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Mapping world-wide distributions of marine mammal species using a Relative Environmental Suitability (RES) model

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ABSTRACT

We developed a large-scale habitat suitability modeling approach to map global distributions of 115 species of marine mammals. Predictions were generated by first assigning each species to broad-scale categories of habitat preferences with respect to depth, sea surface temperature and ice edge association based on synopses of published qualitative and quantitative habitat preference information. Using a global grid with 0.5 degree lat/long cell dimensions, we generated an index of the relative environmental suitability (RES) of each cell for a given species by relating quantified habitat preferences to locally averaged oceanographic conditions in a GIS modeling framework. RES predictions closely matched published maximum range extents for most species, suggesting that our model-based approach for identifying habitat represents a useful, more objective alternative to existing sketched distributional outlines. In addition, raster-based predictions provided more detailed information about heterogeneous patterns of potentially suitable habitat for species throughout their range. We validated RES model outputs for four species (northern fur seal, harbor porpoise, sperm whale and Antarctic minke whale) from a broad taxonomic and geographic range using at-sea sightings from dedicated surveys. Observed relative encounter rates and species-specific predicted environmental suitability were significantly and positively correlated for all species. In comparison, observed encounter rates were positively correlated with < 3 % of 1000 simulated random data sets.

Mapping of suitable habitat for marine mammals using this environmental envelope model is helpful for evaluating current assumptions and knowledge about species' occurrences, especially for data-poor species. Moreover, RES modeling may help to focus research efforts on smaller geographic scales and usefully supplement other, statistical, habitat suitability models.

INTRODUCTION

A number of marine mammal species are currently threatened by a variety of anthropogenic factors, ranging from bycatch and ship-strikes to pollution, global warming and potential food competition (Perrin et al. 2002). Limited information about where these species occur and which areas may be critically important to them is an obstacle to developing efficient management strategies to reduce such impacts. However, delineating geographic ranges of marine mammals is hampered by difficulties in defining distributional limits of these elusive and often highly mobile animals. Due to the vastness of the marine environment, even designated and costly surveys usually cover only a small fraction of the distributional ranges of most species, and often yield little more than a snapshot, both in time and space, of a given species' occurrence and geographic range (e.g. Kasamatsu et al. 2000, Hammond et al. 2002, Waring et al. 2002). The comparatively low densities of many marine mammal species further means that it is often difficult to distinguish between insufficient effort to detect a species in a given area and its actual absence. Conversely, a concentration of sightings may only reflect the concentration of effort rather than a concentration of animals (Kenney & Winn 1986).

As a consequence of the inherent difficulties of surveying marine mammals, the description of the geographic ranges is mostly based on the professional judgment of experts and the synopsis of qualitative information (e.g. Ridgway & Harrison 1981a, b, 1985, 1989, Ridgway & Harrison 1994, Ridgway &

Harrison 1999, Perrin et al. 2002). Distributional ranges published to date therefore mainly consist of rough sketches on maps outlining the proposed maximum area of species' occurrence – often supplemented by relatively large regions covered by question marks, indicating areas of likely occurrence. These maps are greatly confounded by the uncertainty in the degree of interpolation applied to the occurrence data (Gaston 1994), and there is considerable variation amongst range extents proposed by different authors for the same species (Jefferson et al. 1993, Reijnders et al. 1993). Alternative approaches to mapping species distributions have been to summarize documented stranding or sighting locations on maps as point data (e.g. Perrin et al. 1994, Jefferson & Schiro 1997, Ballance & Pitman 1998), or to map relative sighting or catch rates in raster maps (Kasamatsu & Joyce 1995). However, none of these approaches delineate species distributions based on an explicit algorithm that captures patterns of species' occurrences using a rule-based approach or statistical models, as recommended by Gaston (1994).

In recent years, advances in geographic information systems and computational power have allowed the development of habitat suitability models that provide quantitative alternatives to delineating maximum range extents. Habitat suitability modeling has been widely applied in terrestrial systems and a wide range of land-based species (Peterson & Navarro-Sigüenza 1999, Zaniewski et al. 2002, Store & Jokimäki 2003). There are, however, comparatively few such models that concentrate on the marine environment and specifically marine mammals. To date, existing efforts have dealt with only a few species in some restricted areas (Moses & Finn 1997, Hedley et al. 1999, Gregr & Trites 2001, Hamazaki 2002), and few authors have attempted to validate their models (Hedley et al. 1999, Gregr & Trites 2001, Hamazaki 2002).

Most of the existing habitat suitability models use empirical statistical models, such as general linear models (GLMs) or general additive models (GAMs) based on point data such as sighting or catch data sets. These models then investigate the relationships between observed species occurrence and the underlying environmental parameters that – either directly or indirectly – determine a species' presence in a known area to predict occurrence in other, unsurveyed areas (Moses & Finn 1997, Gregr & Trites 2001, Hamazaki 2002).

A shortage of sightings data sets has prevented applying such models to predict patterns of occurrences or maximum range extents for the lesser-known species in more inaccessible or understudied regions of the world oceans. For the most part there is little likelihood of sufficient data being collected in the foreseeable future, although recent modeling advances such the development of ecological niche factor analysis (ENFA) may reduce the amount of data needed (Hirzel et al. 2002, Engler et al. 2004). Nevertheless, we already know quite a bit about the general habitat preferences of most marine mammal species available in the form of qualitative descriptions, mapped outlines, geographically fragmented quantitative observations, and large-scale historical catch data sets. We propose that this type of data may represent an alternative and underutilized resource, which can form the basis for the development of other types of habitat suitability models such as environmental envelope models. Envelope models have frequently been used in the past to predict large-scale terrestrial plant distributions (e.g., Shao & Halpin 1995, Guisan & Zimmermann 2000) but have not yet been applied to describe marine mammal range extents.

The objective of our study was to develop a generic quantitative approach to predict the average annual geographical ranges of all marine mammal species during the late twentieth century using basic descriptive data that were available for almost all species. We also wanted to gain insight into the potential relative environmental suitability (RES) of a given area for a species throughout this range. Unlike most