assessments. Data on seafloor physiographic features, bathymetry, marine productivity and sea surface temperature, among other oceanographic features, have proven relevant to pinpoint areas of potential population subdivision in cetaceans (Fullard *et al.*, 2000; Wares *et al.*, 2001; Elwen and Best, 2004a, b; Norse, 2005; Rosa *et al.*, 2005; Mendez *et al.*, 2008). Although not yet legally established in the region, high-seas reserves may be particularly relevant, as these areas play important roles in the origin and maintenance of marine biodiversity. Pelagic fisheries, migratory species and top predators currently impacted in the high seas have a profound impact on coastal ecosystems through massive species removal and trophic web alteration (Reeves, 2000; Dans *et al.*, 2003; Amaral and Jablonski, 2005; Fernandez and Castilla, 2005). Current efforts for high-seas conservation in the region include the Sea and Sky project in the South Atlantic, which seeks to protect an outstandingly large area between the 30°S and 60°S, and extending from the east coast of South America to 50°W (http://sea-sky.org). In addition, a recent proposal to the IWC by the Governments of Argentina, Brazil and South Africa seeks to establish a whale sanctuary delimited by the Equator to the north, the coasts of South America and Africa to the east and west, and a southern boundary varying between 40°S at its easternmost point and 60°S at its western limit (Truda Palazzo *et al.*, 2008).

Cetaceans in South America suffer from a variety of threats that seriously compromise their persistence, including intentional and incidental catch and entanglement, habitat alteration, prey removal, noise and chemical pollution, collisions with vessels and climate change (Dans *et al.*, 2003; Amaral and Jablonski, 2005; Fernandez and Castilla, 2005). Despite these conspicuous threats, which vary in intensity and by species, there is a lack of rigorous research and appropriate reporting of the status of a significant fraction of the species in the region (Table 1) (IUCN, 2006). Due to its spatial distribution and limited overall area, the current MPA network in SA likely provides few real conservation benefits to cetaceans in the region. To achieve full representation and adequate area coverage of cetacean species, MPA site selection and design should respond to the conservation a series of hierarchical ecological processes in space, from demographic stability and connectivity at the population level, to multispecies interactions, to oceanographic processes controlling species distribution and abundance in an appropriate eco-regional framework.

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