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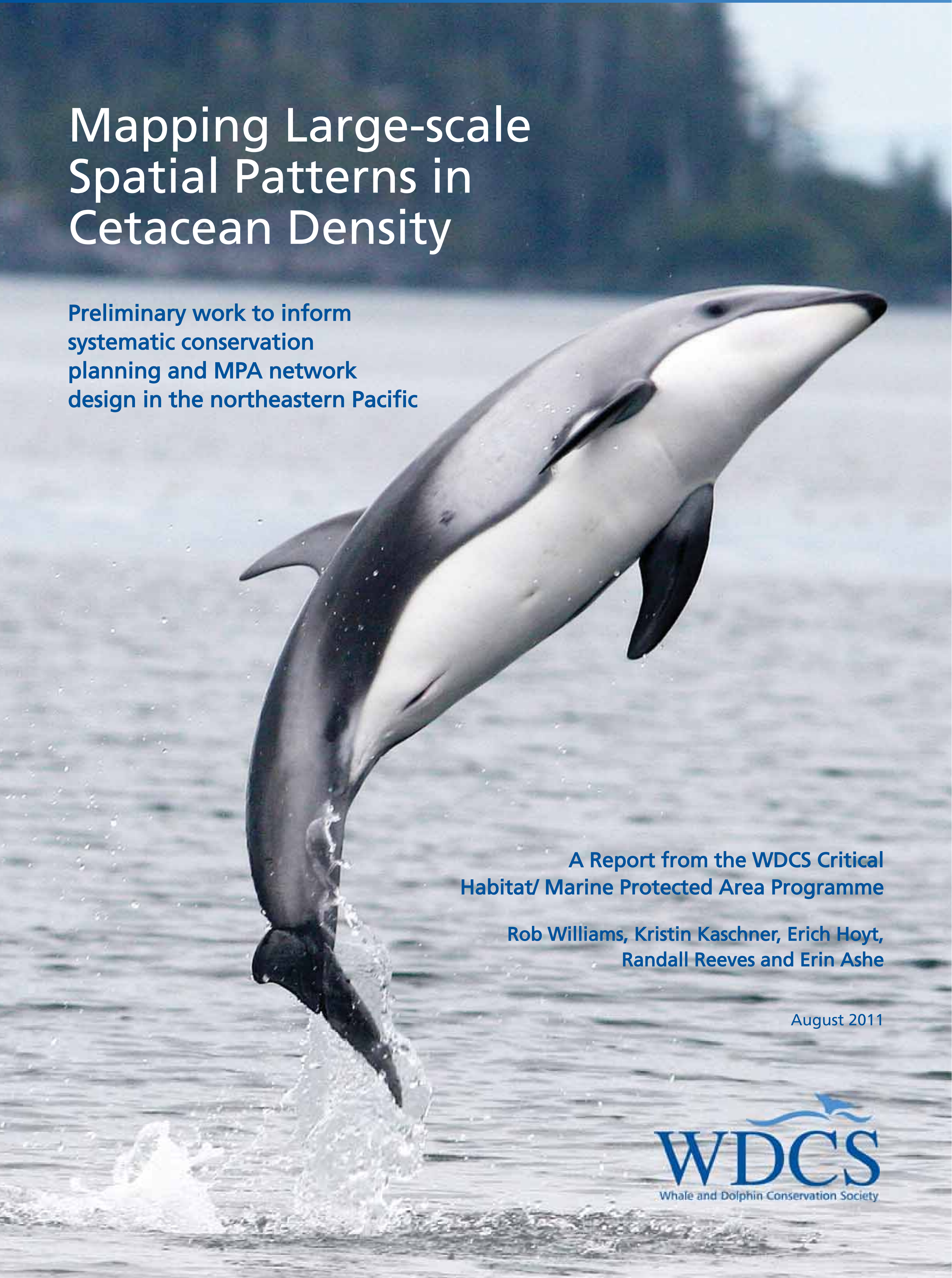

Mapping Large-scale Spatial Patterns in Cetacean Density

Preliminary work to inform systematic conservation planning and MPA network design in the northeastern Pacific

A Report from the WDCS Critical Habitat/ Marine Protected Area Programme

Rob Williams, Kristin Kaschner, Erich Hoyt, Randall Reeves and Erin Ashe

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INTRODUCTION

At the First International Conference on Marine Mammal Protected Areas (ICMMPA) in Maui, Hawaii (April 2009), participants concluded that a global effort was needed "to identify and define important marine mammal habitats and hot spots" (Reeves 2009, p 6). Such information, once integrated and mapped with similar data on other species and with biogeographic data, can be used to design and create marine protected area (MPA) networks in national waters and on the high seas, as called for by the Convention on Biological Diversity (CBD), the International Union for Conservation of Nature (IUCN) and the World Summit on Sustainable Development (WSSD). It was further noted at the ICMMPA that the use of "global databases covering environmental features, ocean processes, and species may help identify critical habitat and contribute to the design of MPAs and MPA networks" (Reeves 2009, p 6). This is a key point, because it means not only that (a) a necessary first step is to compile available information on animal distribution, but also (b) such information is only one of several required inputs.

This paper is intended as a contribution to the effort called for by the Maui conference. It focuses on one of the identified tasks, namely to compile the available information on cetacean distribution in one region (the northeastern Pacific Ocean) as a first stage in a longer process of developing proposals for cetacean-oriented MPAs and MPA networks.

The process of designing marine mammal-oriented MPAs lends itself nicely to the systematic conservation planning process that is now at the centre of the broader fields of spatial analysis, marine conservation, and MPA design (e.g., Margules and Pressey 2000; Stewart et al. 2007). Therefore we begin this paper with a brief review of some recent theoretical literature on the subject of Systematic conservation planning. We also discuss, as additional background, the concept of "critical habitat." We then proceed with a case study of the available data on cetacean distribution and density in the northeastern Pacific Ocean, and we end with an analysis of proposed next steps so that available data on cetacean distribution can be adequately represented in ongoing Systematic conservation planning exercises for the northeastern Pacific.

Systematic conservation planning

Systematic conservation planning (Margules and Pressey 2000) typically aims to protect and promote the persistence of some fraction of a region's biological diversity (Pressey et al. 2007). It provides a structural framework for identifying spatial approaches that can help address the overarching and explicit objectives of agreements like the CBD, often requiring the application of spatial planning tools such as least-cost heuristic algorithms (Ardron et al. 2010). By giving managers visual representations of a region's biodiversity, it helps them pursue the ultimate goal of separating the elements of that diversity (cetaceans in the present case) in space (and/or in time) from anthropogenic processes that threaten species or population persistence (Margules and Pressey 2000). In other words, one aspect of a systematic conservation plan is to identify and characterize what needs protecting, while another aspect is to identify and characterize what the valued assets (species or populations) need protection from. This paper focuses on the first aspect, and it is important to recognize that the second aspect (threats) is inherently dependent on a good understanding of the first.

It is impossible to define MPA boundaries without first establishing management goals, i.e., knowing what we want the MPA to achieve. Hooker and Gerber (2004) reviewed marine mammal-focused MPAs and management objectives from two perspectives: (1) the potential for MPAs to protect marine predators from threats; and (2) the potential for marine predators to serve as ecological indicators or proxies to guide MPA siting and targeting. If the goal of management is to maintain biodiversity, then we would assign highest priority to areas that support the most species. If the goal is to prevent the extinction of species or populations of greatest conservation concern, then the priority would be to protect areas with habitat for those animals. If the particular vulnerability of a group of organisms to a given anthropogenic stressor, such as underwater noise, is the greatest concern, it may be most appropriate to adopt a spatio-temporal approach explicitly to manage the animals' exposure to that stressor (Agardy et al. 2007; Lusseau and Higham 2004). Examples of this latter approach involve mapping and managing the overlap of beaked whale occurrence with military sonar exercises, bowhead whale distribution with seismic surveys, areas of high-density occurrence of fin whales with shipping lanes (Williams and O'Hara 2010), and feeding hotspots for southern resident killer whales with core areas used by whale-watching boats (Ashe et al. 2010). It is rare for animal behaviour to be incorporated into habitat-use models used for MPA planning (Ashe et al. 2010; Lusseau and Higham 2004), but this need not be the case.

After the goals and objectives have been specified, management measures need to be devised in relation to the threat or threats to be mitigated by the MPA. It has to be made clear which human activities will be proscribed, to what degree, and why. A common concern is that eliminating human activities in an MPA simply displaces those activities into adjacent or nearby areas (Agardy et al. 2003). One of the more obvious examples is bycatch (incidental mortality of marine mammals in fishing gear). This problem has been well illustrated by a series of studies on bycatch of Hector's dolphins in commercial and recreational gillnet fisheries in New Zealand (Dawson 1991; Slooten et al. 2000). A marine mammal sanctuary was created around Banks Peninsula to reduce bycatch, but subsequent analyses of dolphin distribution and fishing effort data showed that "creation of a protected area can act to shift fishing effort to nearby areas, thus shifting rather than solving the bycatch problem" (Slooten et al. 2006, p 333). It became clear that an MPA alone was not going to be sufficient for conserving Hector's dolphins in the region and that the MPA would need to be accompanied by an overall reduction in fishing effort (Slooten et al. 2006). Even then, it would be necessary to continue monitoring. In this case, all of the advice was integrated into a quantitative risk assessment that modelled how dolphin populations would likely respond to a range of management actions that either ignored, shifted, reduced or eliminated bycatch (Slooten and Dawson 2010).

A systematic conservation plan ideally includes six stages as described in Table 1 (from Margules and Pressey 2000). Such a plan provides an ordered process to develop and implement management action, although the process will rarely occur in such clear and discrete steps.

This six-stage model provides a context for the task laid out in the ICMMPA report of identifying and defining important marine mammal habitats and hot spots. For our purposes, the first step, regardless of what the conservation targets might be, is to assemble key information on habitat use by whales, dolphins and porpoises in the region, in the present instance the northeastern Pacific Ocean. Determining the locations and scales of threats is also an important, but separate, task.

The field of Systematic conservation planning has benefited tremendously from advances in computing power and GIS (Geographic Information Systems) applications. Ultimately, questions like "How much habitat do we want to protect?" are management and policy questions that reflect societal values about how much risk we are willing to tolerate and can be considered to be aspects of spatial planning. In contrast, questions like "How do we protect X% of the habitat used by species Y?" are mathematical questions that fall under the remit of a relatively new field called "spatial conservation prioritization – the use of quantitative techniques to generate spatial information about conservation priorities…" (Moilanen et al. 2009, p. xix). Good integration between spatial modelling and spatial planning is needed (Elith and Leathwick, cited in Moilanen et al. 2009), because the decision-support software commonly used in spatial planning has a tendency to prioritize for protection those areas containing the most data (Grand et al. 2007). Fortunately, cetacean biologists have been at the forefront of developing statistical tools to describe and predict distribution (Redfern et al. 2006) that can be used to fill in data gaps, thus helping to avoid the pitfall referred to above. We will need all of these tools to adequately prioritize representative cetacean habitat for protection.

The concept of critical habitat

The range of a species or population refers to the geographic area where it is found. It is reasonable to assume that within this range, there is a subset of areas with features that are essential to the long-term survival (viability) of the species. Such features might include aggregations of prey, shelter from predators, or biophysical conditions (e.g., water depth, temperature, and ambient noise levels) needed for successful reproduction including the care and nurture of young. This subset of the range is often referred to as *critical habitat*. The concept of critical habitat has been incorporated into national legislation as well as the scientific literature, which abounds with references to critical habitat (e.g., the term is repeated throughout the ICMMPA report), yet more often than not with no clear indication of what is meant by the term.

Table 1. A six stage systematic conservation plan

1. Compile data on the biodiversity of the planning region

a. Review existing data and decide on which data sets are sufficiently consistent to serve as surrogates for biodiversity across the planning region.

b. If time allows, collect new data to augment or replace some existing data sets.

c. Collect information on the localities of species considered to be rare and/or threatened in the region (these are likely to be missed or under-represented in conservation areas selected only on the basis of land classes such as vegetation types).

2. Identify conservation goals for the planning region

a. Set quantitative conservation targets for species, vegetation types or other features (for example, at least three occurrences of each species, 1,500 ha of each vegetation type, or specific targets tailored to the conservation needs of individual features). Despite inevitable subjectivity in their formulation, the value of such goals is their explicitness.

b. Set quantitative targets for minimum size, connectivity or other design criteria.

c. Identify qualitative targets or preferences (for example, as far as possible, new conservation areas should have minimal previous disturbance from grazing or logging).

3. Review existing conservation areas

a. Measure the extent to which quantitative targets for representation and design have been achieved by existing conservation areas.

b. Identify the imminence of threat to under-represented features such as species or vegetation types, and the threats posed to areas that will be important in securing satisfactory design targets.

4. Select additional conservation areas

a. Regard established conservation areas as 'constraints' or focal points for the design of an expanded system.

b. Identify preliminary sets of new conservation areas for consideration as additions to established areas. Options for doing this include reserve selection algorithms or decision-support software to allow stakeholders to design expanded systems that achieve regional conservation goals subject to constraints such as existing reserves, acquisition budgets, or limits on feasible opportunity costs for other land uses.

5. Implement conservation actions

a. Decide on the most appropriate or feasible form of management to be applied to individual areas (some management approaches will be fallbacks from the preferred option).

b. If one or more selected areas prove to be unexpectedly degraded or difficult to protect, return to stage 4 and look for alternatives.

c. Decide on the relative timing of conservation management when resources are insufficient to implement the whole system in the short term (usually).

6. Maintain the required values of conservation areas

a. Set conservation goals at the level of individual conservation areas (for example, maintain seral habitats for one or more species for which the area is important). Ideally, these goals will acknowledge the particular values of the area in the context of the whole system.

b. Implement management actions and zonings in and around each area to achieve the goals.

c. Monitor key indicators that will reflect the success of management actions or zonings in achieving goals. Modify management as required.

Source: Margules and Pressey 2000

However straightforward the concept might be in theory, defining critical habitat in a practical way, given that knowledge is never complete, is a challenge. This is especially so for highly mobile species like cetaceans. The ICMMPA participants put some bounds on what they meant by the term, noting that “critical habitat is not defined simply as an area of high animal density” (Reeves 2009, p 6). They acknowledged that less densely inhabited areas could also be critical to the survival of a species or population, depending on such things as behaviour, stock structure and threats. Importantly, for many species, patches of critical habitat are not contiguous and it is therefore essential that individuals be able to move between such patches either seasonally or at different life stages. This means that The concept of critical habitat for such species must incorporate consideration of corridors.

Regardless of how critical habitat is defined, scientists and managers need to have a clear understanding of species distribution when designing an MPA or MPA network. To achieve such understanding, it is necessary to consider where researchers have looked for the species, and where animals were and were not determined to be present.

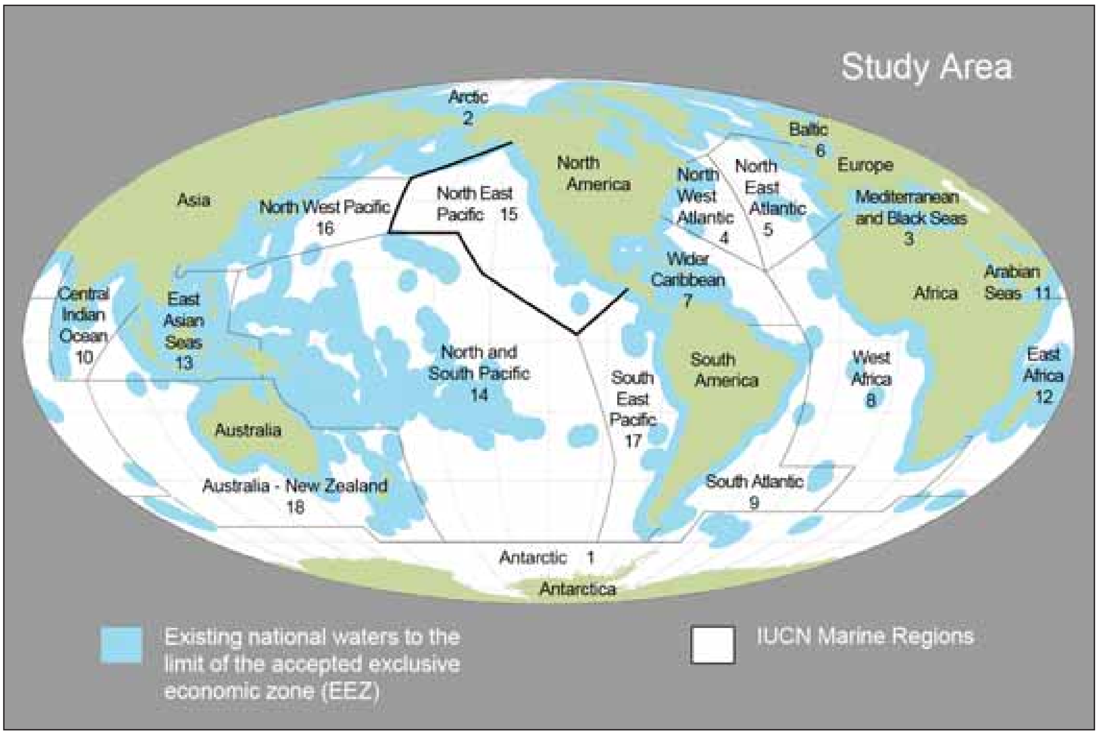


Figure 1. IUCN Marine Region 15, the study area.

METHODS

For this compilation, we assumed that future analytical requirements, conservation targets and management objectives are still broad and open to interpretation. So far, targets have been outlined in qualitative terms. For example, "What we need to do now, adopting a precautionary approach, is to conserve sufficiently large marine areas that include cetacean hot spots as well as the areas that we believe may have such conditions so that we can ensure that the options for future conservation are left open" (Hoyt 2005, p 3). Fortunately, all systematic conservation plans share some common data requirements, and assembling data sets with information on cetacean distribution is a first step (Appendix 1 and 2).

Anticipating that a management process will assign quantitative conservation targets (e.g., to protect 10% of available habitat in a least-cost MPA; or to define critical habitat as that used by 50% of the population on its breeding grounds), the present task is inherently a numerical one. If we are to respond to requests to identify MPAs that protect some proportion of a species' total population or range, it is necessary to assemble information on density or abundance. Presence-absence data can be used, but it can be difficult to discriminate between true absence (no animals) and false absence (missing data, either because the area was not surveyed; or because the species was present but missed by observers, which is often the case for cryptic species, including the deep-diving beaked whales). Moreover, though, presence-absence data do not allow the consideration of relative importance of different areas within a species' range. Similarly, such data do not allow the distinction between sites that are inhabited by thousands of individuals from those that are frequented by a handful of animals.

It is important that the data sets used for analyses and mapping share a consistent methodology and describe distribution or occurrence in the same units of measurement (e.g., relative probability of occurrence versus abundance versus density). This can require conversion of some data sets. All measures of habitat use or occurrence should be corrected for potential variation in survey or data collection effort to avoid the pitfall of confusing areas of high effort with areas of great importance to the population, which they may or may not be.

For our efforts at analysis and mapping, we restricted ourselves to published studies that report cetacean distribution in a common currency, namely spatially defined units of density (number of animals per unit area). We used density estimates derived from aerial and boat-based line-transect surveys in both peer-reviewed and grey literature. Application of such a coarse filter, however, inevitably meant that some potentially relevant and useful information, obtained using other types of monitoring, such as photo-identification (photo-ID) studies, land-based census or acoustic surveys had to be excluded. Similarly, our emphasis on published surveys that report density and abundance meant that the results of a few recent surveys were left out. Our data compilation took place at the same time as our compilation of the Experts Directory (see below), and our conversations with regional experts led us to believe that few large-scale line-transect surveys were missed. Nevertheless, there is a chance that the database is incomplete.

A useful outcome of this data compilation process was the ability to evaluate data sets for consistency and to identify and assess data gaps in the region. Almost inevitably, spatial bias in existing data will result in spatial bias in marine planning, no matter how one defines and designates critical habitat or how one decides on proposed MPA placement and design. As observed by Grand et al. (2007), "reserve networks based on biased data require more area to protect fewer species and identify different locations than those selected with randomly sampled or complete data." Addressing this reality falls into the second phase of a conservation planning process, whereas the first task is simply to evaluate where survey data do and do not exist.

Assembling contact information for the Experts Directory

Contact information for researchers who hold data from sighting networks and surveys, photo-ID, acoustic surveys, etc. from across the planning region is compiled in an Experts Directory (see Appendix 3). This compilation anticipates that targets and objectives will be set in a future conservation plan (Stage 2, Table 1) and that decision-support software will be used to promote transparency and defensibility in a planning process that incorporates species, ecosystem and socioeconomic factors (Agardy et al. 2003).

We collated contact information for all lead authors of documents in the primary literature as well as of scientific or technical papers and reports generally (grey literature). We also included holders of all unpublished data sets that were brought to our attention (e.g., through a search of Marmam postings). The Experts Directory is presumed to be incomplete, and any omissions are unintentional.

Global database on survey coverage, species diversity and cetacean density

Species density maps were generated using the information stored in a global database, featuring marine mammal abundance estimates and associated meta-data from line-transect surveys[1]. This work was originally started by Kaschner as part of her PhD (Kaschner 2004) and was further developed during several projects through the Centre for Research into Ecological and Environmental Modelling (CREEM, St. Andrews, UK). Separate copies of this database are now being held and managed by SMRU Ltd and Kaschner. The database contains more than 1800 abundance records and associated information about uncertainty, geographic and temporal survey coverage, and methodological details for dedicated line-transect surveys of marine mammals, conducted around the world from the 1980s until 2005. The taxonomic focus at present is on a pre-defined subset of 46 species, including mostly cetaceans, but also some pinnipeds. Survey areas were digitized and rasterized to re-express areas on the basis of a standard global grid of 0.5 degree latitude by 0.5 degree longitude cells, with, for each cell, the calculated proportion of the water surface area actually covered by the survey. Species-specific densities were calculated for each survey or survey block, using the reported estimate of total abundance and the survey area calculated during the digitization process (Kaschner et al., submitted).

For the purpose of this analysis, we used a subset of the global survey database focusing on line-transect surveys conducted in Marine Region 15 as defined by the IUCN World Commission on Protected Areas (WCPA), with some information plotted from adjacent waters to offer a broader perspective. Summary maps of frequency of survey coverage and number of species surveyed were generated by counting the number of different surveys that covered a given half-degree cell and the number of species for which any survey provided an abundance estimate (see Appendix 2 for details of survey databases). Note that if a cell was covered by multiple surveys providing independent abundance estimates for the same species, this species was only counted once for the purpose of generating the map of species surveyed.

This type of representation of cetacean species richness is by its nature relatively coarse. The boundary of any given survey's arbitrary study area formed the smallest natural sampling unit, which, in the most extreme case, encompassed the entire eastern tropical Pacific (ETP). Some surveys reported data on only a subset of the species occurring in a given area. Therefore, we also produced a higher-resolution map of cetacean species richness showing the number of cetacean species predicted to occur with a specific relative probability in each half-degree cell, modified from

[1] Referred to subsequently as the "global survey database."

Kaschner et al. (2011). The basis for this analysis is the large-scale predictions of individual cetacean species generated using the Relative Environmental Suitability (RES) approach developed by Kaschner et al. (2006). Updated versions of predictions generated for individual species, using a modified input data set and algorithm, can be viewed online at www.aquamaps.org.

Mean density maps for each species were generated by plotting the observed density in each cell covered by a survey based on the reported abundance estimate for that survey, divided by the associated survey area. If there were multiple estimates for the same species and the same cell (stemming either from surveys covering the same area during different seasons or time periods or from different surveys overlapping in some areas), we calculated the mean reported density (across different seasons, time periods, and survey methods), because we considered this to be more indicative of the relative importance of a given area for a given species in the context of long-term spatial planning and MPA analyses. If a species was reported to have been sighted during a survey but there was insufficient data to estimate its abundance, this is indicated by including a density category on the map to represent "documented presence." However, the term "documented presence" should not be interpreted to refer to more general documentation, i.e., beyond that provided by the selected line-transect survey. See also Box 1, p.14, for important caveats regarding the species density and predicted range maps.

A few surveys have been replicated often enough to provide some indication of variability in observed densities of a given species across space and time. For areas that were surveyed multiple times, we calculated the overall mean density for a given species, together with a measure of variability (CV) of estimates from multiple time periods. For species that were surveyed in multiple sites simultaneously, we also reported geographic variability in estimates (see Appendix 2).

We generally only included density estimates that were recorded in the source document at the species level. In other words, we tried to avoid dealing with density or abundance estimates for species groupings, e.g., at the genus or family level, as is often the case for species that are difficult to distinguish at sea (e.g., *Delphinus* spp., *Kogia* spp., *Globicephala* spp.). The only exceptions were estimates of beaked whales (*Mesoplodon* spp. or family Ziphiidae). A number of species of beaked whales known to occur in the study area are either too rare or too difficult to detect/identify at sea to allow the estimation of species-level abundance from survey data. It is important to bear in mind that the genus- or family-level estimates (1) probably also include individuals from species for which there was enough data to estimate species-level abundance (e.g., in the case of ziphiid estimates for *Mesoplodon densirostris* or *Ziphius cavirostris*) and (2) may represent different combinations of species in different geographic areas. For these multispecies maps, we also included all sighting records available from OBIS (www.iobis.org, 08/2006) for the species within that taxon (genus or family) known to occur in the area.

To give an indication of the proportion of a species' total range that has been surveyed and for which abundance estimates are available, we included each species' maximum range extent, defined as the extent of all cells predicted to provide suitable habitat (i.e., non-zero RES output; Kaschner et al. 2006).

RESULTS

Species List

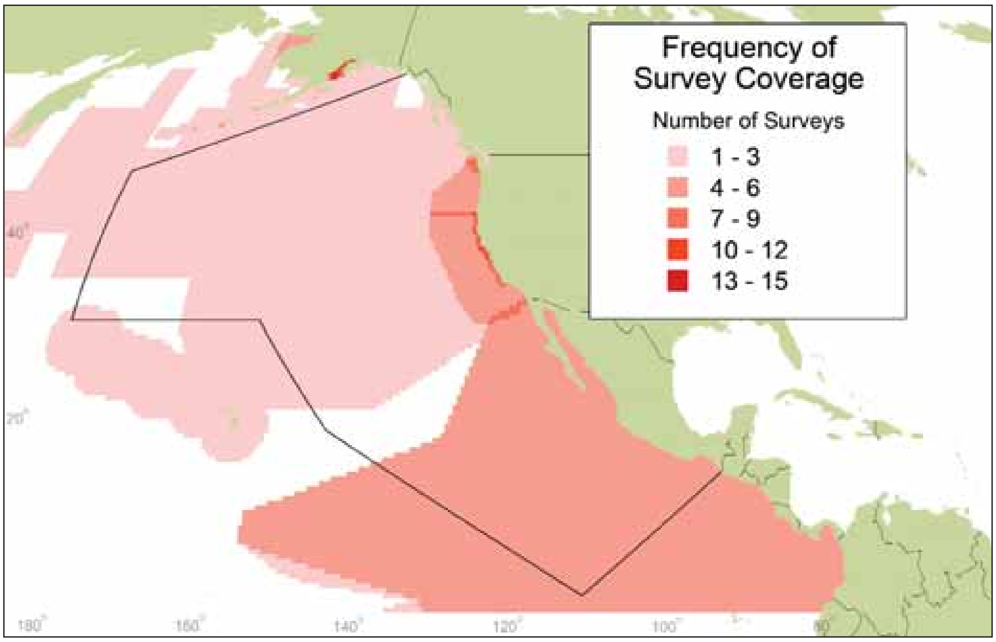
A total of 40 species were expected to occur in the study area as listed in Table 2.

Table 2. List of species included in density maps

Scientific name	Common name	Figures	Comments
Eubalaena japonica	North Pacific right whale	4	Draws heavily on rare sightings that will influence presentation of the species' range
Eschrichtius robustus	gray whale	5	Land-based census data not used because abundance could not be assigned to a quantifiable survey area
Balaenoptera acutorostrata	common minke whale	6	
Balaenoptera borealis	sei whale	7	
Balaenoptera edeni	Bryde's whale	8	Species complex including *B. edeni* and *B. brydei* treated as one species here (nomenclature unsettled, difficult to discriminate)
Balaenoptera musculus	blue whale	9	
Balaenoptera physalus	fin whale	10	
Megaptera novaeangliae	humpback whale	11	
Physeter macrocephalus	sperm whale	12	
Kogia breviceps	pygmy sperm whale	13	
Kogia sima	dwarf sperm whale	14	
Delphinapterus leucas	beluga or white whale	15	
Phocoena phocoena	harbor porpoise	16	
Phocoena sinus	vaquita	17	
Phocoenoides dalli	Dall's porpoise	18	
Steno bredanensis	rough-toothed dolphin	19	
Lagenorhynchus obliquidens	Pacific white-sided dolphin	20	
Grampus griseus	Risso's dolphin	21	
Tursiops truncatus	common bottlenose dolphin	22	
Stenella attenuata	pantropical spotted dolphin	23	
Stenella coeruleoalba	striped dolphin	24	
Stenella longirostris	spinner dolphin	25	
Delphinus capensis	long-beaked common dolphin	26	
Delphinus delphis	short-beaked common dolphin	27	
Lagenodelphis hosei	Fraser's dolphin	28	
Lissodelphis borealis	northern right whale dolphin	29	
Peponocephala electra	melon-headed whale	30	
Feresa attenuata	pygmy killer whale	31	
Pseudorca crassidens	false killer whale	32	
Orcinus orca	killer whale	33	
Globicephala macrorhynchus	short-finned pilot whale	34	
Berardius bairdii	Baird's beaked whale	35, 40	
Indopacetus pacificus	Longman's beaked whale	36, 40	
Mesoplodon densirostris	Blainville's beaked whale	37, 38, 40	
Mesoplodon carlhubbsi	Hubbs' beaked whale	38, 40	No available species-level estimate
Mesoplodon ginkgodens	ginkgo-toothed beaked whale	38, 40	No available species-level estimate
Mesoplodon perrini	Perrin's beaked whale	38, 40	No available species-level estimate
Mesoplodon peruvianus	pygmy beaked whale	38, 40	No available species-level estimate
Mesoplodon stejnegeri	Stejneger's beaked whale	38, 40	No available species-level estimate
Ziphius cavirostris	Cuvier's beaked whale	39, 40	

Effort

IUCN Marine Region 15 and adjacent waters were covered by 162 surveys conducted between 1986 and 2005, which included 103 different survey blocks (including coverage of the same blocks during multiple years) (Kaschner et al., submitted). Survey blocks varied greatly in size, ranging from 1600km² to 21,000,000km² (see Appendix 2 for detailed information about coverage and size of specific survey blocks). Similarly, survey effort, measured as the frequency of survey coverage (i.e., the number of times a cell was covered by surveys), varied greatly between different areas (Figure 2A). As can be seen, although almost all of Marine Region 15 has been covered by at least one survey, published information from survey effort was relatively scant in most of the region, with much more information in US than Canadian waters. (Results of ongoing surveys in Canada's Pacific region by Fisheries and Oceans Canada have not been published, but contact information for scientists in charge of these surveys is included in the Experts Directory.) The greatest concentration of survey effort in the overall area covered by the map was just outside the region in Cook Inlet, which has been covered up to 12 times in 25 years, although a few Cook Inlet estuary cells have been covered up to 15 times.



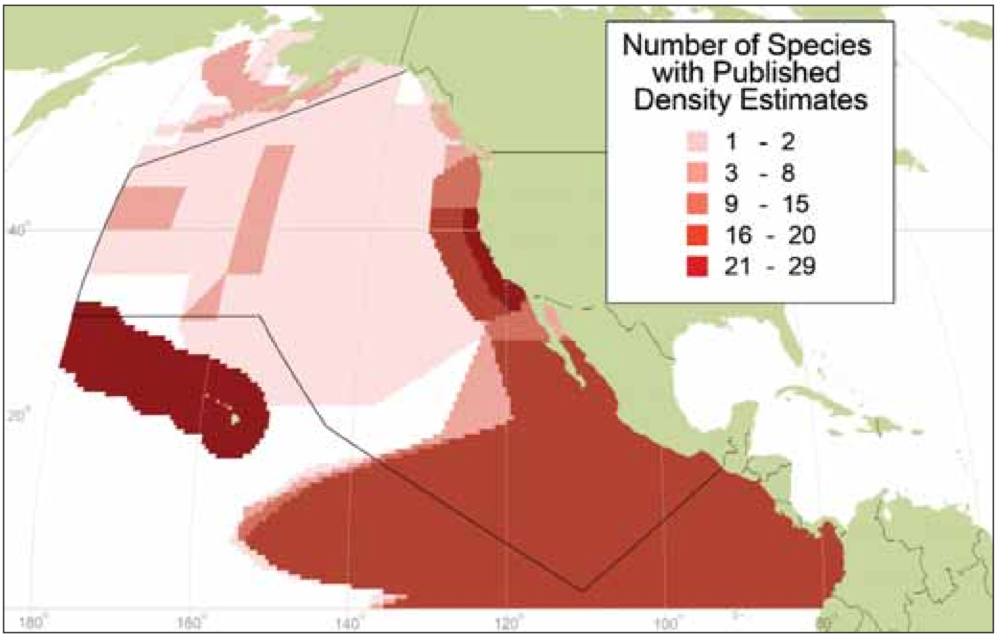


Figure 2A (top) Frequency of survey coverage as an indication of relative survey effort. This shows the number of times a cell was covered by a survey from 1986 to 2005.

Figure 2B (bottom) Number of cetacean species for which there is at least one reported abundance/density estimate in each cell (Kaschner et al., submitted).

Species diversity

A total of 394 species-level abundance estimates were reported for 36 species (Appendix 1), not including species reported to be present but with insufficient sightings to provide an abundance estimate. Of these, 332 were based on ship-board surveys and 62 on aerial surveys. Note that only 226 of the 394 surveys were corrected for g(0), i.e., availability bias. Thus, although in some cases it was assumed that all animals on the trackline were detected, in most cases it was not, and availability bias accounted for this statistically. Unless this bias is accounted for, abundance will usually be underestimated, and the magnitude of underestimation will be greater for small, cryptic or deep-diving species than for large baleen whales, and for aerial surveys than for surveys conducted from large, slowly-moving ships. Addressing this between-study variability is not straightforward. This is an important technical issue relating to standardization of methods. Spatial variability in survey methods may create the false appearance of spatial patterns in animal density. Spatial planning processes that use density estimates should involve sensitivity analyses to evaluate robustness of the algorithms and solutions. In most cases, abundances estimates for the same species reported during different years did not come from the same survey areas, and this makes direct comparison of estimates between years, i.e. the assessment of potential population change, difficult. Nonetheless, 58 multi-year estimates were available (i.e., estimates for the same species collected in the same area in different years), and the highest number of estimates available for the same species in the same area was 12 (for the belugas in Cook Inlet, just outside Marine Region 15).

Species diversity in Marine Region 15 can be shown by counting the number of species in each cell for which any abundance estimate was reported during any survey covering this cell (Figure 2B). For comparison – and because the sampling units for the map in Figure 2B were relatively coarse – we also included a map of the number of species predicted to occur in each 0.5-degree cell, based on RES output (Kaschner et al. 2011; Kaschner et al. 2006) (Figure 3). Despite the differences in underlying sampling units, there is broad agreement between the predicted and observed species diversity, which identifies the northern ETP as the part of Marine Region 15 with the highest diversity of cetacean species. It is important to recognize that the map of observed species diversity will underestimate true diversity because it is based solely on available single-species estimates and ignores sightings scored only to genus (e.g., *Stenella* or *Kogia*) or to even less precise categories (e.g., unknown beaked whale; unknown baleen whale). Diversity will likely also be underestimated in under-surveyed areas.

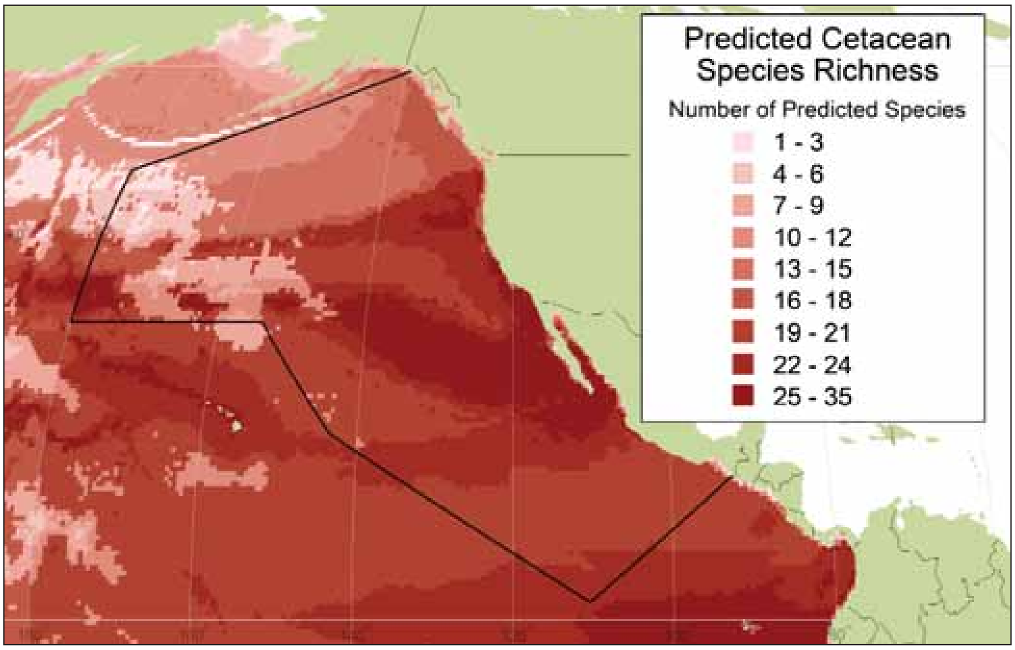


Figure 3. Predicted cetacean species richness in IUCN Marine Region 15, modified from Kaschner (2007). Predictions were based on the distribution of individual cetacean species generated using the RES model (Kaschner et al. 2006), assuming a probability threshold of 0.4 for species presence. See Kaschner et al. (2006) and Kaschner et al. (2011) for methodological details.

SPECIES MAPS

Maps are arranged taxonomically, by family. Mean observed density is plotted according to the global survey database (Kaschner et al., submitted), and predicted range follows Kaschner et al. (2006) and www.aquamaps.org (Kaschner et al. 2008). For more information on the data used to create the maps, please refer to the descriptions of the survey database in Appendix 2.

Box 1. Essential note regarding all density maps

In this section, we present maps of reported mean densities (individuals per 1000 km^2) for each species based on abundance estimates from line-transect surveys. The predicted maximum range extent based on the Relative Environmental Suitability (RES) model (Kaschner et al. 2006) is plotted on each map in the form of a lightly pixelated layer to indicate the completeness of survey coverage for that species. The predictions generated by the RES model tend to correspond more closely to the potential rather than the realized (known) range of a species, thus generally overestimating occurrence.

In most cases, the maximum range extent as shown on the maps encompasses all areas with a predicted relative environmental suitability probability greater than 0. However, a recent comparison with sighting data indicated that a threshold greater than 0 may be more appropriate for some species (Kaschner et al. 2011) and alternative thresholds were therefore applied in a few cases (e.g. the vaquita and the long-beaked common dolphin) where the predicted range otherwise resulted in a gross misrepresentation of current knowledge.

In cases where a site has been sampled by different surveys and/or during different time periods, we plot mean density from all surveys. Colour coding is standardized to facilitate comparisons across species with respect to relative occurrence (areas of high versus low densities), but it should be noted that reported absolute densities can vary among species by several orders of magnitude. Also, such comparisons are confounded to some extent by (a) the uneven treatment of g(0) estimation in the original survey data, (b) incomplete seasonal coverage of most surveys/areas, and (c) the fact that different authors have reported observations of rare species differently or do not include them at all.[2]

The category labeled “documented presence” in the legend of each species map (in the lightest grey-scale shade possible) refers to areas where the species was sighted during at least one line-transect survey but the sample size or effort was insufficient to support an abundance estimate.

We stress that “documented presence” as shown on our maps refers *only* to information provided from published line-transect surveys; we have not attempted to account for other types of evidence, such as opportunistic sightings, observations made during photo-identification surveys, captures, strandings, or acoustic recordings. Note also that temporal coverage of the database is limited to the years 1976-2005 and for non-focal species, such as the humpback whale, not all existing surveys may have been encoded.”

Note: All data sources are provided in Appendix 2.

[2] A commonly used rule of thumb in line-transect surveys is that 60-80 sightings are required to fit a detection function to generate robust estimates of density (Buckland et al. 2001). As a result, some researchers do not report densities for species seen less often than this. For example, Buckland et al. (1993) estimated densities for three cetacean species “commonly” seen on their surveys; if other species were observed during those surveys, they were not mentioned by Buckland et al. (1993). In contrast, surveys conducted by Southwest Fisheries Science Center (e.g., Barlow 1995; Barlow 2003; Forney and Barlow 1993) often rely on “pooled” detection functions in which sample size is built up through time or by combining sightings of species thought to have similar sightability. This approach allows one to estimate generic values for effective strip width [both f(0) and g(0)], which can then be used to estimate densities for mixed-species groups and species seen only once on a given survey. Williams and Thomas (2007) chose a middle ground, and reported densities for species seen as infrequently as 14 times (a highly tentative density estimate for minke whales). Sightings of species seen less often than this were reported in a table, but no attempt was made to estimate density for those species. In practice, these methodological differences mean that a species seen only once in a survey could be (a) unreported, (b) reported as a “documented presence”, or (c) be reported with a density estimate. Consequently, when interpreting our maps, please note that the “documented presence” category derived from one study could reflect a density as high as a relatively low density category derived from another study, and none of the maps documents true absence.

Suborder: Mysticeti

Family: Balaenidae

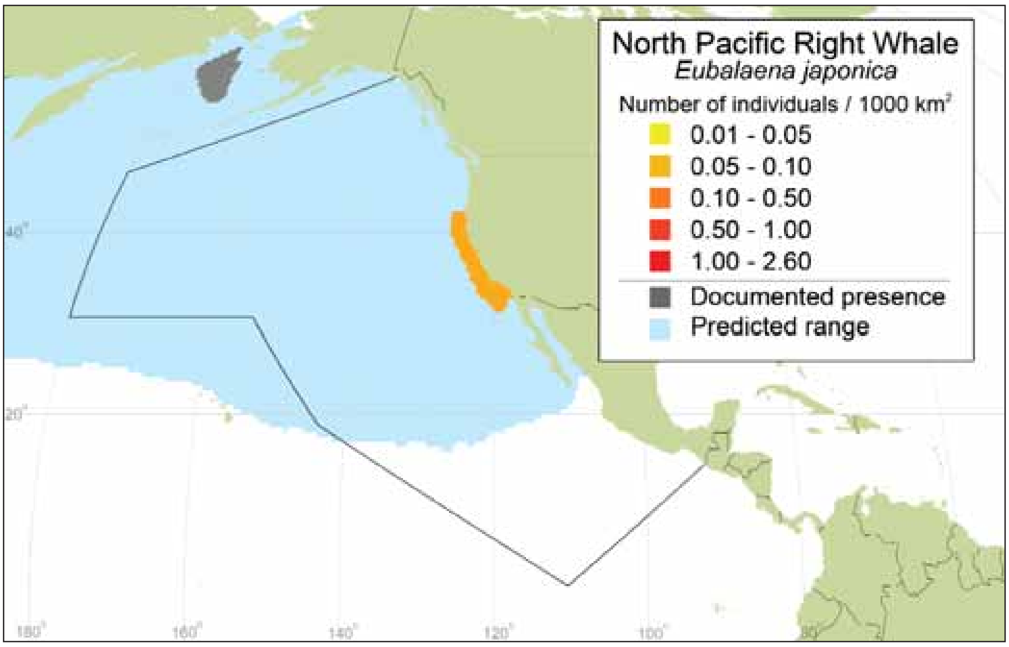


Figure 4. North Pacific right whale (*Eubalaena japonica*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Note that the map for this species is strongly influenced by an abundance estimate based on one sighting of a right whale during an aerial survey off California (Carretta et al. 1994; Forney et al. 1995). It does not include reports of right whales in the Bering Sea and Gulf of Alaska that came from studies other than line-transect surveys (e.g., Shelden et al. 2005; Wade et al. 2006).

Family: Eschrichtiidae

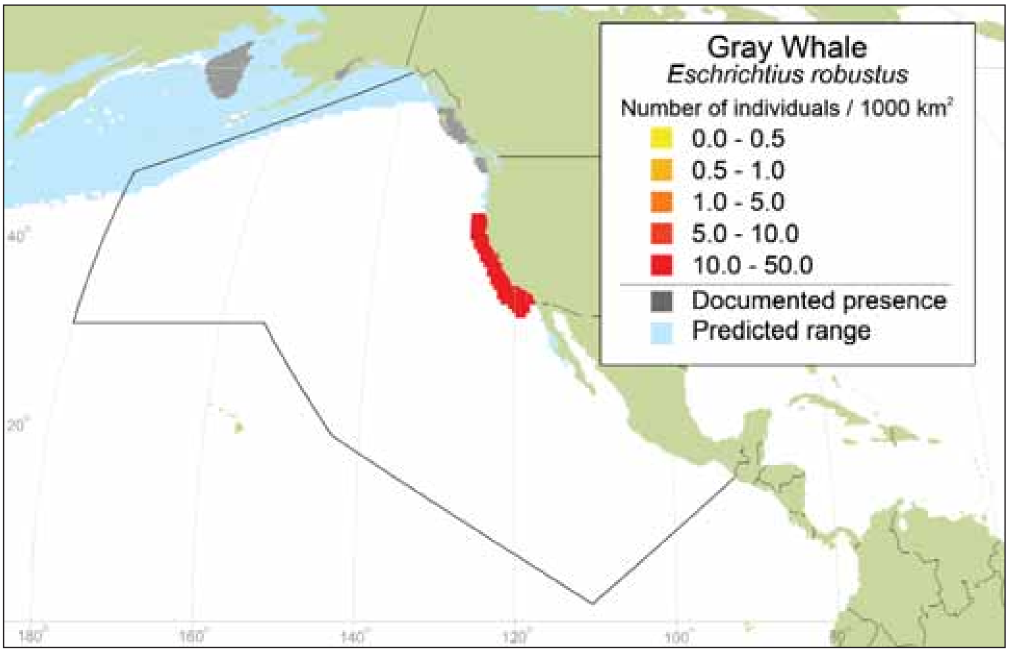


Figure 5. Gray whale (*Eschrichtius robustus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Note that the map for this species is biased toward feeding areas and migratory corridors; it does not show the species' localized, well-known breeding grounds in Baja California, Mexico. Gray whale abundance has been studied primarily using methods other than line-transect surveys. Our maps could not use shore-based gray whale "census" data, because without a specific survey area, no density could be calculated.

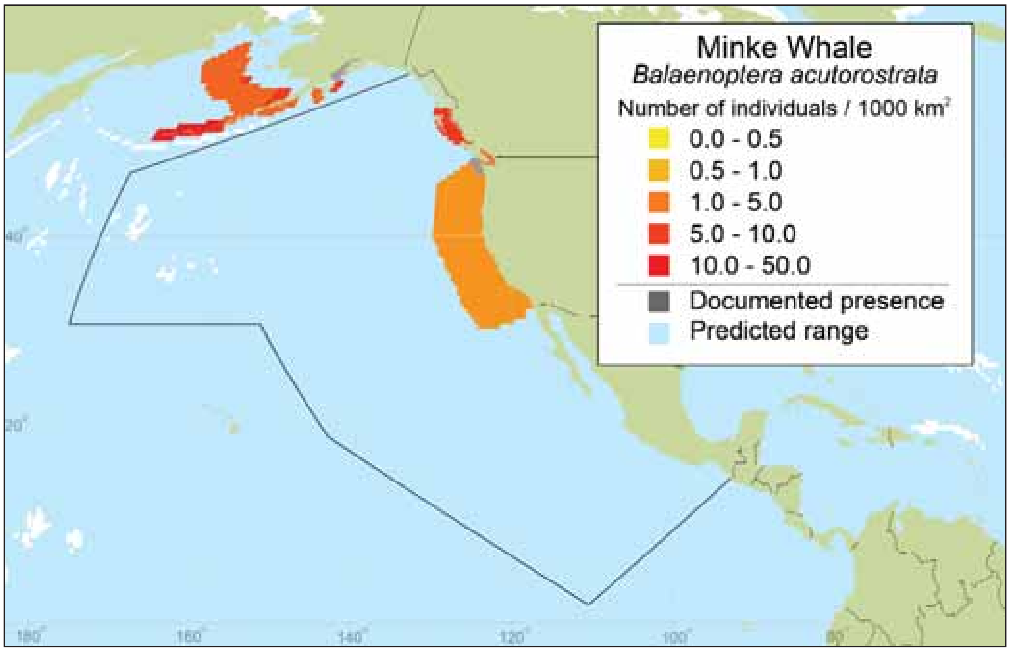


Figure 6. Common minke whale (*Balaenoptera acutorostrata*) mean observed density (Global survey database, Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Note that surveys for seasonally migrating baleen whales will not show their full range, and higher-latitude feeding areas may be particularly underrepresented.

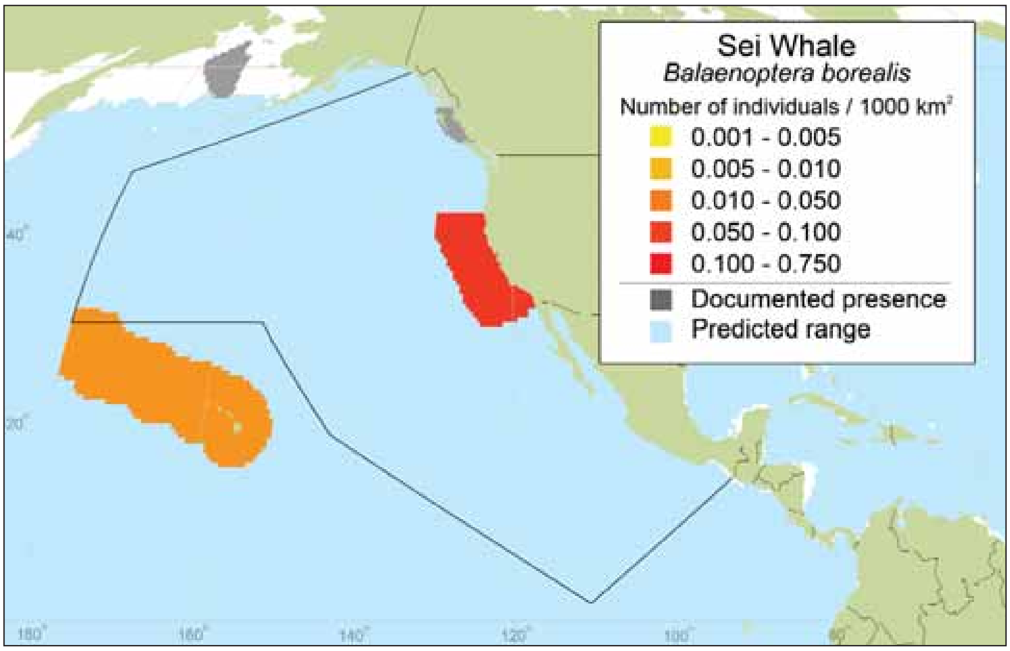


Figure 7. Sei whale (*Balaenoptera borealis*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Note that the relatively high-density area off Hawaii is influenced by rare sightings reported in Barlow (2003a). Also, surveys for seasonally migrating baleen whales will not show their full range, and higher-latitude feeding areas may be particularly underrepresented.

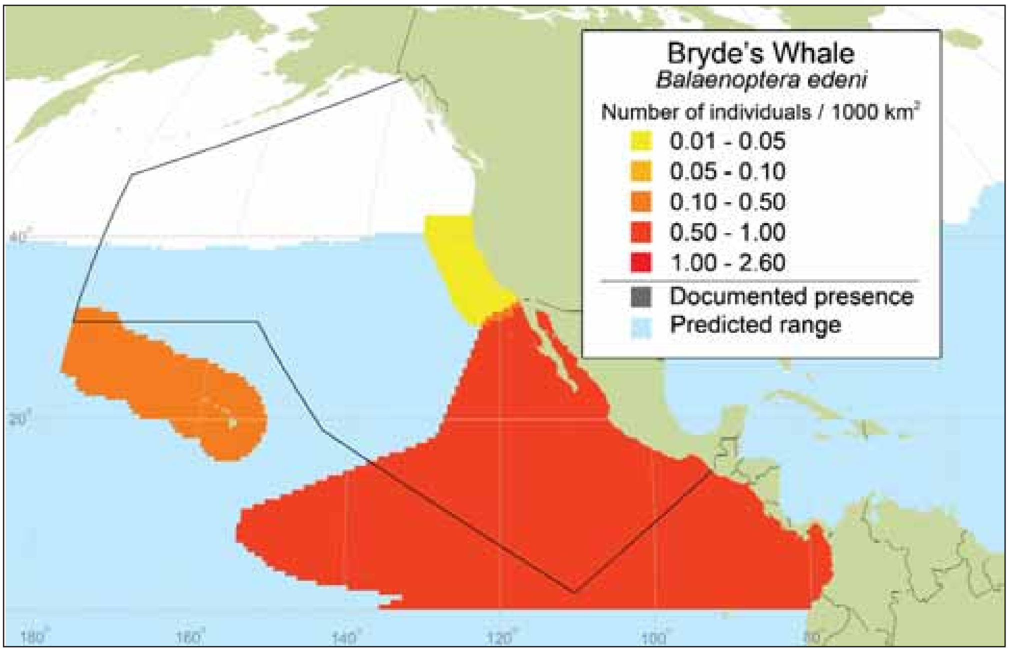


Figure 8. Bryde's whale (*Balaenoptera edeni*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). The documented presence along the US west coast is based on a single sighting reported in Barlow (2003b), which translates to a very small but non-zero average density.

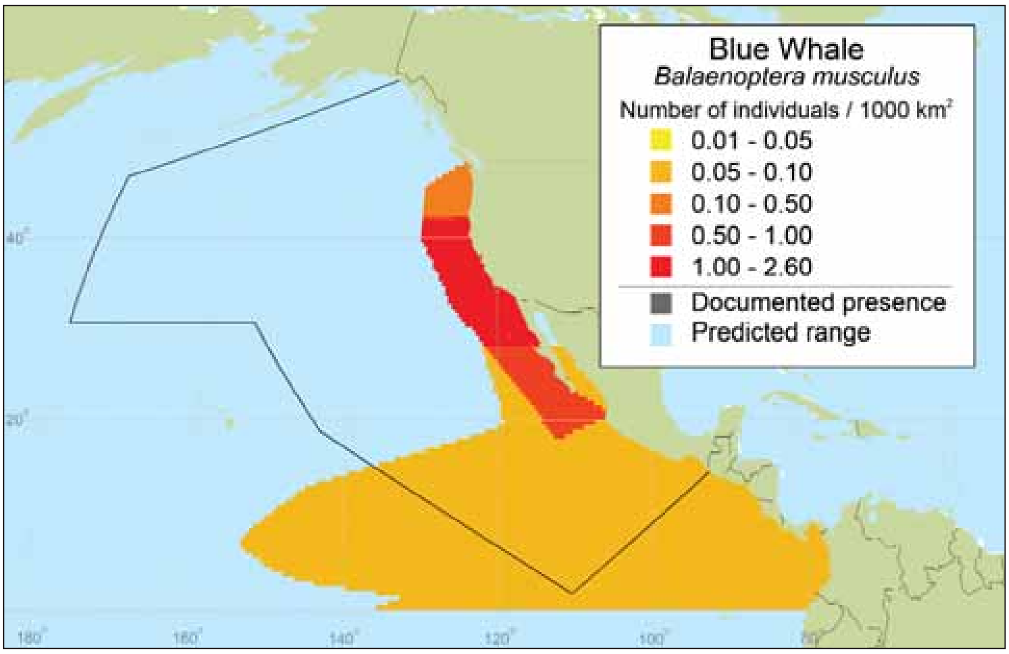


Figure 9. Blue whale (*Balaenoptera musculus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Documented presence is reported in sparse sightings from line-transect surveys, but does not include sightings from much wider areas from photo-ID studies (e.g., Calambokidis and Barlow 2004) or opportunistic sightings. Note that surveys for seasonally migrating baleen whales will not show their full range, and higher-latitude feeding areas may be particularly underrepresented.

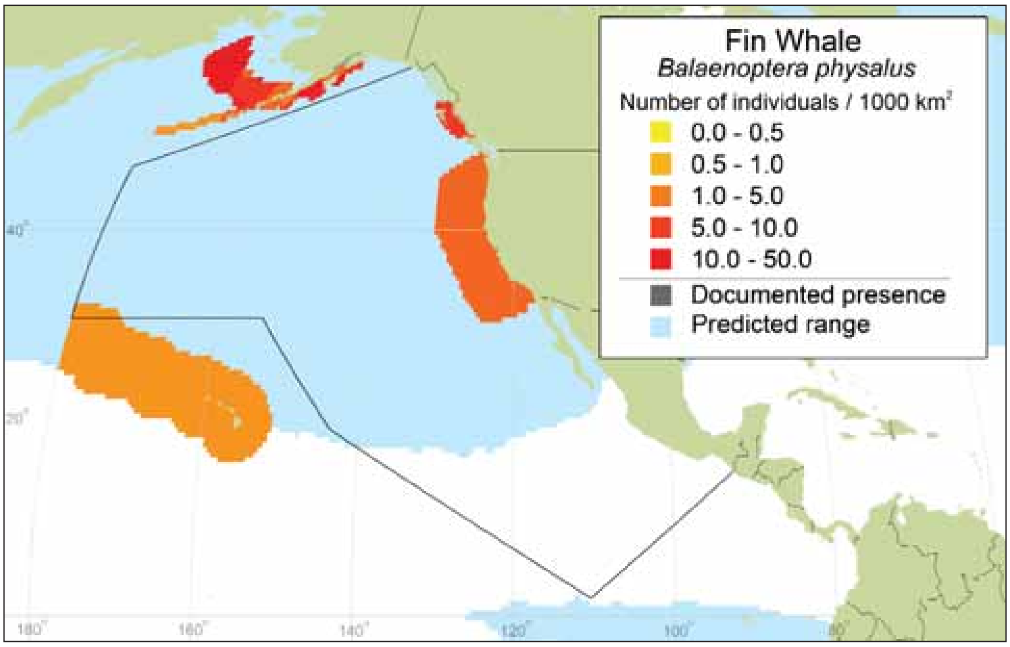


Figure 10. Fin whale (*Balaenoptera physalus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Note that surveys for seasonally migrating baleen whales will not show their full range, and higher-latitude feeding areas may be particularly underrepresented.

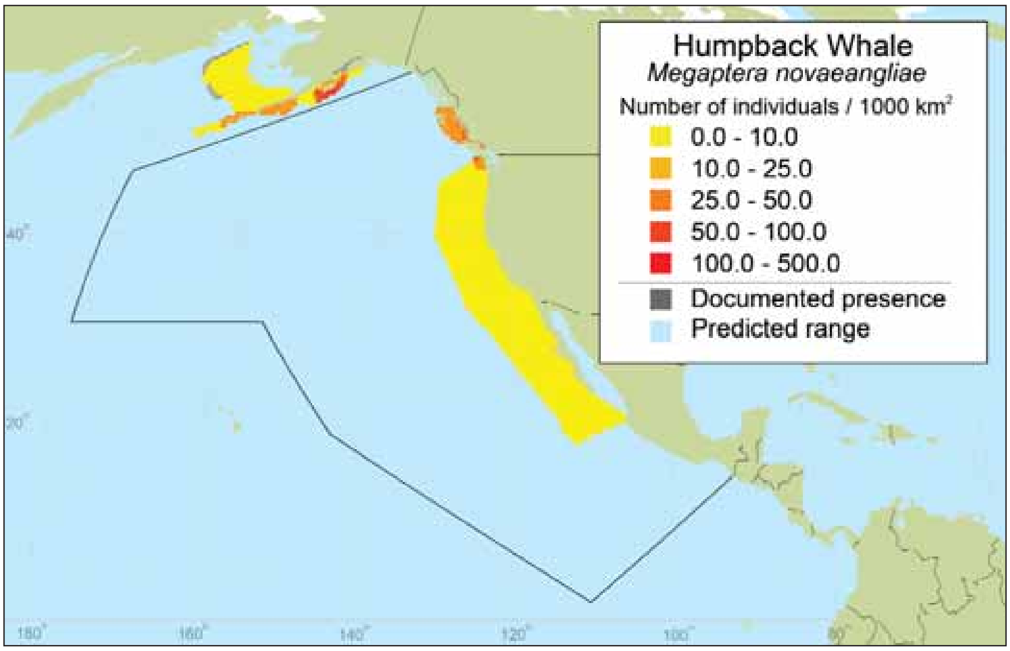


Figure 11. Humpback whale (*Megaptera novaeangliae*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). The line-transect surveys used as the basis for this map were conducted largely outside the peak winter breeding season when densities of humpback whales would be much higher than indicated off Mexico. Winter abundance estimates for humpback whales around Hawaii exist from photo-ID surveys (Cerchio 1998) and from aerial line-transect surveys (Mobley et al. 2001), but are not included here.

Suborder: Odontoceti

Family: Physeteridae

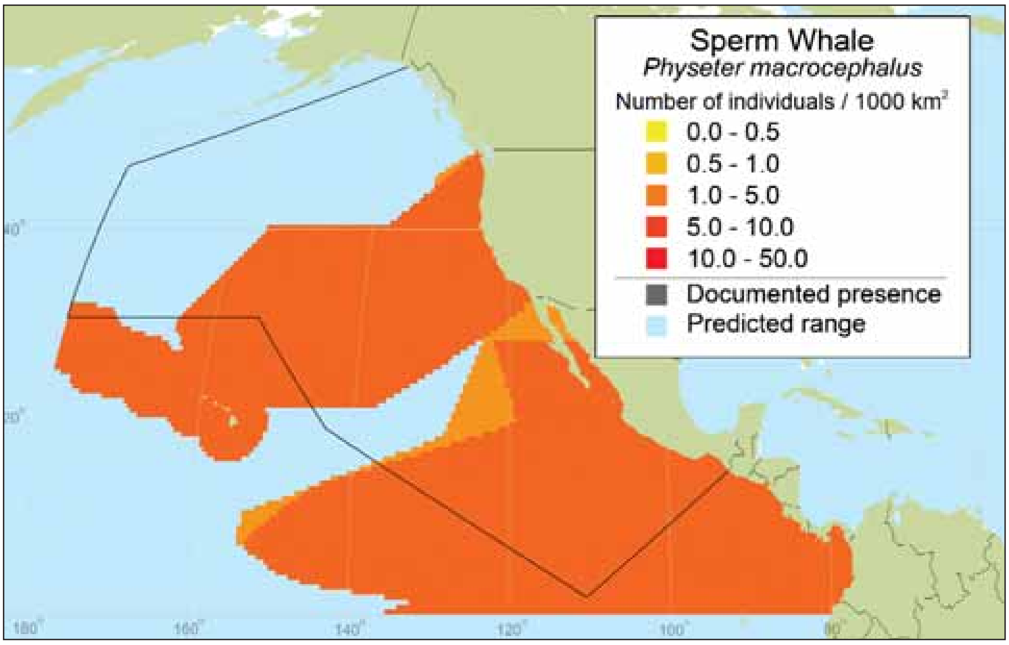


Figure 12. Sperm whale (*Physeter macrocephalus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

Family: Kogiidae

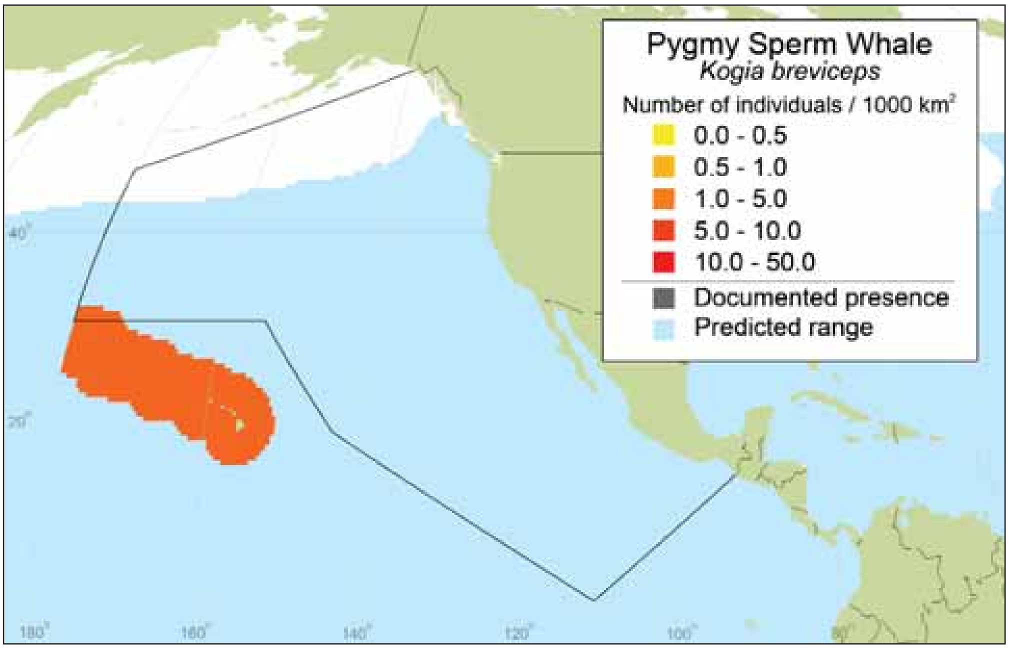


Figure 13. Pygmy sperm whale (*Kogia breviceps*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Only species-specific estimates are shown, but there are a number of combined estimates for the genus *Kogia* that are not included here.

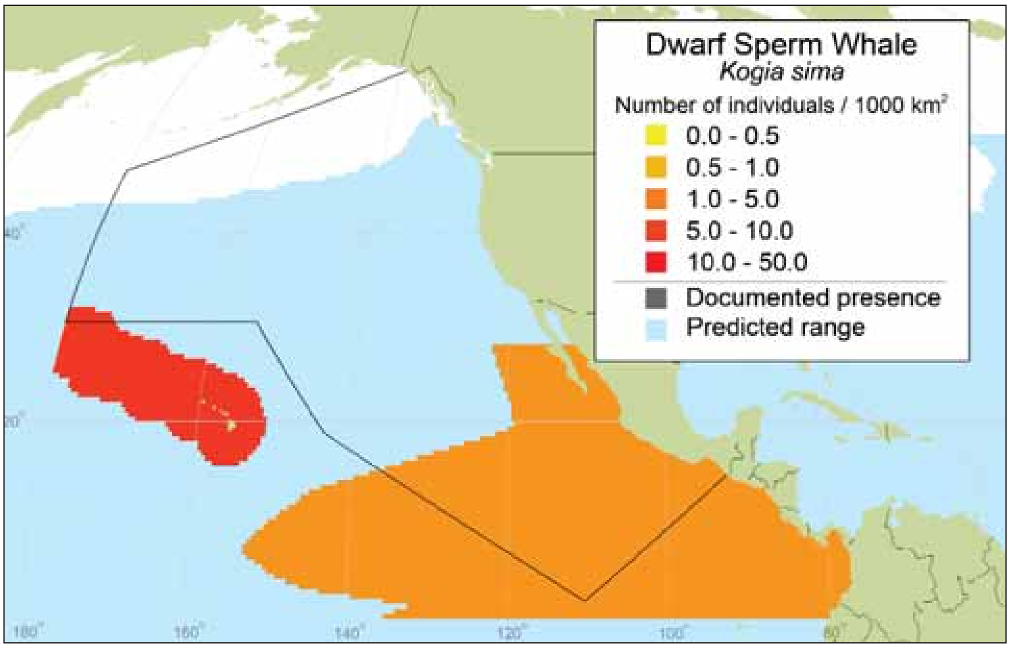


Figure 14. Dwarf sperm whale (*Kogia sima*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Only species-specific estimates are shown, but there are a number of combined estimates for the genus *Kogia* that are not included here.

Family: Monodontidae

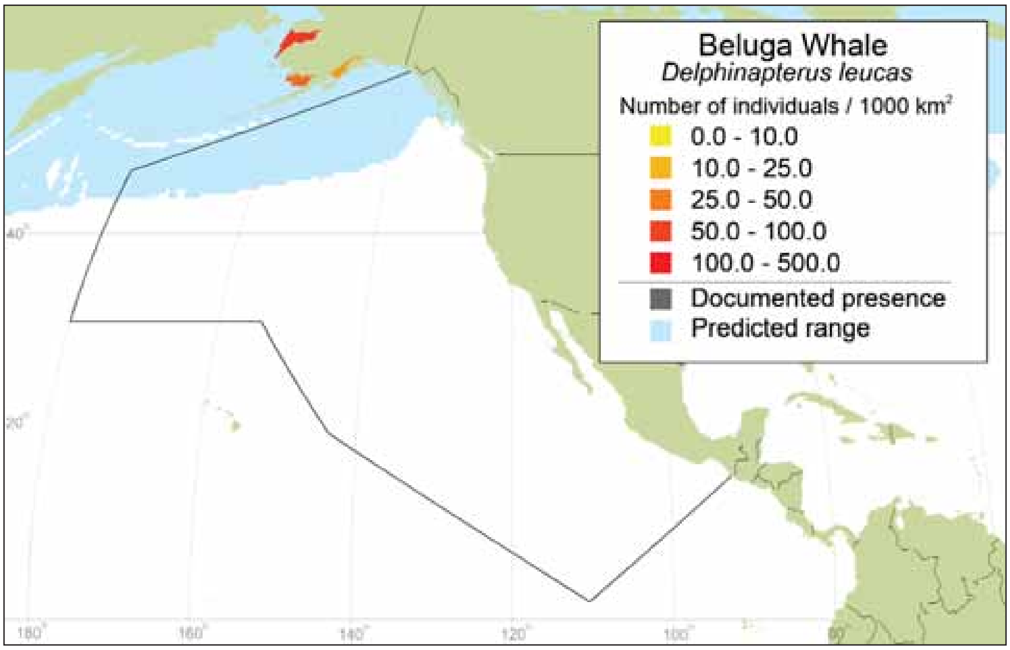


Figure 15. Beluga (*Delphinapterus leucas*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

Family: Phocoenidae

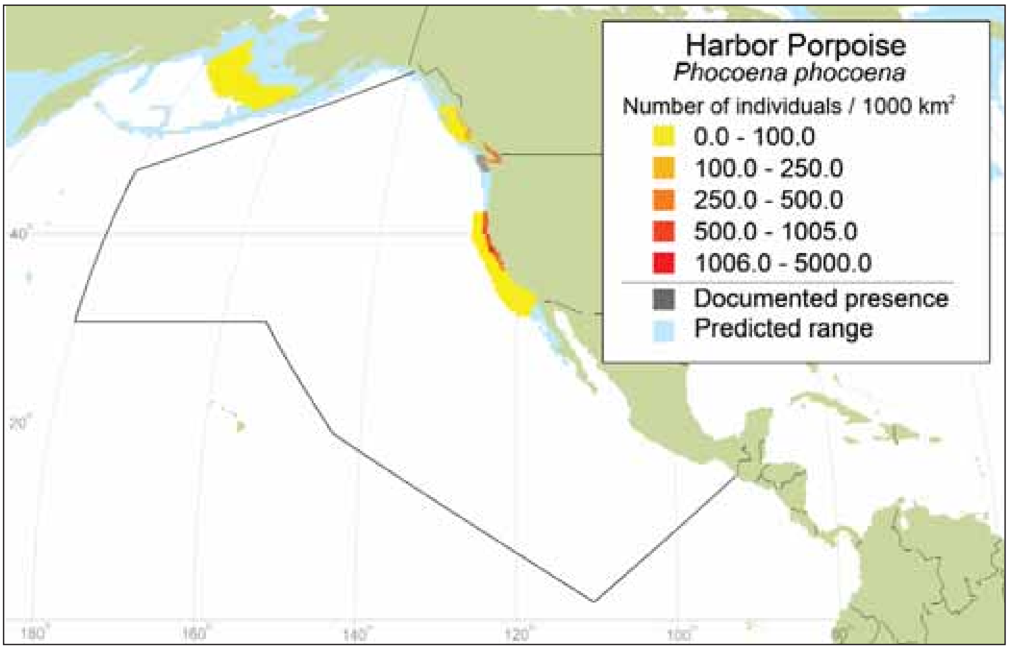


Figure 16. Harbor porpoise (*Phocoena phocoena*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

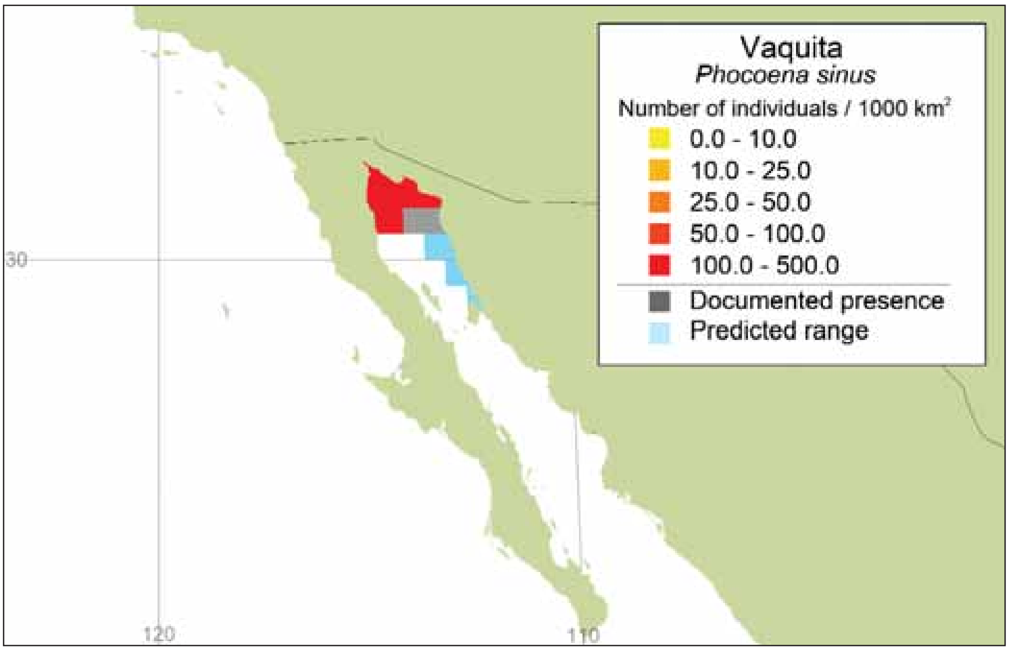


Figure 17. Vaquita (*Phocoena sinus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org), zoomed to show detail due to localized distribution. For this species, we have used a presence threshold of RES > 0.4 to show areas more likely to correspond to the current range (Kaschner et al. 2011), but note that due to the nature of the relatively coarse, large-scale approach of RES modelling, the predicted range may still be closer to the historical or potential range extent and thus exceed the currently known range of this critically endangered species.

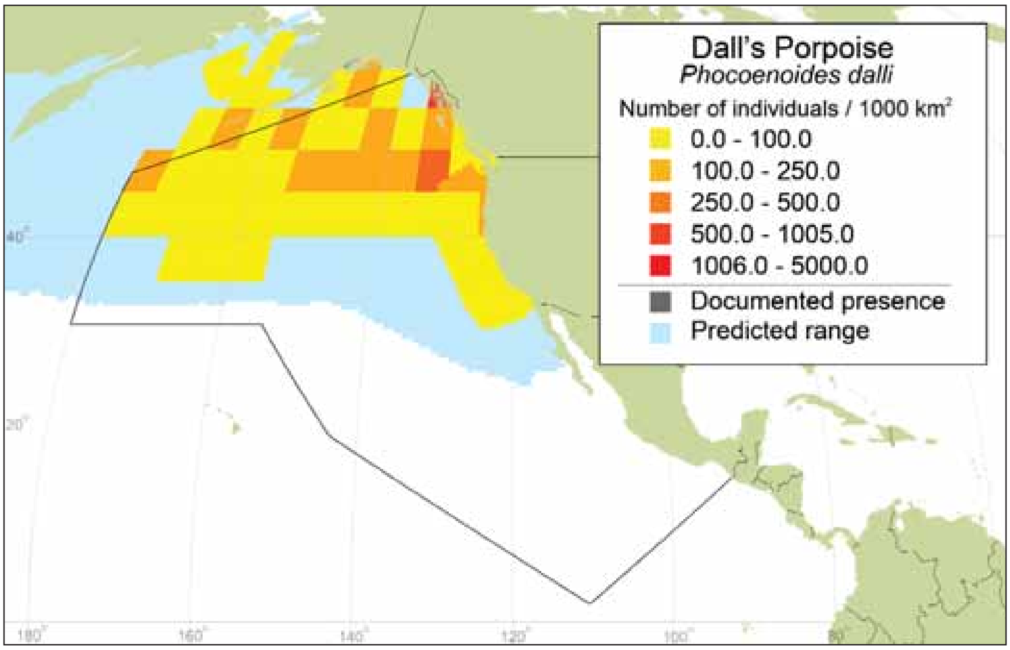


Figure 18. Dall's porpoise (*Phocoenoides dalli*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

Family: Delphinidae

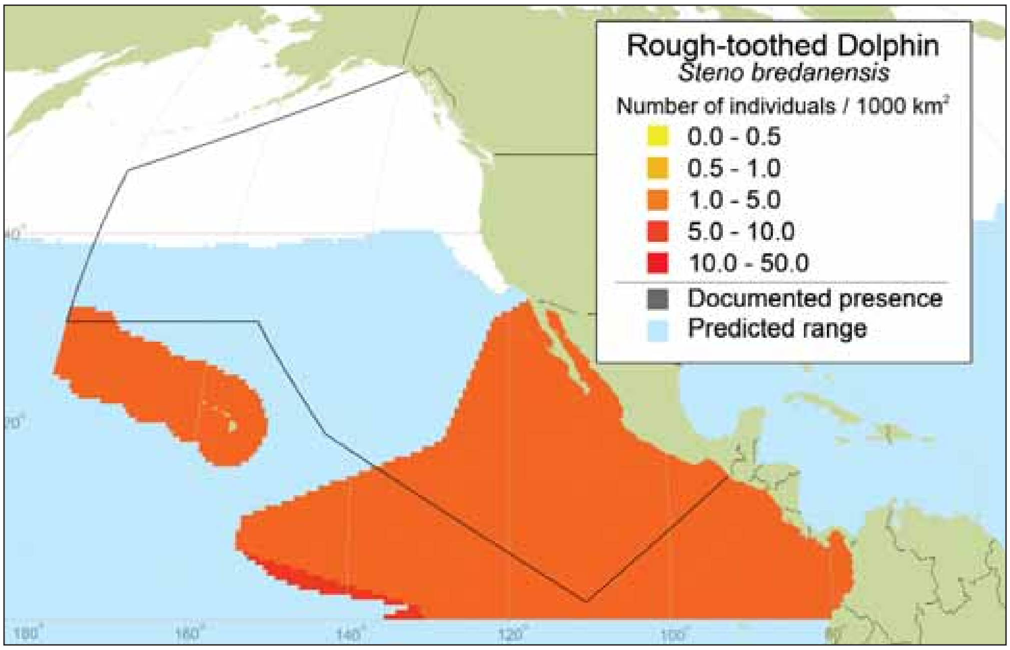


Figure 19. Rough-toothed dolphin (*Steno bredanensis*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

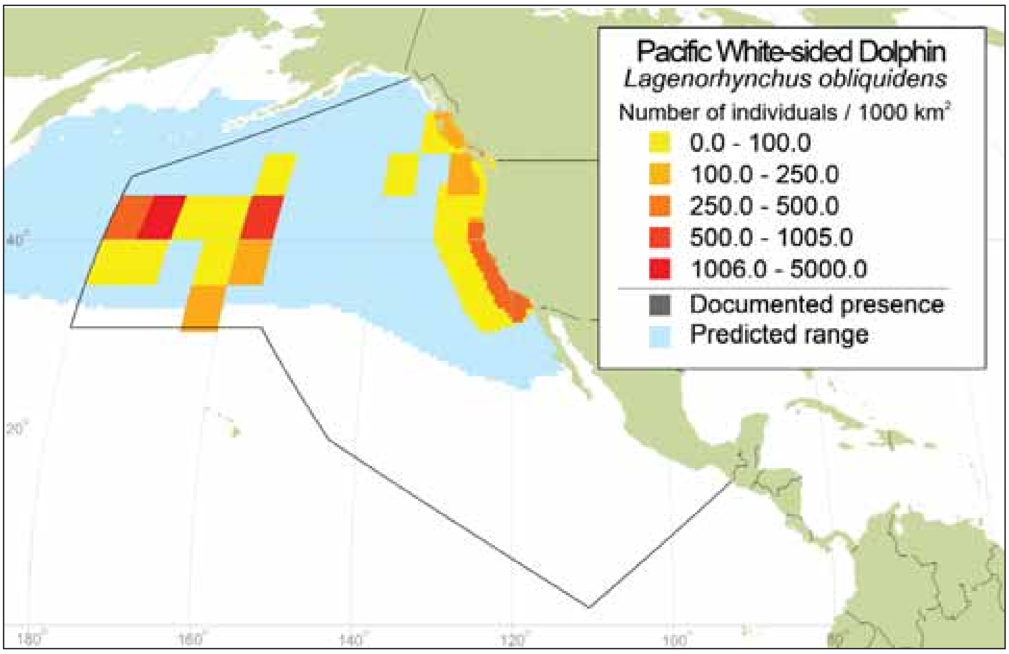


Figure 20. Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

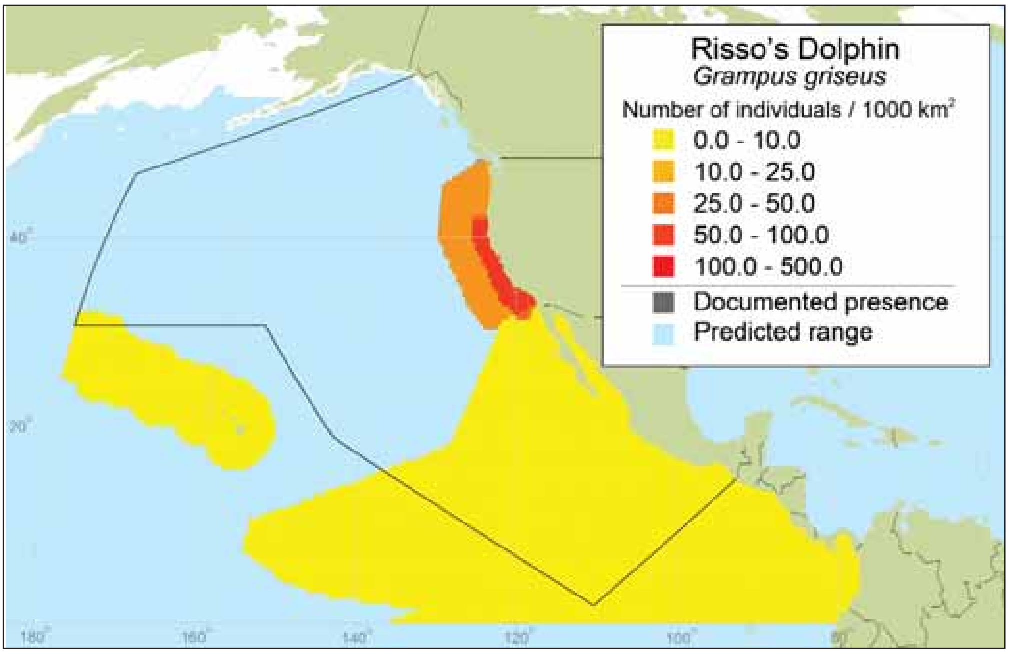


Figure 21. Risso's dolphin (*Grampus griseus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

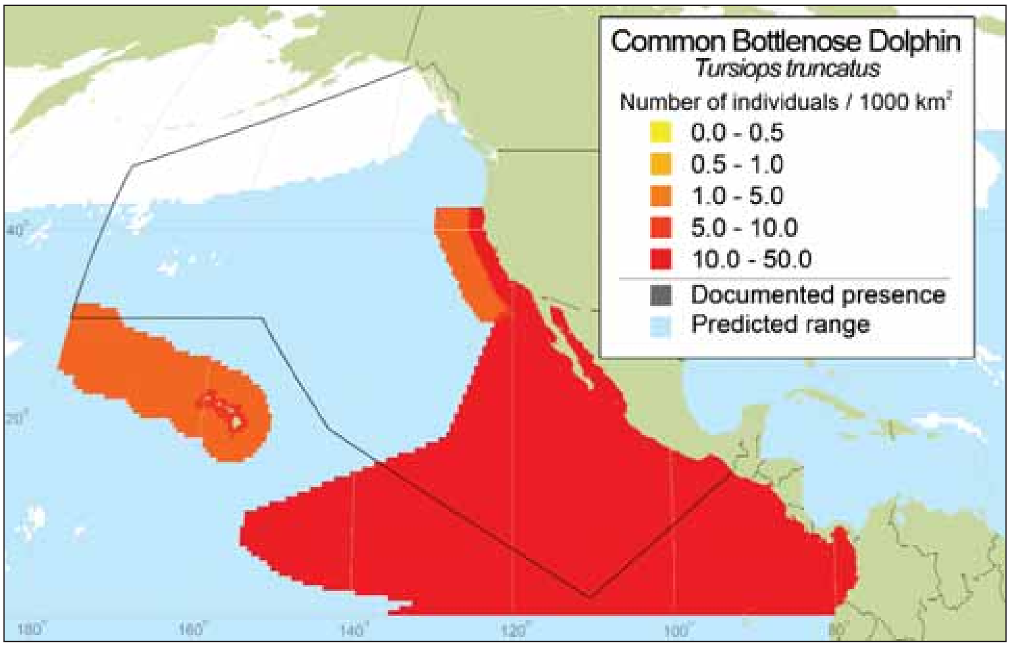


Figure 22. Common bottlenose dolphin (*Tursiops truncatus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

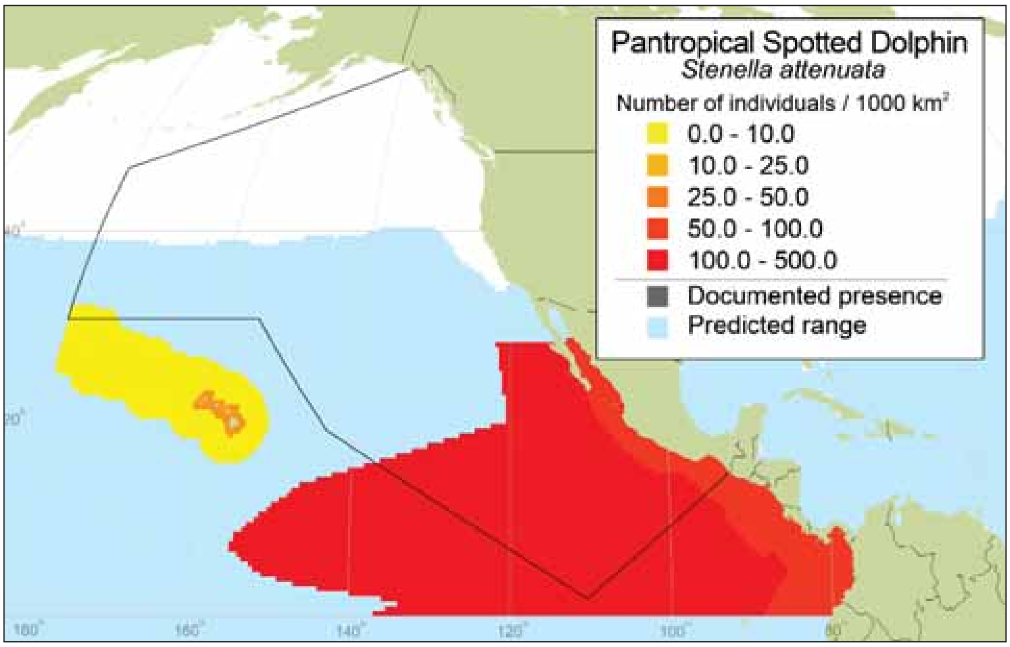


Figure 23. Pantropical spotted dolphin (*Stenella attenuata*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

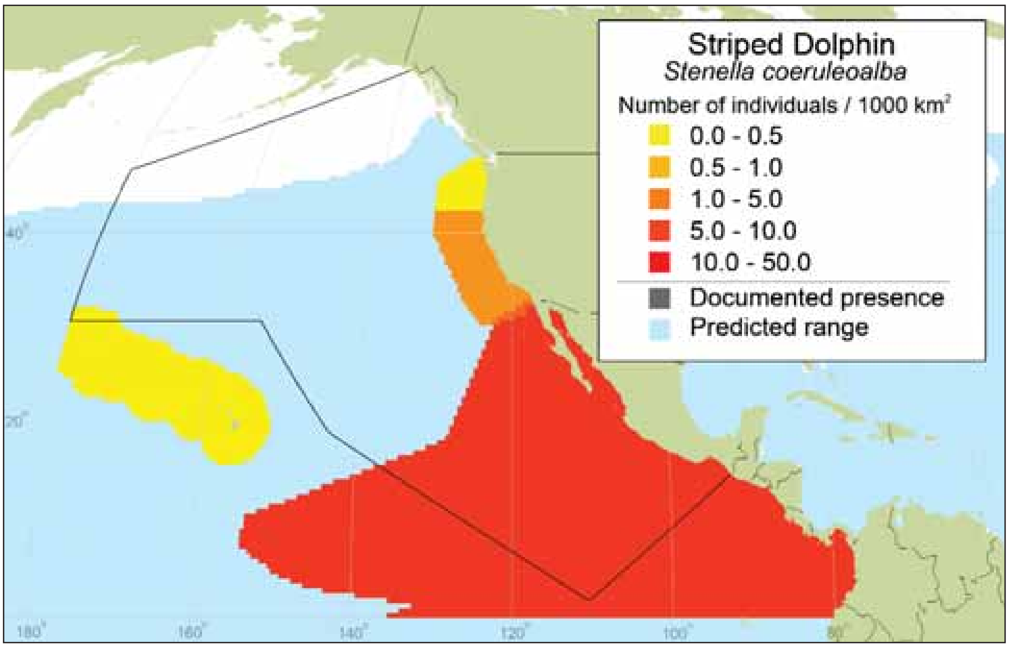


Figure 24. Striped dolphin (*Stenella coeruleoalba*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

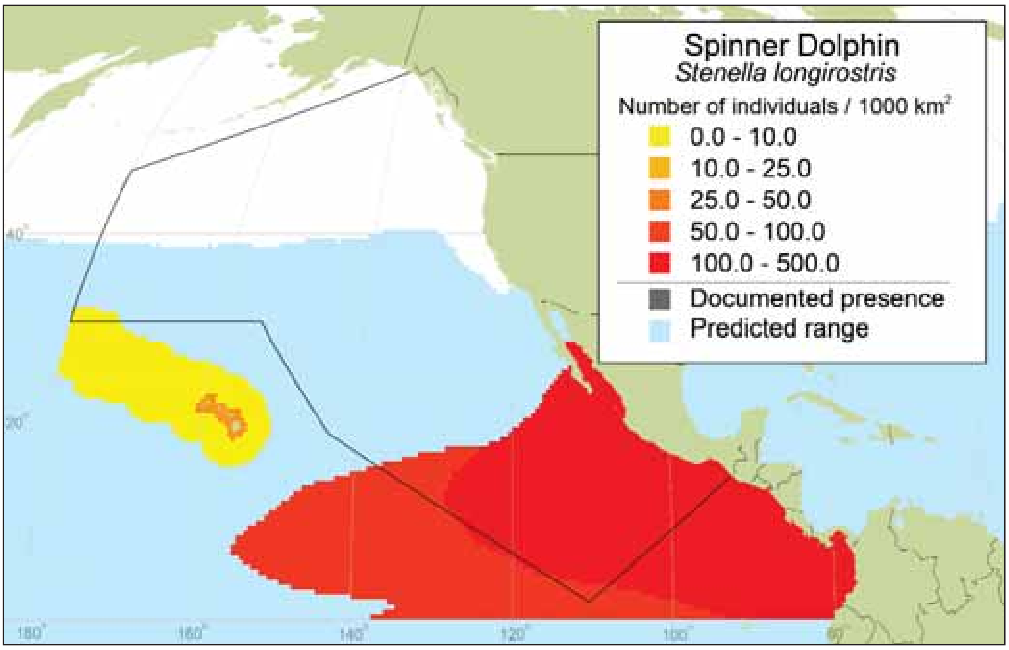


Figure 25. Spinner dolphin (*Stenella longirostris*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

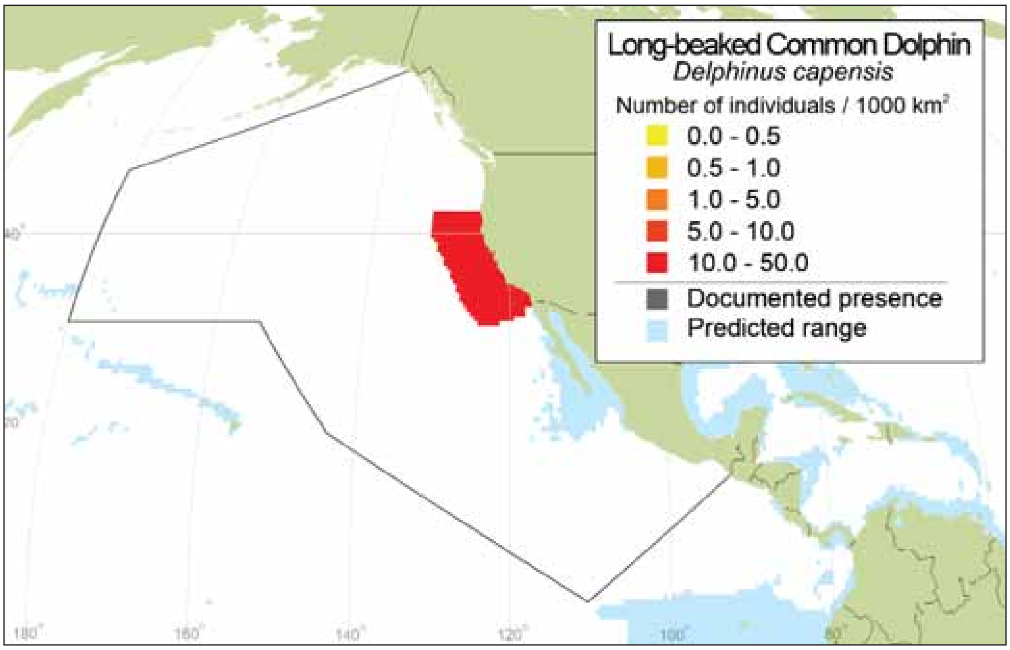


Figure 26. Long-beaked common dolphin (*Delphinus capensis*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Identification of habitat use and consequently range prediction of this species using RES is hampered by difficulties of distinguishing it from its short-beaked congener, *Delphinus delphis*. The predicted range shown here is based on a RES threshold of > 0.4 (Kaschner et al. 2006, 2011) which is assumed to be more representative of the habitat niche of this coastal species. Only species-specific estimates are shown, but there are a number of combined estimates for the genus *Delphinus* not included here.

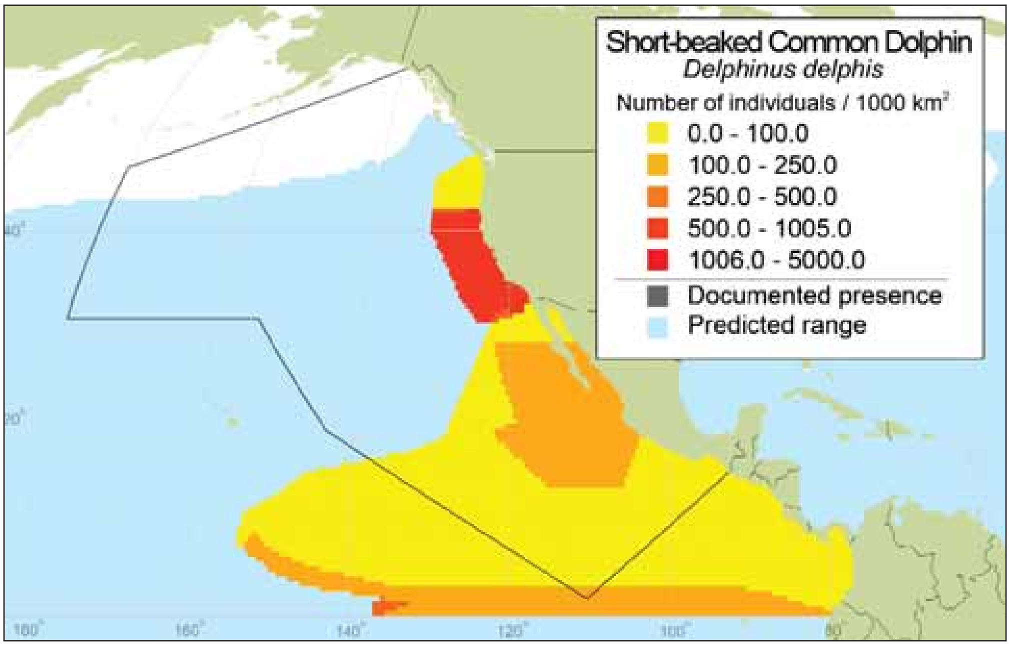


Figure 27. Short-beaked common dolphin (*Delphinus delphis*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). Only species-specific estimates are shown, but there are a number of combined estimates for the genus *Delphinus* not included here.

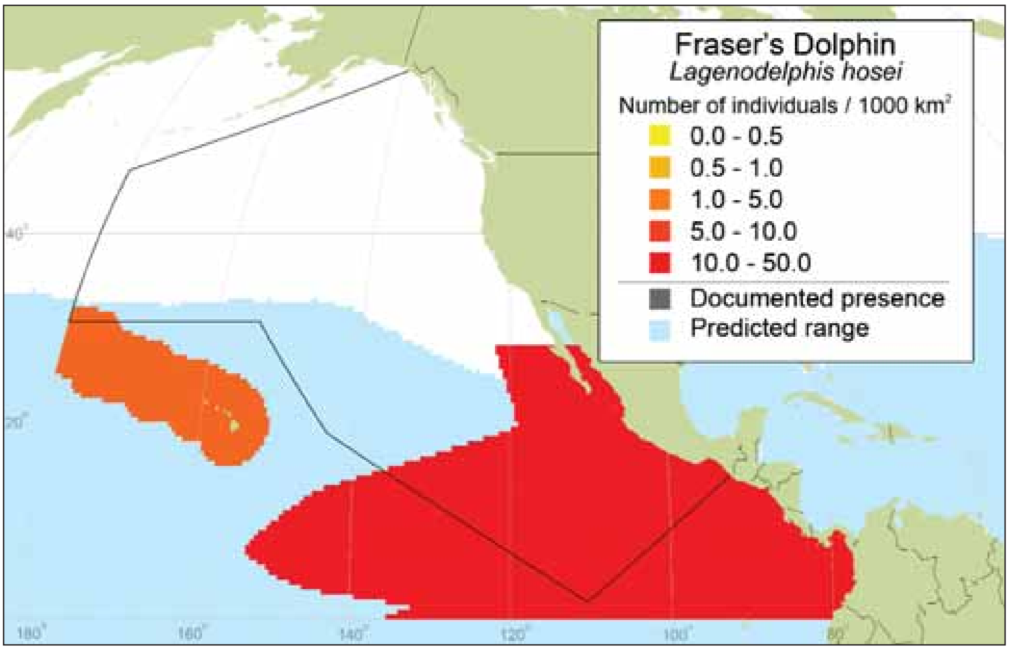


Figure 28. Fraser's dolphin (*Lagenodelphis hosei*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

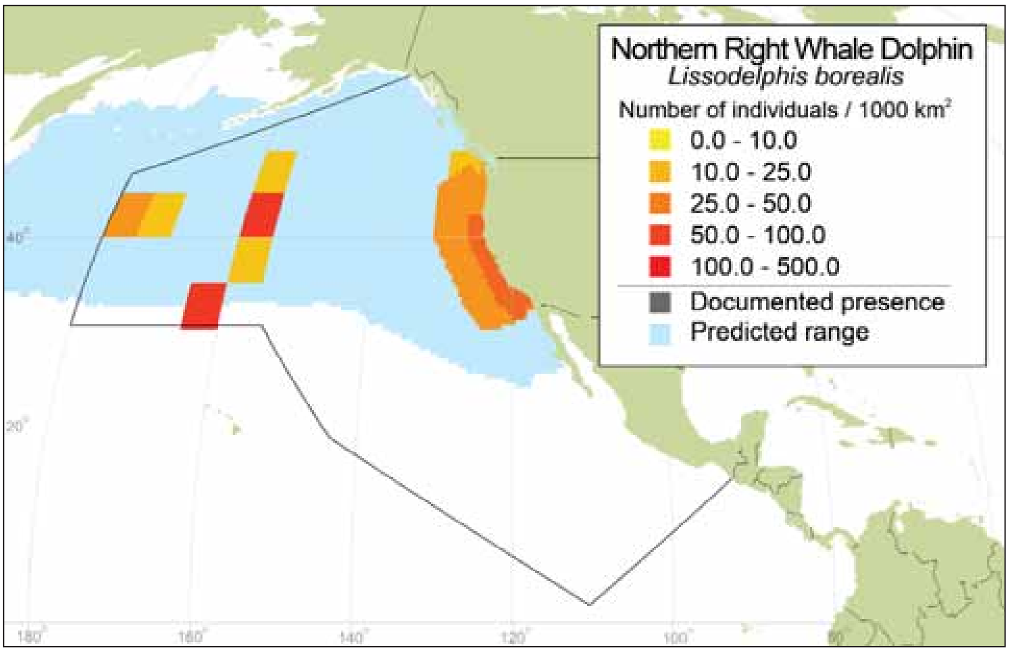


Figure 29. Northern right whale dolphin (*Lissodelphis borealis*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

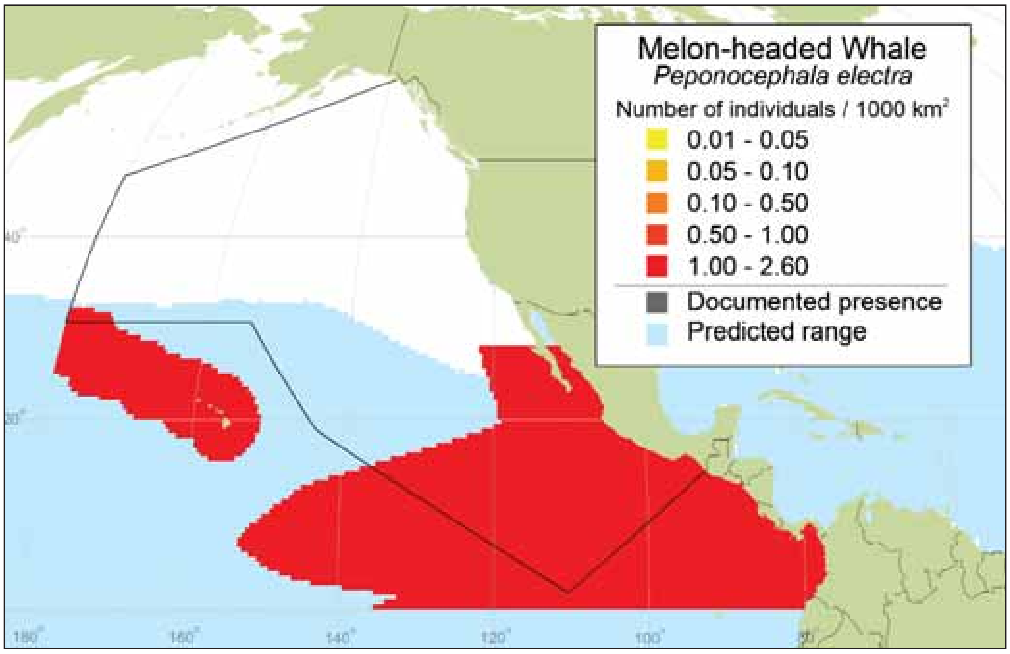


Figure 30. Melon-headed whale (*Peponocephala electra*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

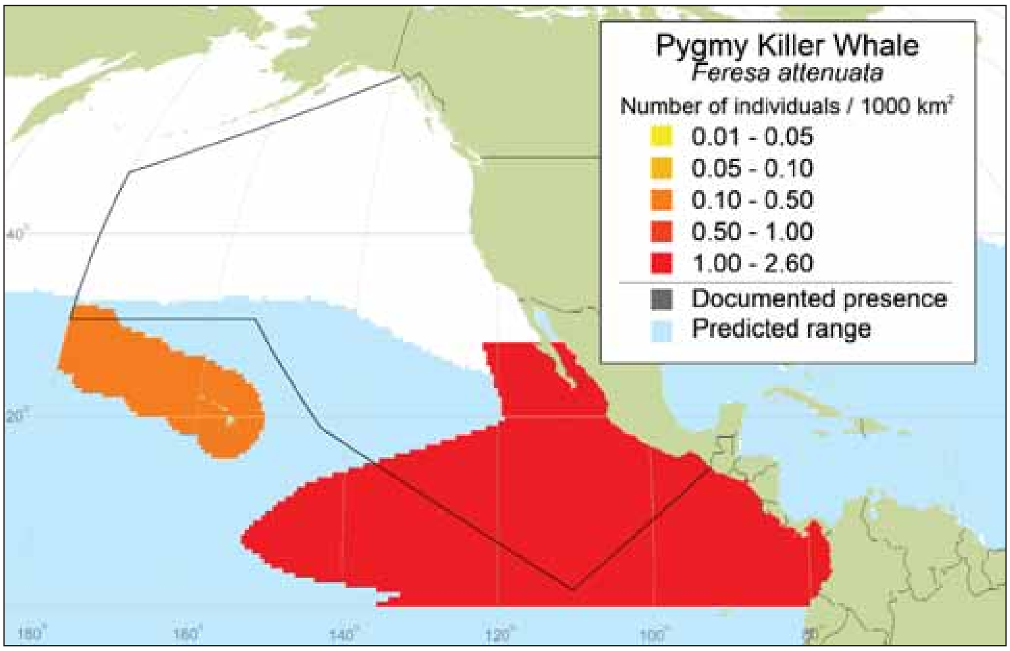


Figure 31. Pygmy killer whale (*Feresa attenuata*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

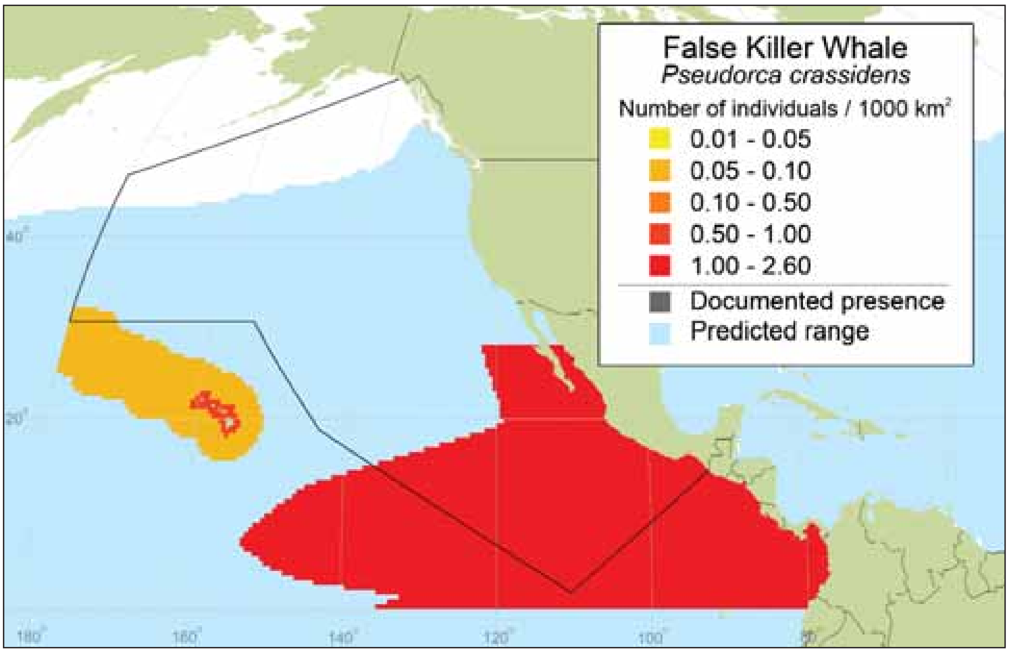


Figure 32. False killer whale (*Pseudorca crassidens*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

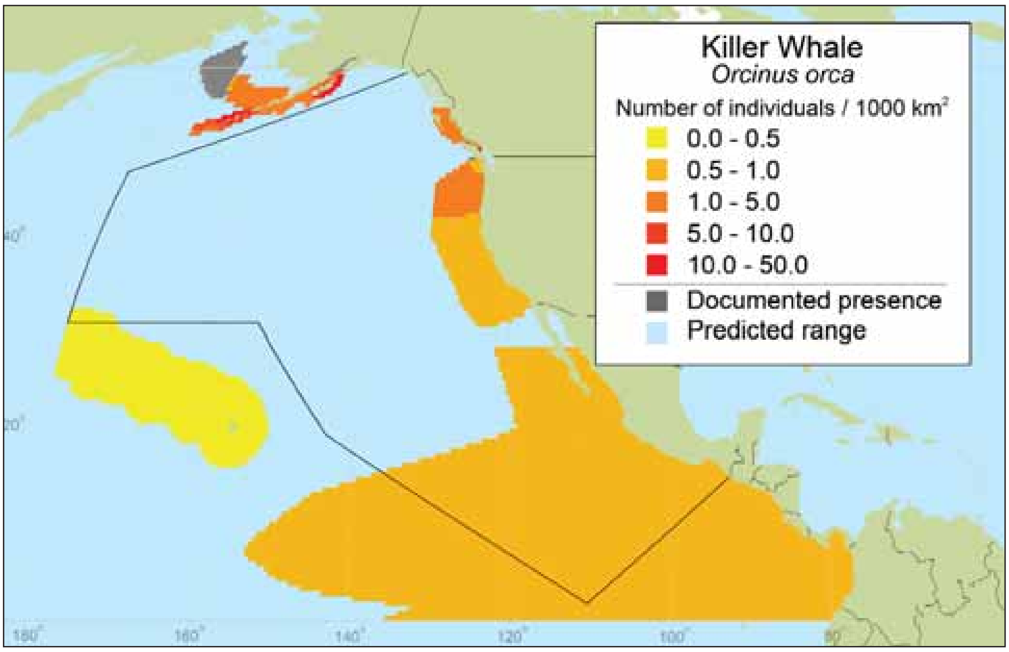


Figure 33. Killer whale (*Orcinus orca*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org). The map does not discriminate among killer whale populations or ecotypes because not all surveys report killer whale sightings and density to ecotype. As a density map, it only includes data from line-transect studies, which excludes the long-term photo-ID studies that are most commonly used to study killer whales in the northeastern Pacific (e.g., Ford et al. 2010; Matkin et al. 2008; Ward et al. 2009; Center for Whale Research, unpublished data; Fisheries and Oceans Canada, Cetacean Research Program, unpublished data).

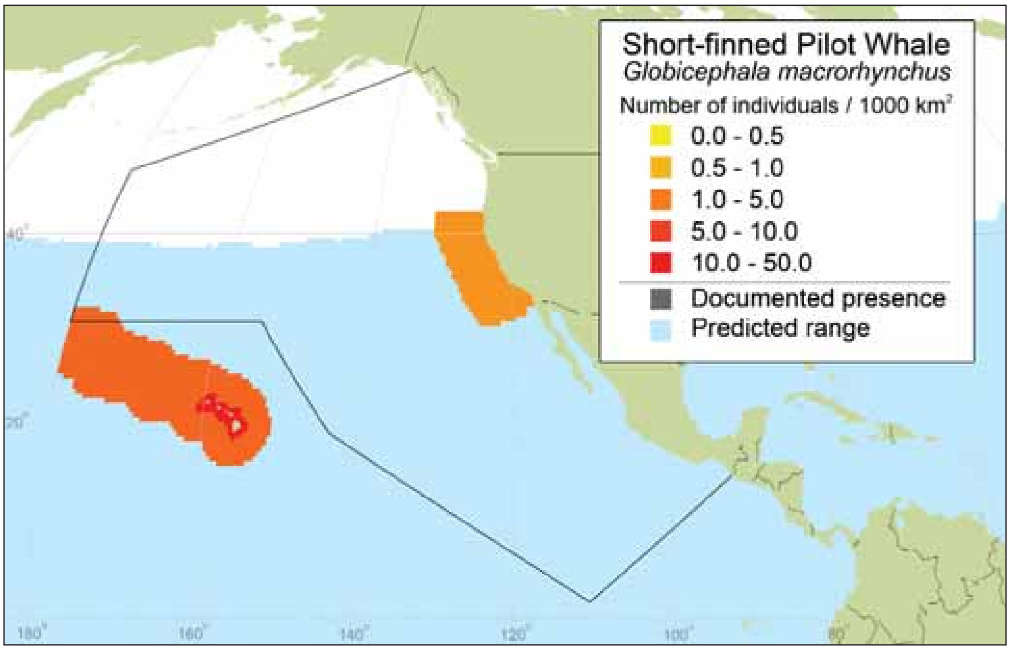


Figure 34. Short-finned pilot whale (*Globicephala macrorhynchus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

Family: Ziphiidae

Beaked whales are rarely seen, elusive, and often difficult to identify to species at sea. As a result, they are treated somewhat differently in our analyses. A paucity of data does not necessarily signify a low density of beaked whales. In addition to the maps presented here for the more common and/or easily identified species of beaked whales (e.g., Cuvier's, Longman's and Baird's), we include distribution data on some groupings (e.g., of *Mesoplodon* spp. or of beaked whales undifferentiated to species) to give a rough idea of overall ziphiid density and distribution, but again we stress that these combined estimates involve different species in different areas. Opportunistic sightings of beaked whales, obtained through OBIS (www.iobis.org), are shown as dots overlaid on the density surfaces.

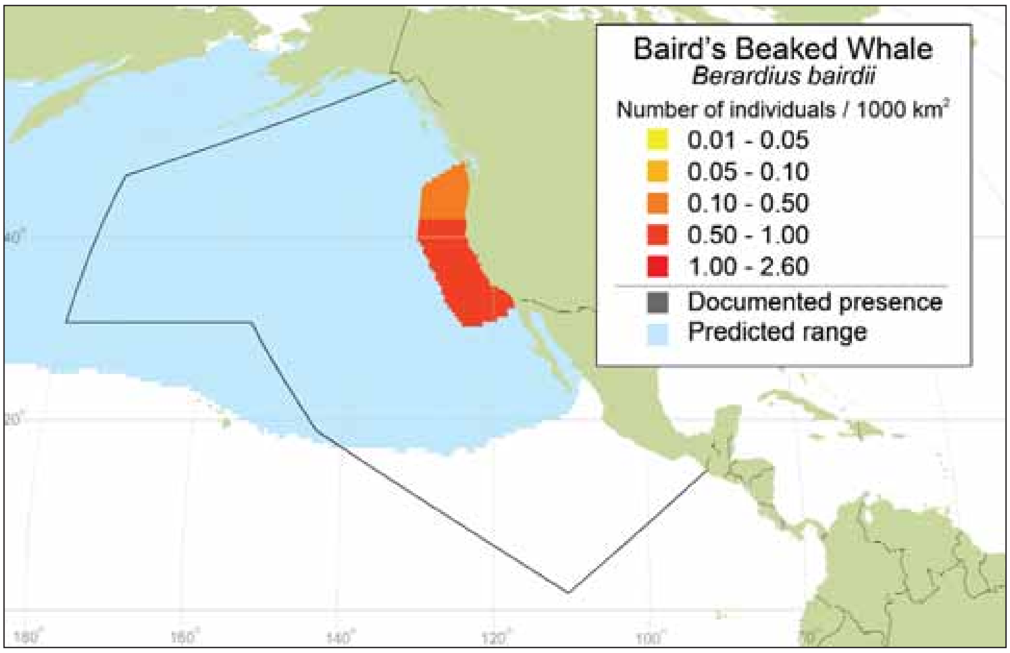


Figure 35. Baird's beaked whale (*Berardius bairdii*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

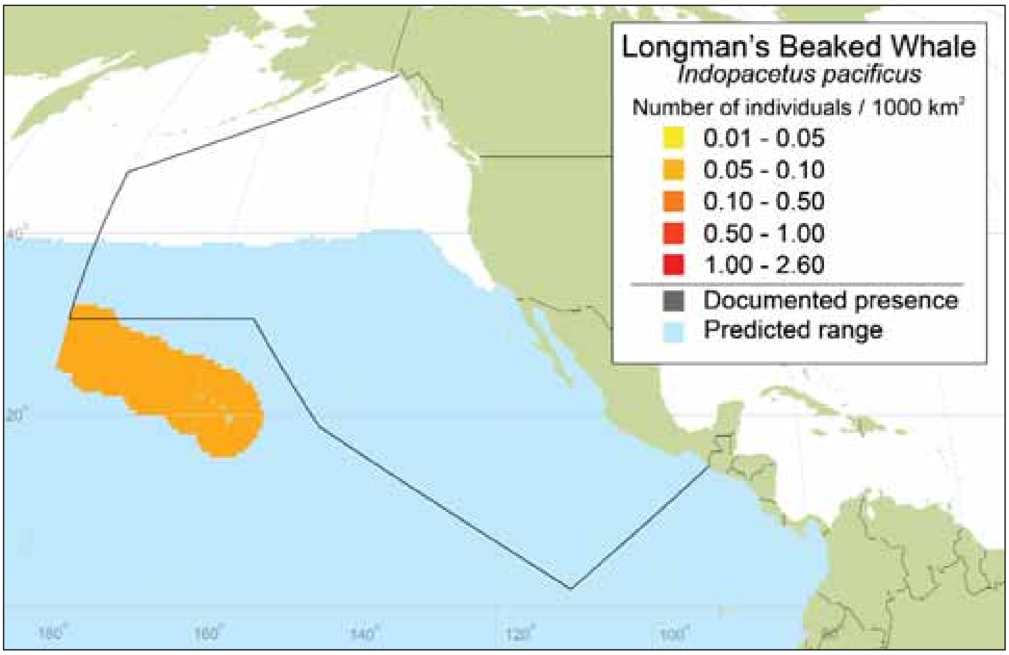


Figure 36. Longman's beaked whale (*Indopacetus pacificus*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

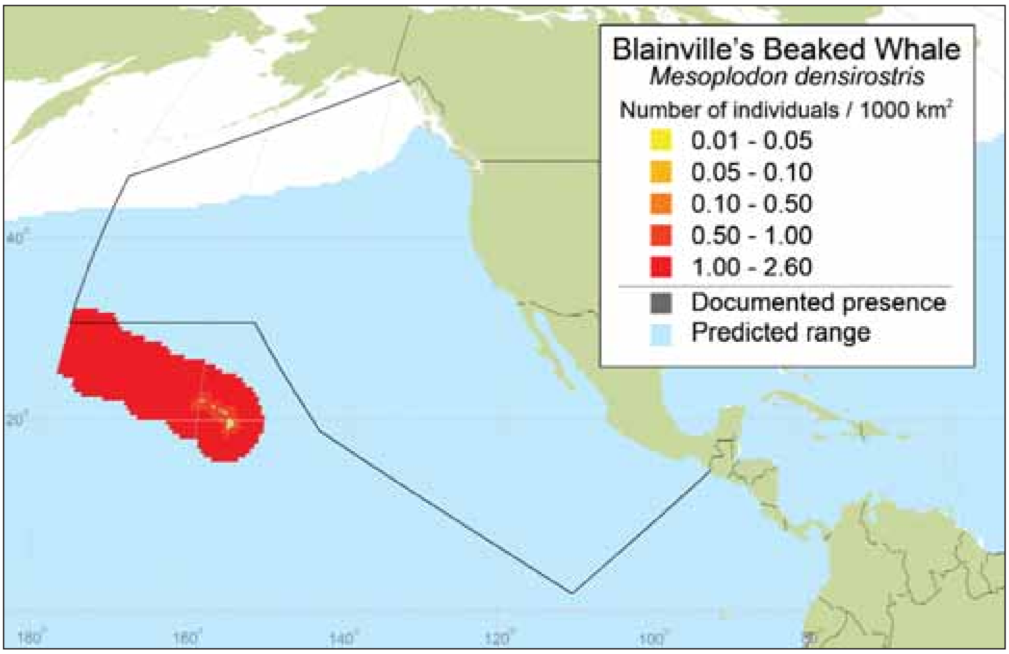


Figure 37. Blainville's beaked whale (*Mesoplodon densirostris*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

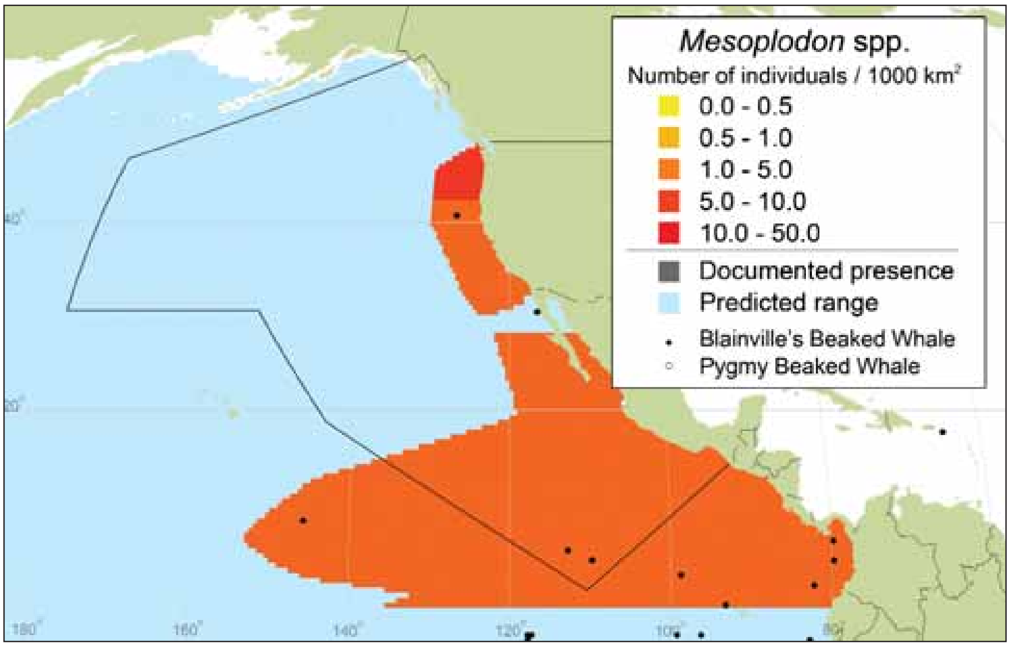


Figure 38. *Mesoplodon* spp. mean observed density (Kaschner et al., submitted) plus maximum range extent (Kaschner et al. 2006 and www.aquamaps.org) encompassing all *Mesoplodon* ranges, plus available *Mesoplodon* sightings from OBIS (mostly Blainville's beaked whales = black dots).

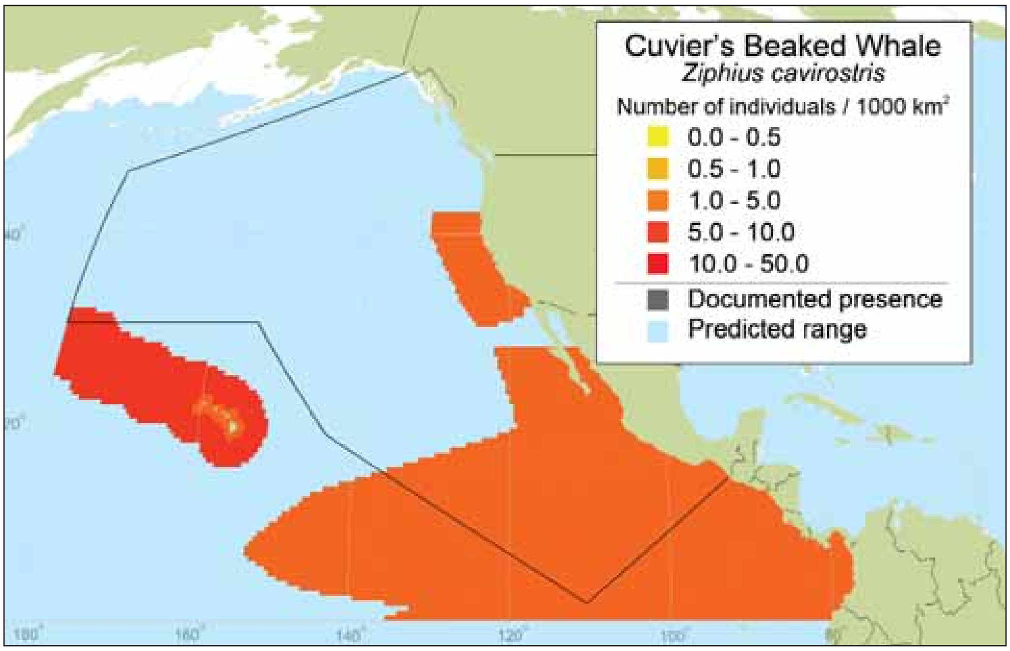


Figure 39. Cuvier's beaked whale (*Ziphius cavirostris*) mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org).

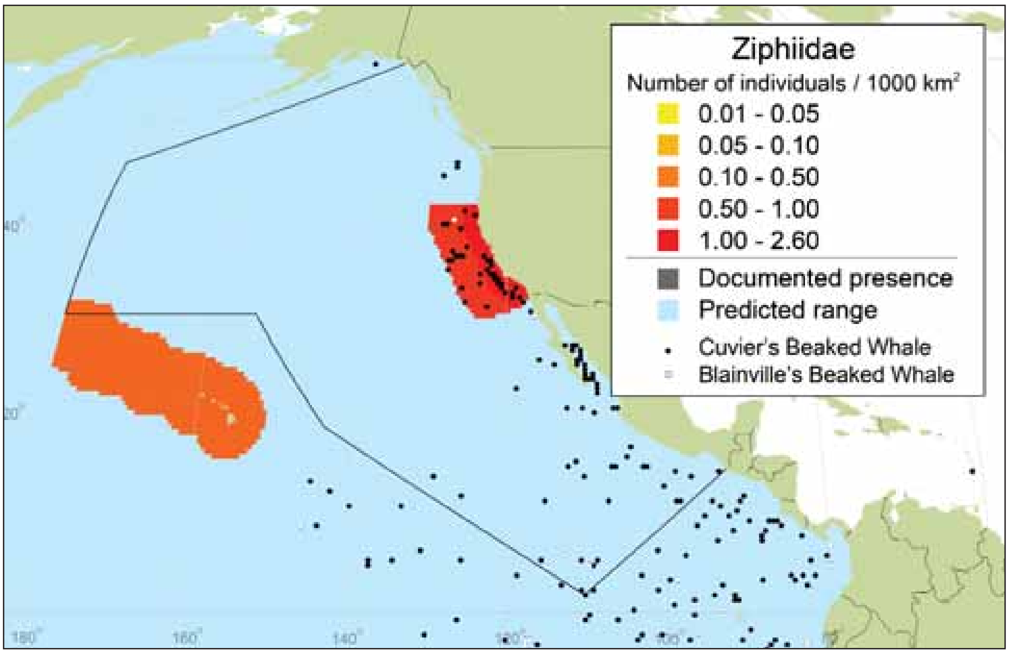


Figure 40. Ziphiid mean observed density (Kaschner et al., submitted) and predicted range (Kaschner et al. 2006 and www.aquamaps.org) plus available sightings from OBIS (black dots = *Ziphius cavirostris*; white dots = *Mesoplodon densirostris*).

DISCUSSION

Density estimates, biases and limitations

Considering the expanse of the study region and the proportion that is beyond the exclusive economic zone (EEZ) of any nation, there is surprisingly good spatial survey coverage for cetaceans in the North Pacific. However, this is a somewhat skewed impression because much of the coverage is represented by one survey (conducted over four years) by fisheries observers on non-randomized fisheries research cruises associated with high-seas salmon, squid, and tuna driftnet fisheries (Buckland et al. 1993). As a result, this one snapshot of the study area from the late 1980s has heavily influenced the impressions given in several of the species maps. The resulting abundance estimates are thought to be positively biased due to responsive movement (i.e., attraction to the survey vessel) of Pacific white-sided dolphins, Dall's porpoises and, to a lesser extent, northern right whale dolphins (Buckland et al. 1993). The direction and magnitude of the bias due to non-random sampling is unknown (Buckland et al. 1993), although newer spatial modelling methods could be used to address this (Hedley et al. 1999). Despite the shortcomings, the quantity and quality of survey data available for the North Pacific are comparatively good. In the global context, the North Pacific data set may be as informative as, or likely more informative than, the data sets from most other IUCN marine regions.

The most obvious result to emerge from this analysis is how much more information is available for the ETP than any other part of the study area (Figures 2-4). This spatially uneven coverage, which is largely a result of the dolphin bycatch (tuna-dolphin) controversy surrounding the economically important purse seine fishery for yellowfin tuna, means, coincidentally, that there is good survey coverage for areas of high species diversity. Depending on the conservation objectives specified in future planning stages, there is a risk that the ETP would be accorded a higher priority than otherwise justified simply because of its fortuitous combination of data richness and species diversity rather than because of its strategic value for cetacean conservation.

Other examples of heterogeneity in spatial coverage are reflected in the number of abundance estimates available for the various species. There are 63 abundance estimates covering a very large geographic area for the widely distributed Dall's porpoise (mostly from survey blocks covered during the 1987-1990 trans-Pacific surveys by Buckland et al. 1993; see Appendix 2). In contrast, the gray whale hardly appears on our maps, because its abundance has been studied primarily using shore-based censuses that do not allow the calculation of densities because the estimate cannot be tied to a specific survey area. Consequently, the gray whale maps are biased toward feeding areas and migratory corridors, and they fail to show this species' highly localized and well-known breeding grounds. Similarly, our maps of the North Pacific right whale are heavily influenced by one sighting of this rare species during an aerial survey conducted along the coast of California (Carretta et al. 1994; Forney et al. 1995). In contrast, the best recent information on its distribution in the eastern part of its range comes from satellite tagging and acoustic recording, which facilitated the discovery of a comparatively large feeding aggregation in the southeastern Bering Sea (Wade et al. 2006). Future efforts should focus on developing methodology that would allow a representative visualization of the different sources of information (acoustics, visual surveys, tagging, etc.) on a single map.

The maps presented here are necessarily coarse, and are intended to present big-picture patterns in known distribution, rather than fine-scaled seasonal or interannual variability (some of this is presented in Appendix 1). In general, it appears that for most species the interannual variation in density was smaller than the variation between different survey areas, indicating that "hotspots" (areas where high mean densities of animals have been reported) may indeed be areas where individuals of certain species are *consistently* present (and not just seasonally or in some years) in higher numbers than elsewhere within their known range.

The only species whose entire known range has been – relatively recently – surveyed is the vaquita. For other species with restricted ranges, such as the harbor porpoise, the survey coverage is reasonably good. Obviously, the more widely distributed the species, the greater the chance that there will be large gaps in survey coverage within its range. Species that are difficult to distinguish at sea (i.e., identify to the species level) are poorly represented, and their distribution and relative density can only be crudely inferred from the maps of species groupings, such as those for *Kogia*, *Stenella*, *Delphinus*, *Mesoplodon* and Ziphiidae. One purpose of these maps is to highlight areas and species that would benefit most from additional survey effort.

Spatial planning and MPA design

The following elements of the present task have now been completed successfully:

1. map distribution of existing survey effort;
2. map cetacean density, by species, in Marine Region 15;
3. map key important/critical habitat areas (although without defined targets, we can only include maps showing relative densities for each species and one map showing species diversity);
4. compile a database of references that link to the maps (Appendices 1, 2);
5. include a directory of area experts (Appendix 3); and
6. identify gaps in knowledge and a cost-effective strategy to address the gaps rapidly (budget, timeframe and details of additional research required) – more details to come in the following pages.

We view the density estimates less as output than as valuable input data to some future MPA planning process. As discussed earlier, management objectives need to be made explicit, and preferably should include quantitative targets to determine location, size and shape of the protected area following a defensible, accountable and transparent process (Lombard et al. 2007). The CBD, for example, considers an MPA to be an area designated, regulated or managed to achieve specific conservation objectives. More broadly, IUCN considers a protected area to be a "clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008).

The maps presented in this report do not identify proposed critical habitat areas or proposed MPA boundaries. Such proposals should emerge only after quantitative management and conservation objectives and targets have been specified and the mapping work has been subjected to expert review in light of those objectives and targets. The setting of objectives is inherently a separate task from the assessment of available data. In our experience, individual researchers are often most familiar with cetacean occurrence on a spatial scale of only a few of the grid cells in our maps; as a result, they may judge the accuracy or plausibility of the maps as a whole by how well the information conveyed fits with their expectations regarding density in just one or a few cells. It is important to anticipate this, and to disseminate the outputs of each phase of planning, particularly the conservation assessments (the raw cetacean density maps in this case), for review by a panel of experts at each stage. It is fundamental to the development of a systematic conservation plan to accept that the tasks along the way are both valuable *outputs* (i.e., they can be useful for outreach materials, focusing discussion, soliciting feedback, identifying data gaps) and *inputs* (i.e., they need to be the most accurate possible representation of available information, because they will feed into an algorithm for marine spatial planning).

It is therefore important that the outputs of each step be subject to peer review along the way to the ultimate MPA design. In our case, experts may not have mentioned opportunistic sightings of North Pacific right whales in our original consultations, but the maps we showed of density surfaces off California prompted one reviewer to mention additional sightings off Hawaii and Baja California. For a species that has only been seen a few times, every sighting affects the picture that emerges. We have acknowledged this for taxa such as beaked whales, which are difficult to discriminate at sea during line-transect surveys, by putting opportunistic sightings on our predicted distribution maps. Adding incidental sightings for other rarely seen species (e.g., North Pacific right whales, sei whales, Bryde's whales) as points on the density maps would be a logical next step. Ignoring such important, but hard-to-find information would alter the inputs that are fed into marine planning software at the next step. By the time the product reached the MPA proposal stage, this flaw in the input stage would have been buried and missed. Feedback is therefore not only about keeping a record of consultation. It is also about the scientific method – peer review of each stage of Systematic conservation planning can improve the quantity and quality of data that feed into subsequent stages, which will affect the final output.

As observed by Smith et al. (2009, p 191), "Draft maps can lead casual observers to doubt the value of the whole process … and can cause antagonism when seen by stakeholders who were not involved in developing them, especially if they appear to affect their livelihoods." Experience has taught us that an MPA is far more likely to be successful if the justification for its inputs, targets, boundaries and restrictions on human activities can be buttressed with a well-documented record of expert peer review, stakeholder consultation, and revision. Ideally, then, any announcement is less likely to be perceived as a fait accompli resulting from a process shrouded in mystery than as a logical outcome of a transparent, adaptive and inclusive process that explicitly builds iterative peer and stakeholder review into its processes.

We see enormous benefits to the use of decision-support software in the next phase of Systematic conservation planning. Marxan, a commonly used software (Ardron et al. 2010), and its new counterpart, Marzone or Marxan with Zones[3], can be used to generate, evaluate, and compare multiple MPA solutions. This is an important development, particularly with coarse data from a highly dynamic system, because it creates a philosophical shift away from the notion that there is one best solution. Instead, the aim becomes an array of good solutions that can be compared. Regardless of how this planning step is conducted, the algorithms do require data – neither piece of software can cope well with scenarios that fail to discriminate between zeroes (areas that have been surveyed but no animals of the target species were seen) and missing values (areas that have not been surveyed).

Marxan works with whatever data it is given in the form of input files, so "the algorithm will gravitate towards data-rich areas" if certain planning units have no data, either due to a real absence of that feature or because of a data gap (Lieberknecht et al., cited in Ardron et al. 2010). Those planning units may still be chosen by Marxan due to the presence of other features (e.g., certain sites in Hawaii may have information on humpback whale use such that they would be included in an MPA network, even though they have little information on the other cetacean species (e.g., false killer whales) that are found there and might also stand to benefit from an MPA).

Considerations for the next phase: use of decision-support software for marine spatial planning

The use of decision-support software does not solve all of the problems we have outlined. "Marxan will not tell you how to set conservation objectives, engage the appropriate stakeholders, or whether its input data are reliable" (Ardron et al. 2010). However, using decision-making support software would be a useful way to focus discussion in the next phase around such things as: setting explicit objectives regarding cetacean species (or diversity) to protect; specifying objectives with regard to threats; setting quantitative targets for types and quantities of animals and habitat (e.g., area, number of animals per unit area, total number of animals, prey); setting explicit targets for other valued features (e.g., bird areas, tourism access, quiet areas); evaluating socio-economic costs and benefits; and zoning and estimating zone-by-zone contributions to the various objectives or targets. This would provide a strong, objective visual tool for negotiation, MPA delineation, management and monitoring, and be scientifically defensible and transparent – all of which are key to the successful implementation of a protected areas strategy (Hoyt 2005).

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[3] http://www.uq.edu.au/marxan/index.html?p=1.1.1

The fact that the algorithms used in software programs for designing marine protected areas tend to gravitate towards data-rich areas, coupled with large gaps in spatial coverage in the region, convinces us that it is preferable to use derived values (e.g., estimate the probability of species presence, predict density) for all parts of the study area (i.e., including surveyed and unsurveyed areas) than to use spatially biased data (Grand et al. 2007). If future tasks involve setting conservation targets and objectives to be met by an MPA/MPA network solution, then the next step should be to derive values for cetaceans in areas that have not yet been surveyed. We see a few options for such a task (from the simplest approach to the most complex, which tends to be the most expensive):

a. use presence/absence data, which in this case would be approximated by the maximum range;

b. use a probability surface, such as the Kaschner et al. (2006) RES approach;

c. extrapolate species densities to unsurveyed areas throughout the study region using predicted habitat suitability and an investigation of the relationship between predicted local habitat suitability (such as RES values) in individual survey areas and corresponding observed values (reported density);

d. test that prediction with new field data (either visual surveys or passive acoustic monitoring, ideally of a randomly selected sample of sites).

A philosophically different approach would be to state explicitly that certain areas are data gaps (i.e., assign each cell a data versus no-data code) and then give Marxan targets for such gaps (i.e., tell Marxan that we want the MPA solution to include protection of a certain proportion of no-data cells). Features can be weighted for the amount of survey effort. For example, many areas of the North Pacific would have a weight of zero because no surveys have been conducted there. Ignoring this would inherently bias the MPA solution away from these unsurveyed areas. A variation on this theme would be to conduct task c above (i.e., derive a predicted density for each cell), and then set separate targets for empirical versus derived data. A more arbitrary solution would be simply to assign each no-data cell a small number, so that at least those cells would have non-zero probabilities of being sampled. This is not a preferred option.

Methodological development is required to provide density maps for species whose abundance is estimated in ways other than line-transect surveys. For example, in the case of the gray whale, one approach could be to “down-weight” the few sightings reported from line-transect surveys along the migration corridor, and agree on a way to quantify the obvious fact that densities are very high (seasonally) in the breeding lagoons. The annual gray whale censuses tell us that there are about 26,300 gray whales in the eastern North Pacific[4]. So, if we divided the rare sightings of gray whales from line-transect surveys by 26,300, the Marxan algorithms would “know” that these occasional sightings represented only trivial fractions of the overall population. If targets were set at some substantial fraction of the population, then Marxan would have to include sufficiently large numbers of cells to meet population-level objectives.

Killer whales, like many cetacean species, are studied primarily through photo-ID. This has generated exceptionally precise and accurate information about killer whale populations (Ford et al. 2010; Ward et al. 2009; Center for Whale Research, unpublished data), but makes it difficult to provide spatially explicit information in the same currency (i.e., density maps) that we have generated for species covered by line-transect surveys. New analytical methods are needed to make the best use of observations from dedicated photo-ID surveys, as well as sightings from whale watching boats. For species whose abundance is estimated through photo-ID, there are methods to generate density estimates from photographic encounter histories using spatially explicit capture-recapture analyses (e.g., Borchers and Efford 2008). We see great promise in the use of these analytical methods to allow the wealth of photo-ID data to be better incorporated into marine spatial planning processes that rely on density estimates.

One shortcut to incorporate abundance estimates from existing censuses or mark-recapture studies might be to take the reported abundance estimate and use a simple spatial model to “distribute” that many animals throughout a species’ range. This could be done in a subjective way, or according to some spatially explicit data on habitat use. Perhaps occupancy and area use have been estimated from tagging data, acoustic recordings, presence/absence data or photo-ID records, and these could be converted to density such that the predicted density surface sums to the total (known) abundance. Again, this would require substantial methodological development.

Given the highly technical challenges to using existing, patchy datasets and existing spatial planning software, we propose that a session be included in the agenda for the 2nd International

4 http://www.iwcoffice.org/conservation/estimate.htm

Conference on Marine Mammal Protected Areas to promote dialogue between Marxan users and scientists with expertise in estimating abundance and distribution of cetaceans from spatial models. We flag this technical issue here to note that: (a) reducing the maps to the common currency of animal density excludes some excellent, long-term studies; and (b) methodological developments are required to incorporate data from studies that use methods other than line-transect surveys. One approach may be to incorporate a large component of expert knowledge and advice, although this raises additional technical issues about combining quantitative and qualitative data, and dealing with biases toward known coastal areas (e.g., few people possess first-hand knowledge on the abundance and distribution of cetaceans in the middle of the North Pacific).

Analytical versus field methods to fill data gaps

The best analytical solution for filling gaps is to build statistically robust models capable of predicting density in unsurveyed regions. Filling the gaps is beyond the scope of this report, but methods are available for doing so (e.g., Whitehead 2002). Using an approach similar to Whitehead's, preliminary global density estimates of 46 marine mammal species have been generated by Kaschner and collaborators at CREEM and SMRU, University of St Andrews as part of the Environmental Risk Mitigation Capability (Sonar) project (2005-2007) (Mollet et al. 2009). By comparing reported densities with existing large-scale predictions of species occurrence and habitat suitability in different survey areas as generated by the RES model (Kaschner et al. 2006) a species-specific relationship between predicted habitat suitability and observed densities using regression analysis was derived. Using the derived coefficients from spatially and temporally nested models, densities were then extrapolated beyond survey area boundaries, thus providing species-specific density estimates for unsurveyed areas. We prefer this method that would derive model-based predictions of density throughout the study area over one that would attempt to analyze such patchy data as though it represented truth. At the very least, the first option should give a powerful means of making interim guesses about how much difference it would make to critical habitat predictions or MPA network designs if data from currently unsurveyed areas were to become available. Like all model predictions, ground-truthing with new data is an essential component.

The best approach for filling data gaps is, of course, simply to collect new data, and that is what we strongly recommend. Ideally, systematic and frequent sightings surveys would be conducted in the gap areas. This is a costly and relatively long-term option. One solution would be to randomly or systematically select a subset of the unsurveyed areas, and measure cetacean density in this subset (e.g., see an application for randomly sampling fjord systems in British Columbia, Canada; Thomas et al. 2007). Although in recent years a number of published papers have offered advice on how to generate robust abundance estimates for cetaceans from low-cost survey platforms (Dawson et al. 2007; Williams and Thomas 2007, 2009), these will be of little use for filling data gaps in the vast, inhospitable unsurveyed parts of the North Pacific or the larger world ocean, 64 per cent of which is on the high seas. Spatial modelling can be used to estimate cetacean abundance from line-transect survey data collected from non-random surveys such as those conducted from platforms of opportunity (Williams et al. 2006). We suggest that it is worthwhile re-analyzing the data from Buckland et al. (1993) using newer methods, but note that there is little chance of piggybacking new cetacean surveys on high-seas fisheries observer programmes due to the success of the UN ban on high-seas driftnetting. Putting observers on container ships crossing the Pacific is perhaps the most logistically feasible way of achieving trans-oceanic coverage, but may not give sufficiently broad latitudinal coverage to justify the trouble and expense. Marques et al. (2009) offer an intriguing method to estimate cetacean density from passive acoustic monitoring, but the equipment is expensive, and it is conceivable that deploying hydrophones along a grid, retrieving them some time later, and analysing the resulting data would end up costing just as much if not more than a systematic sightings survey. Moreover, passive acoustic monitoring only applies to animals when they are vocal. This may rule out some baleen whales outside of the breeding season, or killer whales that use passive listening to detect prey. Many of the data gaps are in the temperate high seas, where solitary and silent baleen whales might not be detected through passive acoustic monitoring. Whatever detections were made would of course be valuable (especially if passive acoustic monitoring were combined with ambient noise measurement; see below), but an absence of acoustic detections could not reliably tell us that cetaceans were absent from that area. Perhaps the most likely means by which a large-scale cetacean sightings survey across the North Pacific would be accomplished in the next few years is through the Government of Japan, motivated by the need for IWC assessment-related data. Until results from such surveys become available, we recommend that efforts be undertaken to derive model-based predictions of cetacean density in unsurveyed areas, and to assess the sensitivity of various planning designs to data gaps, as described above.

Dynamic versus static environment

Our static maps and tables offer few hints concerning the dynamic nature of cetacean movements and habitat use. There is evidence to suggest that mobile or dynamic MPAs may become useful tools for protecting time- and space-varying features of marine ecosystems and marine biodiversity (Hyrenbach et al. 2007; Hooker et al. 2011), although this is not without controversy. Conceptually, it would be desirable if marine spatial planning tools could respond to changes in cetacean distribution over time (Wilson et al. 2004). This is appealing not only because of the variability in density estimates in surveyed areas (see Appendix 2) within and between years due to changing prey distribution and other environmental conditions (Forney et al. 2000), but also because it would offer flexibility for responding to climate change over longer timescales (see e.g. Kaschner et al. 2011). Management plans that explicitly allow for responses to changing environmental conditions, threats and management needs through zoning are much desired. Hoyt (2005, pp 25-28), among others, describes a biosphere reserve-type approach with a large precautionary outer zone and flexible, highly protected core zones that can be moved from year to year or even within years as animals adopt new feeding or socializing areas.

Threats

All of the concerns that we have raised about the use of spatially biased data on cetacean distribution and density apply equally to the use of patchy data on the anthropogenic threats that cetaceans face. The tendency for algorithms (Marxan) and the human eye to gravitate toward data-rich areas means that the threat data incorporated into analyses need to be spatially explicit and available for all parts of the study area. Such a rigorous filter eliminates most information on threats, because the data for many of them (e.g., oil spills, naval sonar, seismic surveys) either do not exist in spatial form or vary considerably in quality from place to place.

One approach to dealing with this problem would be to choose an already-existing, spatially explicit, global human-use data layer and trust that it will serve as a reasonable proxy for exposure to human activities (i.e., threats). Such a map[5] of global patterns in cumulative human-use impacts (reproduced in Figure 41) has been modelled as part of a Global Map of Human Impacts to Marine Ecosystems[6], which gives a big-picture overview (Halpern et al. 2008). This layer could easily be overlaid on the distribution maps for each species, thereby creating a "risk" layer in the way that regional assessments have been conducted to identify areas of elevated ship strike risk to whales (Williams and O'Hara 2010). Shipping intensity serves as a good proxy for some human activities because of the risks ships pose to cetaceans in terms of direct mortality and injury from collisions, disturbance from chronic noise (including hearing loss, masking, etc.), and contamination from oil spills (Williams et al. 2009). Obviously, good information on fishing effort is needed to understand global patterns in cetacean bycatch, but unbiased, credible fisheries data are notoriously difficult to find at all, and particularly so in a spatially explicit format (Watson et al. 2004). Fisheries location data are considered commercially valuable and proprietary and are sometimes unavailable even from regulatory agencies responsible for fisheries management within EEZs. Other complicating factors include (1) the need to stratify fishing data according to gear used, target species, bycatch mitigation measures (however rare), among other things; (2) the fact that many fisheries are dynamic, which means effort is rarely constant over time; and (3) the fact that in some jurisdictions where cetacean conservation problems are probably most acute (e.g., southern Asia, western and eastern Africa, Latin America), effort data are unreliable and incomplete. Halpern's cumulative impact index incorporates the available information on shipping and fisheries as well as on oil exploration and extraction, pollution, and invasive species. We would encourage the use of such a proxy variable that can be applied on a global scale over the use of patchily available measures of direct impacts. Efforts are also currently under way to create more detailed threat layers in specific marine regions which may provide more localized proxies for threats. In the California Current system, it was shown that the local and global values of cumulative impacts were strongly correlated, so the global proxy value could be used in cases where fine-scale data on threats are lacking (Halpern et al. 2009).

We are particularly interested in the potential for MPAs to serve as a spatio-temporal tool to mitigate impacts of noise on cetaceans (Agardy et al. 2007). In other fora, it has been agreed that there is an urgent need for a global ocean ambient noise budget to address issues surrounding military sonar, seismic surveys, alternative energy development and noise from global shipping activities. We see an opportunity for mutual benefit if efforts to produce such a global noise budget were linked to marine spatial planning generally, such that information on marine mammal presence could be extracted inexpensively from equipment designed to

[5] http://knb.ecoinformatics.org/GlobalMarine/images/model/model_high_res.jpg
[6] http://www.nceas.ucsb.edu/globalmarine

measure anthropogenic noise levels. In an ideal world, hydrophones could be deployed in a systematic sample of locations, densities of cetacean species in that region could be predicted, and acoustic detections could be used to test the predictions. A global network of noise monitors would make it possible to generate a crucial human-use layer (noise), while simultaneously providing additional information on distribution and density of cetaceans that are vocal.

Of course, it is in the nature of scientific endeavour that data collection can never be considered complete. That said, the lack of data is no excuse for perpetual inaction. This report has identified some large areas where there is a lot of data and others where more work is needed. We have offered suggestions about ways to incorporate the patchy data available into marine conservation planning through processes that are robust to the difficulties of studying a dynamic, vast, complex ecosystem using the relatively crude observation tools available. We hope that this paper will be a useful starting point, but recognize that much work remains.

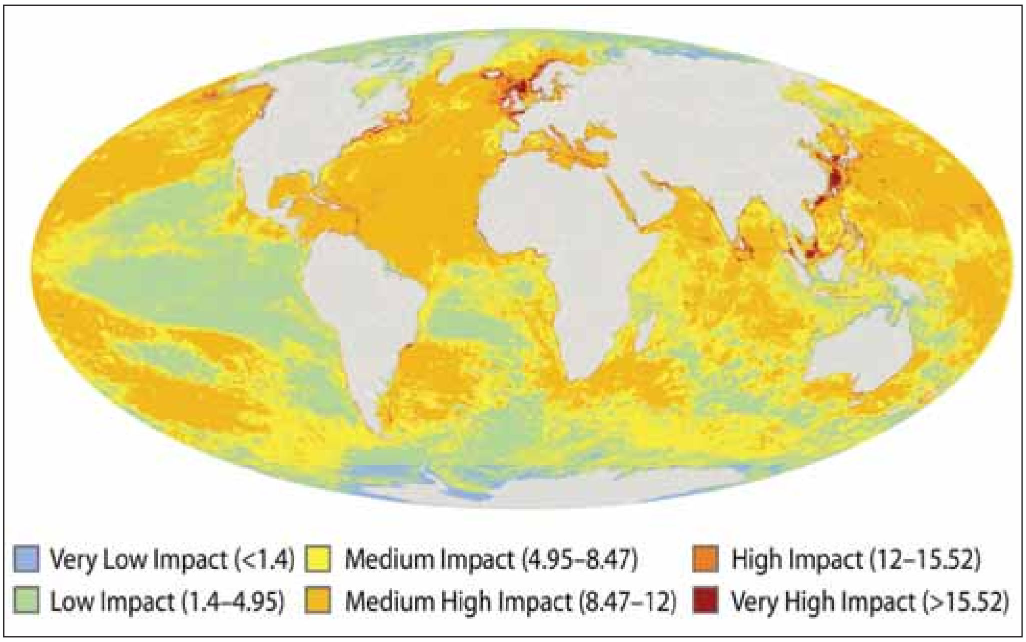

Figure 41. Global map of modelled human impacts on marine ecosystems, from the Halpern et al. (2008) project at the National Center for Ecological Analysis and Synthesis.

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REFERENCES

Papers that report density estimates used for the mapping

Barlow, J. 2003a. Cetacean abundance in Hawaiian waters during summer/fall 2002. La Jolla, CA, USA, Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA). Admin. Rept. LJ-03-13, 20pp.

Barlow, J. 2003b. Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991-2001. In. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, CA, USA, 31pp.

Barlow, J. and Taylor, B.L. 2005. Estimates of sperm whale abundance in the northeastern temperate Pacific from a combined acoustic and visual survey. *Marine Mammal Science* 21:429-445.

Buckland, S.T., Cattanach, K.L. and Hobbs, R.C. 1993. Abundance estimates of Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise and northern fur seal in the North Pacific, 1987-1990. *International North Pacific Fisheries Commission Bulletin* 387-407.

Calambokidis, J. and Barlow, J. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. *Marine Mammal Science* 20:63-85.

Calambokidis, J., Steiger, G.H., Ellifrit, D.K., Troutman, B.L. and Bowlby, C.E. 2004. Distribution and abundance of humpback whale (*Megaptera novaeangliae*) and other marine mammals off the northern Washington coast. *Fishery Bulletin* 102:563–580.

Carretta, J.V. 2003. Preliminary estimates of harbor porpoise abundance in California from 1997 and 1999 aerial surveys. In. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California.

Carretta, J.V., Lynn, M.S. and LeDuc, C.A. 1994. Right whale (*Eubalaena glacialis*) sighting off San Clemente Island, California. *Marine Mammal Science* 10:101–105.

Carretta, J.V. and Forney, K.A. 2004. Preliminary estimates of harbor porpoise abundance in California from 1999 and 2002 aerial surveys. In. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California.

Carretta, J.V., Forney, K.A., Muto, M.M., Barlow, J., Baker, J. and Lowry, M. 2003. U.S. Pacific Marine Mammal Stock Assessments - 2003. U.S. Department of Commerce, 291pp.

Carretta, J.V., Taylor, B.L. and Chivers, S.J. 2001. Abundance and depth distribution of harbor porpoise (*Phocoena phocoena*) in northern California determined from a 1995 ship survey. *Fishery Bulletin* 99:29-39

Dudley, N. (ed.) 2008. Guidelines for Applying Protected Area Management Categories. Gland, Switzerland: IUCN. x + 86pp.

Forney, K.A. 1999. The abundance of California harbor porpoise estimated from 1993–97 aerial line-transect surveys. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California.

Forney, K.A. and Barlow, J. 1993. Preliminary winter abundance estimates for cetaceans along the California coast based on a 1991 aerial survey. *Reports of the International Whaling Commission*:407-415.

Forney, K.A., Barlow, J. and Carretta, J.V. 1995. The abundance of cetaceans in California waters: Part II. Aerial surveys in winter and spring of 1991 and 1992. *US National Marine Fisheries Service Fishery Bulletin* 93:15-26.

Forney, K.A., Barlow, J., Muto M.M., Lowry, M., Baker, J., Cameron, G., Mobley, J., Stinchcomb, C. and Carretta, J.V. 2000. U.S. Pacific Marine Mammal Stock Assessments - 2000. NOAA-TM-NMFS-SWFSC-300, U.S. Department of Commerce, NOAA, NMFS, Southwest Fisheries Science Center, 276pp.

Gerrodette, T. 1999. Preliminary estimates of 1998 abundance of four dolphin stocks in the eastern tropical Pacific. In: Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California, 20pp.

Gerrodette, T. 2000. Preliminary estimates of 1999 abundance of four dolphin stocks in the eastern tropical Pacific. In: Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service, (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California, 22pp.

Gerrodette, T. and Forcada, J. 2002. Estimates of abundance of northeastern offshore spotted, coastal spotted, and eastern spinner dolphins in the eastern tropical Pacific ocean. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, CA, USA, 41pp

Gerrodette, T. and Forcada, J 2002. Estimates of abundance of western/southern spotted, whitebelly spinner, striped and common dolphins, and pilot, sperm and Bryde's whales in the Eastern Tropical Pacific Ocean. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California, 24pp.

Gerrodette, T., Watters, G. and Forcada, J. 2005. Preliminary estimates of 2003 dolphin abundance in the Eastern Tropical Pacific. Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), La Jolla, California, 28pp.

Hobbs, R.C., Rugh, D.J. and DeMaster, D.P. 2000. Abundance of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994-2000. *Marine Fisheries Review* 62:37-45.

Lowry, F.L., DeMaster, D.P., Frost, K.J. and Perryman, W. 1999. Alaska beluga whale committee surveys of beluga whales in the eastern Chukchi Sea, 1992-1995. (SC/51/SM34). International Whaling Commission Scientific Committee Meeting (unpublished), Grenada, 20pp.

Moore, S.E., Waite, J.M., Friday, N.A. and Honkalehto, T. 2002. Cetacean distribution and relative abundance on the central-eastern and the southeastern Bering Sea shelf with reference to oceanographic domains. *Progress in Oceanography* 55:249-261.

Moore, S.E., Waite, J.M., Mazzuca, L.L. and Hobbs, R.C. 2000. Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf. *Journal of Cetacean Research and Management* 2:227-234.

Rugh, D.J., Shelden, K.E.W., Sims, C.L., Mahoney, B.A., Smith, B.K., Litzky, L.K. and Hobbs, R.C. 2005. Aerial surveys of belugas in Cook Inlet, Alaska, June 2001, 2002, 2003, and 2004. NOAA Tech Memo. NMFS-AFSC-149. 71pp.

Wade, P.R. and Gerrodette, T. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. *Reports of the International Whaling Commission* 43:477-493.

Waite, J.M., Friday, N.A., Moore, S.E. 2002. Killer whale (*Orcinus orca*) distribution and abundance in the central and southeastern Bering Sea, July 1999 and June 2000. *Marine Mammal Science* 18:779-786.

Whitehead, H.P. 2002. Estimates of the current global population size and historical trajectory for sperm whales. *Marine Ecology Progress Series* 242:295-304.

Williams, R. and Thomas, L. 2007. Distribution and abundance of marine mammals in the coastal waters of British Columbia, Canada. *Journal of Cetacean Research and Management* 9:15-28.

Willis, P.M. and Baird, R.W. 1998. Status of the dwarf sperm whale, *Kogia simus*, with special reference to Canada. Canadian Field Naturalist 112:114-125.

Zerbini, A.N., Waite, J.M., Durban, J.W., LeDuc, R.G., Dahlheim, M.E., Wade, P.R. (2006) Estimating abundance of killer whales in the nearshore waters of the Gulf of Alaska and Aleutian Islands using line-transect sampling. *Marine Biology* 150:1033-1045.

Additional publications cited in the text

Agardy T., Bridgewater, P., Crosby, M.P., Day, J., Dayton, P.K., Kenchington, R., Laffoley, D., McConney, P., Murray, P.A., Parks, J.E. and Peau, L. 2003. Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems* 13:353–367.

Agardy, T., Aguilar, N., Cañadas, A., Engel, M., Frantzis, A., Hatch, L., Hoyt, E., Kaschner, K., LaBrecque, E., Martin, V., Notarbartolo di Sciara, G., Pavan, G., Servidio, A., Smith, B., Wang, J., Weilgart, L., Wintle, B. and Wright, A. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44pp. [Available from: http://www.okeanos-stiftung.org/ okeanos/sound.php?id=41]

Ardron, J.A., Possingham, H.P. and Klein, C.J. (eds.) 2010. Marxan Good Practices Handbook. Version 2. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada, 165pp.

Ashe, E., Noren, D.P. and Williams, R. 2010. Animal behaviour and marine protected areas: incorporating behavioural data into the selection of marine protected areas for an endangered killer whale population. *Animal Conservation* 13:196-203.

Borchers, D.L. and Efford, M.G. 2008. Spatially explicit maximum likelihood methods for capture–recapture studies. *Biometrics* 64: 377–385.

Cerchio, S. 1998. Estimates of humpback whale abundance off Kauai, 1989 to 1993: Evaluating biases associated with sampling the Hawaiian Islands breeding assemblage. *Marine Ecology Progress Series* 175:23-34

Dawson, S. M. 1991. Incidental catch of Hector's dolphin in inshore gillnets. *Marine Mammal Science* 7:283–295.

Dawson, S.M., Wade, P., Slooten, E. and Barlow, J. 2008. Design and field methods for sighting surveys of cetaceans in coastal and riverine habitats. *Mammal Review* 38: 19-49.

Ford, J.K.B., Ellis, G.M., Olesiuk, P.F. and Balcomb, K.C. 2010. Linking killer whale survival and prey abundance: Food limitation in the oceans' apex predator? *Biology Letters* 6:139-142.

Forney, K. 2000. Environmental models of cetacean abundance: reducing uncertainty in population trends. *Conservation Biology* 14:1271-1286.

Grand, J., Cummings, M.P., Rebelo, T.G., Ricketts, T.H. and Neel, M.C. 2007. Biased data reduce efficiency and effectiveness of conservation reserve networks. *Ecology Letters* 10:364-374.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R. and R. Watson. 2008. A global map of human impact on marine ecosystems. *Science* 319:948-952.

Halpern, B.S., Kappel, C.V., Selkoe, K.A., Micheli, F., Ebert, C.M., Kontgis, C., Crain, C.M., Martone, R.G., Shearer, C. and Teck, S.J. 2009. Mapping cumulative human impacts to California Current marine ecosystems. *Conservation Letters* 2:138–148.

Hooker, S. and Gerber, L.R. 2004. Potential importance of megafauna: marine reserves as a tool for ecosystem-based management? *BioScience* 54(1):29-41

Hooker, S.K., Cañadas, A., Hyrenbach, K.D., Corrigan, C., Polovina, J.J. and Reeves, R.R. 2011. Making protected area networks effective for marine top predators. *Endangered Species Research* 13:203-218.

Hoyt, E. 2005. *Marine Protected Areas for Whales, Dolphins and Porpoises: A World Handbook for Cetacean Habitat Conservation.* Earthscan, London. 516pp.

Hyrenbach, D., Worm, B., Fonteneau, A. and Gilman, E. 2007. Using marine reserves to protect highly migratory species: scientists discuss potential strategies, including mobile MPAs. *MPA News*, International News and Analysis on Marine Protected Areas, 8 (8). Mar.

Kaschner, K. 2004. Modelling and mapping resource overlap between marine mammals and fisheries on a global scale. Ph.D. thesis, Department of Zoology, University of British Columbia, Vancouver, Canada, 225pp.

Kaschner, K. 2007. Air-breathing visitors to seamounts. Section A: Marine mammals. In: T. Pitcher, T.J. Morato, P.J.B. Hart, M.R. Clark, N. Haggan and R.S. Santos (eds.), *Seamounts: Ecology, Fisheries & Conservation*. Blackwell, Oxford. pp230-238.

Kaschner, K., Watson, R., Trites, A.W. and Pauly, D. 2006. Ma pping worldwide distributions of marine mammals using a Relative Environmental Suitability (RES) model. *Marine Ecology Progress* Series 316:285-310.

Kaschner, K., Ready, J.S., Agbayani, E., Rius, J., Kesner-Reyes, K., Eastwood, P.D., South, A.B., Kullander, S.O., Rees, T., Close, C.H., Watson, R., Pauly, D. and Froese, R. 2008. AquaMaps: Predicted range maps for aquatic species. World wide web electronic publication, www.aquamaps.org, Version 10/2008.

Kaschner, K., Tittensor, D.P., Ready, J., Gerrodette, T. and Worm, B. 2011. Current and future patterns of global marine mammal biodiversity. PLoS ONE 6(5): e19653. doi:10.1371/journal.pone.0019653

Kaschner, K., Quick, N.J, Jewell, R., Williams, R. and Harris, C.M. (submitted). How much do we actually know: Global coverage of cetacean line-transect surveys. *Marine Ecology Progress Series*.

Klein, C.J., Steinback, C., Scholz, A.J. and Possingham, H.P. 2008. Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: a comparison of two approaches used in California. *Conservation Letters* 1:44–51.

Lombard, A.T., Reyers, B., Schonegevel, L.Y., Cooper, J., Smith-Adao, L.B., Nel, D.C., Froneman, P.W., Ansorge, I.J., Bester, M.N., Tosh, C.A., Strauss, T., Akkers, T., Gon, O., Leslie, R.W. and Chown, S.L. 2007. Conserving pattern and process in the Southern Ocean: designing a Marine Protected Area for the Prince Edward Islands. *Antarctic Science* 19:39-54.

Lotze, H.K. and Worm, B. 2009. Historical baselines for large marine animals. *Trends in Ecology and Evolution* 24:254-262.

Lusseau, D. and Higham, J.E.S. 2004. Managing the impacts of dolphin-based tourism through the definition of critical habitats: the case of bottlenose dolphins (*Tursiops* spp.) in Doubtful Sound, New Zealand. *Tourism Management* 25:657-667.

Lynch, T.P. 2008. The difference between spatial and temporal variation in recreational fisheries for planning of marine protected areas: response to Steffe. *Conservation Biology* 22:486–491.

Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. *Nature* (London) 405:243–253.

Marques, T.A., Thomas, L., Ward, J., DiMarzio, N. and Tyack, P.L. 2009. Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. *Journal of the Acoustical Society of America* 125:1982-1994.

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P. and Rice, S.D. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series* 356:269-281.

Mobley, Jr., J.R., Spitz, S.S., Grotefendt, R, Forestell, P.H., Frankel, A.S. and Bauer, G.A. 2001. Abundance of humpback whales in Hawaiian waters: Results of 1993-2000 aerial surveys. Report prepared for the Hawaiian Islands Humpback Whale National Marine Sanctuary, Nov. 26, 2001.

Mollett, A., Schofield, C., Miller, I., Harwood, J., Harris, C.M., Donovan, C.R. 2009. Environmental Risk Management Capability: Advice on minimising the impact of both sonar and seismic offshore operations on marine mammals Offshore Europe, 8-11 September 2009. Society of Petroleum Engineers, Aberdeen, UK

Pressey, R.L., Cabeza, M., Watts, M.E., Cowling, R.M. and Wilson, K.A. 2007. Conservation planning in a changing world. *Trends in Ecology and Evolution* 22, 583–592.

Read, A.J., Drinker, P. and Northridge, S. 2006. Bycatch of marine mammals in US and global fisheries. *Conservation Biology* 20:163-169.

Redfern, J.V., Ferguson, M.C., Becker, E.A., Hyrenbach, K.D., Good, C., J. Barlow, J., Kaschner, K., Baumgartner, M., Forney, K.A., Ballance, L.T., Fauchald, P., Halpin, P., Hamazaki, T., Pershing, A.J., Qian, S., Read A., Reilly, S., Torres, L. and Werner, C. 2006. Techniques for cetacean-habitat modeling. *Marine Ecology Progress Series* 310:271-295.

Reeves, R.R. (ed.). 2009. Proceedings of the First International Conference on Marine Mammal Protected Areas (ICMMPA). Maui, Hawai'i, USA, March 30 - April 3, 2009. 135pp.

Shelden, K.E.W., Moore, S.E., Waite, J.M., Wade, P.R. and Rugh, D.J. 2005. Historic and current habitat use by North Pacific right whales *Eubalaena japonica* in the Bering Sea and Gulf of Alaska. *Mammal Review* 35:129-155.

Slooten, E., Fletcher, D. and Taylor, B. L. 2000. Accounting for Uncertainty in Risk Assessment: Case Study of Hector's Dolphin Mortality due to Gillnet Entanglement. *Conservation Biology* 14:1264–1270.

Slooten, E., Dawson, S.M. and Rayment, W.J. 2006. Offshore distribution of Hector's dolphins at Banks Peninsula: Is the Banks Peninsula Marine Mammal sanctuary large enough? *NZ Journal of Marine and Freshwater Research* 40(2):333-343.

Slooten, E. and Dawson, S.M. 2010. Assessing the effectiveness of conservation management decisions: likely effects of new protection measures for Hector's dolphin (*Cephalorhynchus hectori*). *Aquatic Conservation: Marine and Freshwater Ecosystems* 20:334–347.

Smith, R.J., Eastwood, P.D., Ota, Y. and Rogers, S.I. 2009. Developing best practice for using Marxan to locate marine protected areas in European waters. ICES *Journal of Marine Science* 66:188-194.

Stewart, R.R., Ball, I.R., Possingham, H.P. 2007. The effect of incremental reserve design and changing reservation goals on the long-term efficiency of reserve systems. *Conservation Biology* 21:346–354.

Stewart, R.R. and Possingham, H.P. 2005. Efficiency, costs and trade-offs in marine reserve system design. *Environmental Modeling and Assessment* 10:203–213.

Wade, P., Heide-Jørgensen, M.P., Shelden, K., Barlow, J., Carretta, J., Durban, J., Leduc, R., Munger, L., Rankin, S., Sauter, A. and Stinchcomb, C. 2006. Acoustic detection and satellite-tracking leads to discovery of rare concentration of endangered North Pacific right whales. *Biology Letters* 2:417–419.

Ward, E.J., Holmes, E.E. and Balcomb, K.C. 2009. Quantifying the effects of prey abundance on killer whale reproduction. *Journal of Applied Ecology* 46:632–640.

Watson, R., Kitchingman, A., Gelchu, A. and Pauly, D. 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5:168-177.

Whitehead, H. 2002. Estimates of the current global population size and historical trajectory for sperm whales. *Marine Ecology Progress* Series 242:295-304.

Williams, R., Hedley, S. and Hammond, P.S. 2006. Modelling distribution and abundance of Antarctic baleen whales using ships of opportunity. Ecology and Society 11(1). [http://ecologyandsociety.org/vol11/iss1/art1/]

Williams, R., Hall, A. and Winship, A. 2008. Potential limits to anthropogenic mortality of small cetaceans in coastal waters of British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 65(9):1867-1878.

Williams, R., Lusseau, D. and Hammond, P.S. 2009. The role of social aggregations and protected areas in killer whale conservation: the mixed blessing of critical habitat. *Biological Conservation* 142:709-719.

Williams, R. and Thomas, L. 2009. Cost-effective abundance estimation of rare animals: testing performance of small-boat surveys for killer whales in British Columbia. *Biological Conservation* 142:1542-1547.

Williams, R. and O'Hara, P. 2010. Modelling ship strike risk to fin, humpback and killer whales in British Columbia, *Canada. Journal of Cetacean Research and Management* 11:1-8.

Wilson, B., Reid, R.J., Grelier, K., Thompson, P.M. and Hammond, P.S. 2004. Considering the temporal when managing the spatial: a population range expansion impacts protected areas-based management for bottlenose dolphins. *Animal Conservation* 7:331-338.

Zacharias, M.A. and Gregr, E.J. 2005. Sensitivity and vulnerability in marine environments: an approach to identifying vulnerable marine areas. *Conservation Biology* 19:86-97.

APPENDIX 1

Number of available estimates, observed densities and variation by species

Scientific name	Common name	Number of available estimates	Mean observed density across all estimates	Min observed density	Max observed density
			[Individuals / 1000 km²]		
Eubalaena japonica	North Pacific right whale	1	0.06	0.06	0.06
Eschrichtius robustus	gray whale	1	10.90	10.90	10.90
Balaenoptera acutorostrata	common minke whale	21	4.52	0.27	16.95
Balaenoptera borealis	sei whale	4	0.05	0.03	0.10
Balaenoptera edeni	Bryde's whale	6	0.42	0.02	0.67
Balaenoptera musculus	blue whale	10	1.51	0.00	4.96
Balaenoptera physalus	fin whale	24	8.84	0.07	43.16
Megaptera novaeangliae	humpback whale	34	16.35	0.00	82.77
Physeter macrocephalus	sperm whale	14	1.40	0.16	3.42
Kogia breviceps	pygmy sperm whale	1	2.88	2.88	2.88
Kogia simus	dwarf sperm whale	2	3.82	0.57	7.07
Delphinapterus leucas	beluga or white whale	17	41.14	15.37	135.19
Phocoena phocoena	harbor porpoise	20	498.19	3.51	2365.48
Phocoenoides dalli	Dall's porpoise	63	87.56	1.11	609.62
Steno bredanensis	rough-toothed dolphin	4	3.67	1.45	7.48
Lagenorhynchus obliquidens	Pacific white-sided dolphin	25	217.13	8.33	1080.39
Grampus griseus	Risso's dolphin	10	25.33	0.96	124.09
Tursiops truncatus	common bottlenose dolphin	9	8.46	1.30	14.50
Stenella attenuata	pantropical spotted dolphin	17	145.74	3.62	285.22
Stenella coeruleoalba	striped dolphin	11	35.08	0.20	98.27
Stenella longirostris	spinner dolphin	12	92.94	1.35	147.70
Delphinus capensis	long-beaked common dolphin	3	39.13	0.37	104.03
Delphinus delphis	short-beaked common dolphin	20	258.14	1.22	1004.26
Lagenodelphis hosei	Fraser's dolphin	2	9.48	4.13	14.82
Lissodelphis borealis	northern right whale dolphin	13	26.46	6.63	81.76
Peponocephala electra	melon-headed whale	3	1.78	1.19	2.33
Feresa attenuata	pygmy killer whale	2	1.19	0.39	1.99
Pseudorca crassidens	false killer whale	3	1.19	0.10	2.04
Orcinus orca	killer whale	25	6.03	0.14	33.66
Globicephala macrorhynchus	short-finned pilot whale	4	6.32	0.73	20.12
Berardius bairdii	Baird's beaked whale	4	0.45	0.20	0.92
Indopacetus pacificus	Longman's beaked whale	1	0.41	0.41	0.41
Mesoplodon densirostris	Blainville's beaked whale	2	0.98	0.80	1.16
Ziphius cavirostris	Cuvier's beaked whale	6	3.70	0.51	10.01

	Observed overall variation	Mean observed interannual variation	Mean observed variation across all surveys surveyed during the same years	Sources/References
	Coefficient of Variation			
	0.00			Forney et al. 1995
				Forney et al. 1995
	1.03	0.49	0.48	Moore et al. 2000; Moore et al. 2002; Forney & Barlow 1993; Forney et al. 1995; Zerbini et al. 2006; Barlow 2003; Williams & Thomas 2007
	0.65	0.63		Barlow 2003
	0.62	0.19		Wade & Gerrodette 1993; Gerrodette & Forcada 2002; Barlow 2006; Barlow 2003
	1.12	0.94	0.99	Calambokidis & Barlow 2004
	1.29	0.44	0.72	Moore et al. 2000; Moore 2002; Forney et al. 1995; Zerbini et al. 2006; Barlow 2003; Barlow 2003; Williams & Thomas 2007
	1.39	0.55	1.04	Moore et al. 2000; Moore et al. 2002; Forney & Barlow 1993; Forney et al. 1995; Zerbini et al. 2006; Barlow 2003; Barlow. 2003; Calambokidis et al. 2004; Calambokidis & Barlow 2004; Williams & Thomas 2007
	0.79	0.79	0.94	Wade & Gerrodette 1993; Forney & Barlow 1993; Forney et al. 1995; Gerrodette & Forcada 2002; Barlow 2006; Barlow 2003; Barlow & Taylor 2005; Mobley et al. 2000
	0.00			Barlow 2003; Barlow 2006
	1.20			Wade & Gerrodette 1993; Barlow 2003; Barlow 2006
	0.88	0.23	0.44	Lowry et al. 1999; Rugh et al. 2005; Lowry et al. 1999; Hobbs et al. 2000
	1.16	0.20	0.74	Moore et al. 2002; Carretta et al. 2001; Forney & Barlow 1993; Forney et al. 1995; Forney 1999; Carretta & Forney 2004; Carretta 2003; Williams & Thomas 2007
	1.12	0.51	0.70	Buckland et al. 1993; Moore et al. 2002; Forney et al. 1995; Barlow 2003; Calambokidis et al. 2004; Williams & Thomas 2007
	0.73			Wade & Gerrodette 1993; Gerrodette et al. 2005; Barlow 2006; Mobley et al. 2000
	1.31	0.45	0.90	Buckland et al. 1993; Forney et al. 1995; Barlow 2003; Williams & Thomas 2007
	1.43	0.17	0.46	Wade & Gerrodette 1993; Forney & Barlow 1993; Forney et al. 1995; Gerrodette et al. 2005; Barlow 2006; Barlow 2003
	0.59	0.58		Wade & Gerrodette 1993; Forney & Barlow 1993; Forney et al. 1995; Gerrodette et al. 2005; Barlow 2006; Barlow 2003; Mobley et al. 2000
	0.64	0.32	0.60	Wade & Gerrodette 1993; Gerrodette & Forcada 2002; Gerrodette et al. 2005; Barlow 2006; Gerrodette & Forcada 2002; Mobley et al. 2000
	0.89	0.41	1.33	Wade & Gerrodette 1993; Gerrodette & Forcada 2002; Gerrodette et al. 2005; Barlow 2006; Barlow 2003; Mobley et al. 2000
	0.53	0.35	0.33	Wade & Gerrodette 1993; Gerrodette & Forcada 2002; Gerrodette et al. 2005; Barlow 2006; Mobley et al. 2000
	1.45	1.45		Forney et al. 1995; Barlow 2003
	0.96	0.39	0.88	Wade & Gerrodette 1993; Forney & Barlow 1993; Forney et al. 1995; Gerrodette & Forcada 2002; Gerrodette et al. 2005; Barlow 2003
	0.80			Wade & Gerrodette 1993; Barlow 2006
	0.96	0.34	0.57	Buckland et al. 1993; Forney et al. 1995; Barlow 2003
	0.32			Wade & Gerrodette 1993; Barlow 2006; Mobley et al. 2000
	0.96			Wade & Gerrodette 1993; Barlow 2006
	0.84			Wade & Gerrodette 1993; Barlow 2006; Mobley et al. 2000
	1.35	0.38	0.91	Wade & Gerrodette 1993; Forney & Barlow 1993; Forney et al. 1995; Waite et al 2002; Zerbini et al. 2006; Barlow 2006; Barlow 2003; Williams & Thomas 2007
	1.47	0.11		Wade & Gerrodette 1993; Gerrodette & Forcada 2002; Barlow 2006; Barlow 2003; Mobley et al. 2000
	0.71	0.54	0.36	Forney et al. 1995; Barlow 2006; Barlow 2003
	0.00			Forney et al. 1995; Barlow 2006; Barlow 2003; Mobley et al. 2000
	0.26			Wade & Gerrodette 1993; Forney et al. 1995; Barlow 2003; Barlow 2006; Mobley et al. 2000
	0.99	0.92		Wade & Gerrodette 1993; Forney et al. 1995; Barlow 2006; Barlow 2003; Mobley et al. 2000

APPENDIX 2

Survey area information

Survey_Area_ID	Survey Region	Number of times that survey area has been covered during different time periods	Number of different single species estimates in this survey block	Total Survey Area [km²]	Reference
NMFS_86_04	ETP	1	15	19,517,070	Wade & Gerrodette 1993
NMFS_86_04_111	ETP	4	1	2,136,958	Wade & Gerrodette 1993
NMFS_86_04_112	ETP	4	1	10,139,910	Wade & Gerrodette 1993
NMFS_86_04_113	ETP	4	1	6,615,109	Wade & Gerrodette 1993
NMFS_86_04_168	ETP	5	1	2,583,011	Wade & Gerrodette 1993
NMFS_86_04_169	ETP	5	1	6,157,062	Wade & Gerrodette 1993
NMFS_86_04_170	ETP	5	1	1,501,928	Wade & Gerrodette 1993
NMFS_86_04_171	ETP	5	1	4,277,705	Wade & Gerrodette 1993
NMFS_86_04_172	ETP	5	1	6,978,367	Wade & Gerrodette 1993
NMML_87_55_292	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_279	N Pacific	1	1	185,831	Buckland et al. 1993
NMML_87_55_280	N Pacific	1	2	47,691	Buckland et al. 1993
NMML_87_55_282	N Pacific	1	2	208,763	Buckland et al. 1993
NMML_87_55_284	N Pacific	1	3	196,709	Buckland et al. 1993
NMML_87_55_286	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_287	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_288	N Pacific	1	1	34,589	Buckland et al. 1993
NMML_87_55_289	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_278	N Pacific	1	1	182,374	Buckland et al. 1993
NMML_87_55_291	N Pacific	1	3	208,763	Buckland et al. 1993
NMML_87_55_266	N Pacific	1	1	27,240	Buckland et al. 1993
NMML_87_55_290	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_277	N Pacific	1	1	188,041	Buckland et al. 1993
NMML_87_55_276	N Pacific	1	1	188,112	Buckland et al. 1993
NMML_87_55_274	N Pacific	1	1	188,112	Buckland et al. 1993
NMML_87_55_293	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_267	N Pacific	1	1	188,112	Buckland et al. 1993
NMML_87_55_275	N Pacific	1	1	188,112	Buckland et al. 1993
NMML_87_55_265	N Pacific	1	1	163,222	Buckland et al. 1993
NMML_87_55_264	N Pacific	1	1	164,720	Buckland et al. 1993
NMML_87_55_263	N Pacific	1	1	125,381	Buckland et al. 1993
NMML_87_55_261	N Pacific	1	1	164,569	Buckland et al. 1993
NMML_87_55_260	N Pacific	1	1	124,421	Buckland et al. 1993
NMML_87_55_259	N Pacific	1	1	12,997	Buckland et al. 1993
NMML_87_55_272	N Pacific	1	2	168,967	Buckland et al. 1993
NMML_87_55_325	N Pacific	1	1	245,153	Buckland et al. 1993
NMML_87_55_273	N Pacific	1	1	181,926	Buckland et al. 1993
NMML_87_55_294	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_326	N Pacific	1	1	245,153	Buckland et al. 1993
NMML_87_55_324	N Pacific	1	1	245,153	Buckland et al. 1993
NMML_87_55_322	N Pacific	1	3	245,153	Buckland et al. 1993
NMML_87_55_316	N Pacific	1	2	245,153	Buckland et al. 1993
NMML_87_55_315	N Pacific	1	3	227,825	Buckland et al. 1993
NMML_87_55_314	N Pacific	1	1	33,111	Buckland et al. 1993
NMML_87_55_313	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_306	N Pacific	1	3	227,825	Buckland et al. 1993
NMML_87_55_328	N Pacific	1	2	260,615	Buckland et al. 1993
NMML_87_55_312	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_304	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_295	N Pacific	1	1	208,763	Buckland et al. 1993
NMML_87_55_307	N Pacific	1	2	227,825	Buckland et al. 1993
NMML_87_55_308	N Pacific	1	2	227,825	Buckland et al. 1993
NMML_87_55_309	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_310	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_311	N Pacific	1	1	227,825	Buckland et al. 1993
NMML_87_55_305	N Pacific	1	3	227,825	Buckland et al. 1993
NOAA_99_18	Bering Sea	1	3	322,263	Moore et al. 2000
NOAA_99_18_114	Bering Sea	1	4	197,412	Moore et al. 2002
NOAA_00_18_115	Bering Sea	1	6	156,654	Moore et al. 2002
NMFS_95_25_11	California	1	1	5,728	Carretta et al. 2001
NMFS_95_25_61	California	2	1	3,018	Carretta et al. 2001
NMFS_95_25_62	California	2	1	5,557	Carretta et al. 2001

Survey_Area_ID	Survey Region	Number of times that survey area has been covered during different time periods	Number of different single species estimates in this survey block	Total Survey Area [km^2]	Reference
NMFS_95_25_60	California	1	1	2,953	Carretta et al. 2001
NMFS_91_25	California	1	8	276,604	Forney & Barlow 1993
NOAA_92_18_242	Bering Sea	4	1	52,852	Lowry et al. 1999
NOAA_93_18_241	Bering Sea	2	1	23,561	Lowry et al. 1999
NMFS_98_04	ETP	4	7	21,493,292	Gerrodette & Forcada 2002
NMFS_97_25_116	California	2	1	6,817	Carretta & Forney 2004
NMFS_97_25_117	California	2	1	2,907	Carretta & Forney 2004
NMFS_97_25_118	California	2	1	11,014	Carretta & Forney 2004
NMFS_97_25_119	California	2	1	11,222	Carretta & Forney 2004
NMML_01_32_124	Gulf of Alaska & Aleutian Islands	1	4	4,621	Zerbini et al. 2007
NMML_01_32_131	Gulf of Alaska & Aleutian Islands	1	4	27,861	Zerbini et al. 2007
NMML_01_32_122	Gulf of Alaska & Aleutian Islands	1	2	8,938	Zerbini et al. 2007
NMML_01_32_123	Gulf of Alaska & Aleutian Islands	1	3	5,076	Zerbini et al. 2007
NMML_01_32_135	Gulf of Alaska & Aleutian Islands	1	3	14,169	Zerbini et al. 2007
NMML_01_32_129	Gulf of Alaska & Aleutian Islands	1	3	13,370	Zerbini et al. 2007
NMML_01_32_125	Gulf of Alaska & Aleutian Islands	1	3	13,602	Zerbini et al. 2007
NMML_01_32_220	Gulf of Alaska & Aleutian Islands	1	1	21,53	Zerbini et al. 2007
NMML_01_32_219	Gulf of Alaska & Aleutian Islands	1	2	22,796	Zerbini et al. 2007
NMML_01_32_134	Gulf of Alaska & Aleutian Islands	1	3	14,670	Zerbini et al. 2007
NMML_01_32_133	Gulf of Alaska & Aleutian Islands	1	4	14,681	Zerbini et al. 2007
NMML_01_32_132	Gulf of Alaska & Aleutian Islands	1	1	18,079	Zerbini et al. 2007
NMML_01_32_130	Gulf of Alaska & Aleutian Islands	1	3	5,156	Zerbini et al. 2007
NMML_01_32_128	Gulf of Alaska & Aleutian Islands	1	3	9,249	Zerbini et al. 2007
NMML_01_32_127	Gulf of Alaska & Aleutian Islands	1	3	8,568	Zerbini et al. 2007
NMML_01_32_126	Gulf of Alaska & Aleutian Islands	1	2	8,616	Zerbini et al. 2007
NMFS_94_32_240	Gulf of Alaska	11	1	20,363	Rugh et al. 2005
NMFS_91_10_08	CA, OR/WA	3	19	830,639	Barlow 2003
NMFS_96_10_09	CA, OR/WA	2	13	326,547	Barlow 2003
NMFS_02_06	Hawaii	1	21	2,477,498	Barlow 2003
NMFS_97_05	E. Temperate N. Pacific	1	1	7,816,324	Barlow & Taylor 2005
NOAA_95_10_176	CA, OR, WA	5	2	8,741	Calambokidis et al. 2004
NOAA_95_10_177	CA, OR, WA	1	2	6,790	Calambokidis et al. 2004
NOAA_96_29_105	California	1	2	319,608	Calambokidis & Barlow 2004
NOAA_93_29_106	California	1	2	923,504	Calambokidis & Barlow 2004
NOAA_91_29_103	California	1	14	260,899	Calambokidis & Barlow 2004
NOAA_91_29_104	California	1	2	547,314	Calambokidis & Barlow 2004
NMFS_93_06	Hawaii	1	11	84,881	Mobley et al. 2000
RCS_04_39_189	Coastal waters of British Columbia	1	3	3,069	Williams & Thomas 2007
RCS_04_39_186	Coastal waters of British Columbia	2	7	65,3347	Williams & Thomas 2007
RCS_04_39_187	Coastal waters of British Columbia	1	4	12,979	Williams & Thomas 2007
RCS_04_39_188	Coastal waters of British Columbia	1	3	1,690	Williams & Thomas 2007

APPENDIX 3

Experts directory

Species	Contact Name	Affiliation/Agency	Email	Data Type
Balaenoptera acutorostrata: common minke whale	Alex Zerbini	National Marine Mammal Laboratory	Alex.Zerbini@noaa.gov	
	Jonathan Stern	Northeast Pacific Minke Whale Project	jonathanstern@northeastpacificminke.org	photo-identification
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	photo-identification, behaviour
	Tom Norris	Bio-waves	thomas.f.norris@cox.net	acoustic
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	Alexandra Morton	Raincoast Research Society	wildorca@island.net	
	Paul Spong and Helena Symmonds	Orcalab	orcalab@island.net	
	Volker Deecke	University of St Andrews	vd2@st-andrews.ac.uk	
	Lance Barrett-Lennard	British Columbia Cetacean Sightings Network	Lance.Barrett-Lennard@vanaqua.org	
	Doug Sandilands	Cetus Research Society and Straitwatch	dsandilands@cetussociety.org	
	Susan and Howard Berta	Orca Sighting Network	info@orcanetwork.org	
	John Calambokidis	Cascadia Research	calambokidis@cascadiaresearch.org	
	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	Scott Baker	Oregon State University	scott.baker@oregonstate.	
	Rus Hoelzel	School of Biological and Biomedical Sciences Durham University	a.r.hoelzel@dur.ac.uk	
	Jared Towers	SeaSmoke Whalewatching	jrtowers@gmail.com	photo-identification
	Jorge Urban	Universidad Autonoma de Baja California Sur	jurban@calafia.uabcs.mex	
Balaenoptera borealis: sei whale	Sally Mizroch	National Marine Mammal Laboratory	sally.mizroch@noaa.gov	
	Scott Baker	Oregon State University	scott.baker@oregonstate.	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	
Balaenoptera edeni: Bryde's whale	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Balaenoptera musculus: blue whale	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	Diane Gendron	UABCS Universidad Autonoma de Baja California Sur	dgendron@ipn.m	
	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
	Bruce Mate	Oregon State University	bruce.mate@oregonstate.edu	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
Balaenoptera physalus: fin whale	Janie Wray	North Coast Cetacean Society		acoustics, photo-identification
	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
	Sally Mizroch	National Marine Mammal Laboratory	sally.mizroch@noaa.gov	
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	
	Don Croll	University of California, Santa Cruz	croll@biology.ucsc.edu	
	Jorge Urban	Universidad Autonoma de Baja California Sur	jurban@calafia.uabcs.mex	
	Scott Baker	Oregon State University	scott.baker@oregonstate.	
	Sue Moore	National Marine Mammal Laboratory	Sue.Moore@nooa.gov	
	Phil Clapham	National Marine Mammal Laboratory Alaska Fisheries Science Center	Phillip.Clapham@noaa.gov	
	Alex Zerbini	National Marine Mammal Laboratory	Alex.Zerbini@noaa.gov	
Berardius bairdii: Baird's beaked whale	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	Ken Balcomb	Center for Whale Research	orcasurv@rockisland.com	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
Delphinapterus leucas: beluga or white whale	David Rugh	National Marine Mammal Laboratory Alaska Fisheries Science Center	dave.rugh@noaa.go	
	Mandy Migura	NOAA Fisheries Alaska Regional Office	Mandy.Migura@noaa.gov	
	Barbara Mahoney	NOAA Fisheries Alaska Regional Office	Barbara.Mahoney@noaa.gov	
	Sue Moore	National Marine Mammal Laboratory Alaska Fisheries Science Center	Sue.Moore@nooa.gov	
	Kristin Laidre	Applied Physics Lab, University of Washington	klaidre@apl.washington.edu	
	Rod Hobbs	National Marine Mammal Laboratory Alaska Fisheries Science Center	Rod.Hobbs@noaa.gov	

Species	Contact Name	Affiliation/Agency	Email	Data Type
Delphinus capensis: long-beaked common dolphin	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Delphinus delphis: short-beaked common dolphin	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
Balaenoptera edeni: gray whale	Lorenzo Rojas Bracho	Programa Nacional de Mamíferos Marinos, Instituto Nacional de Ecología, Ensenada, Baja California, México	lrojas@cicese.mx	
	Jorge Urban	Universidad Autonoma de Baja California Sur	jurban@calafia.uabcs.mex	
	Jim Darling	Pacfic WildLIfe Foundation	darling@island.net	
	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	Bruce Mate	Oregon State University	bruce.mate@oregonstate.edu	
	Volker Deecke	University of St Andrews	vd2@st-andrews.ac.uk	
	Dave Rugh	National Marine Mammal Laboratory	Dave.Rugh@noaa.gov	
	Jeff Laake	National Marine Mammal Laboratory	Jeff.Laake@noaa.gov	
	Sue Moore	National Marine Mammal Laboratory	Sue.Moore@noaa.gov	
	Dawn Goley	Humboldt State University Marine Mammal	pdg1@humboldt.edu	
	Paul Wade	Education and Research Program (Arcata) Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jan Straley	University of Alaska Southeast Sitka	Jan.Straley@uas.alaska.edu	
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	
Eubalaena japonica: North Pacific right whale	Paul Wade	National Marine Mammal Laboratory	Paul.Wade@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
	Christopher Clark	Cornell University	cwc2@cornell.edu	
Feresa attenuata: pygmy killer whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Daniela Maldini	Okeanis	dmaldini@okeanis.org	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Globicephala macrorhynchus: short-finned pilot whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Dan McSweeney	Wild Whales Research Foundation	P. O. Box 139, Holualoa, Hawai'i 96725, U.S.A.	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
Grampus griseus: Risso's dolphin	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
Indopacetus pacificus: Longman's beaked whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Dan McSweeney	Wild Whales Research Foundation		
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Kogia breviceps: pygmy sperm whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	DaniellaMaldini	Okeanis	dmaldini@okeanis.org	
	Joe Mobley	University of Hawaii, Oahu	jmobley@hawaii.ed	

Experts directory (cont.)

Species	Contact Name	Affiliation/Agency	Email	Data Type
Kogia sima: dwarf sperm whale	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	Daniella Maldini	Okeanis	dmaldini@okeanis.org	
	Joe Mobley	University of Hawaii, Oahu	jmobley@hawaii.ed	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Lageno delphishosei: Fraser's dolphin	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	DaniellaMaldini	Okeanis	dmaldini@okeanis.org	
Lagenorhynchus obliquidens: Pacific white-sided dolphin	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	photo-identification
	Kathy Heise	Raincoast Conservation Society	kathy@raincoast.org	photo-identification
	Erin Ashe	University of St Andrews	ea84@st-andrews.ac.uk	photo-identification, acoustic, effort & sightings
	Alexandra Morton	Raincoast Research Society	wildorca@island.net	acoustic, photo-identification
	Paul Spong and Helena Symmonds	Orcalab	orcalab@island.net	acoustic
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	acoustic, effort & sightings
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	effort & sightings
	John Calambokidis	Cascadia Research	calambokidis@cascadiaresearch.org	effort & sightings
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	effort & sightings
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	effort & sightings
Lissodelphis borealis: northern right whale dolphin	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
Mesoplodon carlhubbsi: Hubbs' beaked whale	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Megaptera novaeangliae: humpback whale	Paul Spong and Helena Symmonds	Orcalab	orcalab@island.net	acoustic
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	acoustic, effort & sightings
	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	photo-identification
	Janie Wray	North Coast Cetacean Society	info@whaleresearch.ca	acoustics, photo-identification
	Fred Sharpe	Alaska Whale Foundation	FSharpe@alaskawhalefoundation.org	
	Bruce Mate	Oregon State University	bruce.mate@oregonstate.edu	
	Diane Gendron	UABCS Universidad Autonoma de Baja California Sur	dgendron@ipn.mex	
	Olga von Ziegesar	Eye of the Whale	P.O. Box 15191, Fritz Creek, AK, 99603	opportunistic photo-id
	Barbara Taylor	Southwest Fisheries Science Center	Barbara.Taylor@noaa.gov	
	Sally Mizroch	National Marine Mammal Laboratory	sally.mizroch@noaa.gov	
	Jorge Urban	Universidad Autónoma de Baja California Sur		
	Chris Gabriele	Glacier Bay National Park	chris_gabriele@nps.gov	
	Jan Straley	University of Alaska Southeast Sitka	Jan.Straley@uas.alaska.edu	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Kate Wynn	University of Alaska, Fairbanks	kate.wynne@alaska.edu	
	David Weller	Southwest Fisheries Science Center	Dave.Weller@noaa.gov	
	Lorenzo Rojas Bracho	Programa Nacional de Mamíferos Marinos, Instituto Nacional de Ecología, Ensenada, Baja California, México	lrojas@cicese.mx	
	Jorge Urban	Universidad Autonoma de Baja California Sur	jurban@calafia.uabcs.mex	
	Phil Clapham	National Marine Mammal Laboratory Alaska Fisheries Science Center	Phillip.Clapham@noaa.gov	
	Alex Zerbini	National Marine Mammal Laboratory	Alex.Zerbini@noaa.gov	

Species	Contact Name	Affiliation/Agency	Email	Data Type
Mesoplodon densirostris: Blainville's beaked whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Mesoplodon ginkgodens: ginkgo-toothed beaked whale	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	dmaldini@okeanis.org	
Mesoplodon perrini: Perrin's beaked whale	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Mesoplodon peruvianus: pygmy beaked whale	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Mesoplodon stejnegeri: Stejneger's beaked whale	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
	William Perrin	Southwest Fisheries Science Center	william.perrin@noaa.gov	
Orcinus orca: killer whale	Ken Balcomb	Center for Whale Research	orcasurv@rockisland.net	
	Nancy Black	Monterey Bay Whale Watch	whaletrips@gowhales.com	
	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	behaviour, foraging ecology
	Scott Veirs	Beam Reach Marine Sustainability School	scott@beamreach.org	acoustic, behaviour
	Erin Ashe	University of St Andrews	erineashe@gmail.com	
	David Bain	University of Washington	dbain@u.washington.edu	
	Rob Williams	University of British Columbia	r.williams@fisheries.ubc.ca	
	John Ford	Fisheries and Oceans Canada	John.K.Ford@dfo-mpo.gc.ca	
	Lance Barrett-Lennard	Vancouver Aquarium	Lance.Barrett-Lennard@vanaqua.org	
	Graeme Ellis	Fisheries and Oceans Canada	Graeme.Ellis@dfo-mpo.gc.ca	
	Volker Deecke	University of St Andrews	vd2@st-andrews.ac.uk	
	Paul Spong and Helena Symonds	Orcalab	orcalab@island.net	
	Doug Sandilands	Cetus Society	dsandilands@cetussociety.org	
	Janie Wray	North Coast Cetacean Society	info@whaleresearch.ca	acoustics, photo-identification
	Tom Norris	Bio-waves	thomas.f.norris@cox.net	
	Dawn Noren	Northwest Fisheries Science Center	dawn.noren@noaa.gov	
	Craig Matkin	North Gulf Oceanic Society	contact@whalesalaska.org	acoustics, photo-identification
	Paula Olson	Southwest Fisheries Science Center	Paula.Olson@noaa.gov	ETP photo-identification catalogue
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	Rich Osborne	The Whale Museum, Friday Harbor	c/o soundwatch@whalemuseum.org	
Peponocephala electra: melon-headed whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
	Jay Barlow	Southwest Fisheries Science Center	Jay.Barlow@noaa.gov	
Phocoena phocoena: harbour porpoise	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
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Phocoenoides dalli: Dall's porpoise	John Calambokidis	Cascadia Research Collective	calambokidis@cascadiaresearch.org	
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Pseudorca crassidens: false killer whale	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
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Stenella attenuata: pantropical spotted dolphin	Robin Baird	Cascadia Research Collective	rwbaird@cascadiaresearch.org	
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Stenella coeruleoalba: striped dolphin	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
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Stenella longirostris: spinner dolphin	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
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Steno bredanensis: rough-toothed dolphin	Paul Wade	Head, Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, NOAA Fisheries	Paul.Wade@noaa.gov	
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	Karin Forney	Southwest Fisheries Science Center	karin.forney@noaa.gov	
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Acoustic information	John Hildebrand	Scripps Institute of Oceanography		
	Erin Oleson	University of California	eoleson@uscsd.edu	Bryde's whale
	Scott Veirs	Beam Reach Sustainability School	scott@beamreach.org	
	Shannon Rankin	Southwest Fisheries Science Center	Shannon.Rankin@noaa.gov	sei whales, minke whales, Blainvilles beaked whales,
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	Kate Stafford	Applied Physics Lab	stafford@apl.washington.edu	acoustics baleen whales North Pacific, Aleutian killer whales
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Cetacean Sightings networks	Alaska Whale Sightings		http://www.alaskawhalesightings.com/	
	BC Cetacean Sightings Network		http://wildwhales.org/	all cetacean species sightings reported
	Orca Sightings Network		orcanetwork.org	all cetacean species sightings reported
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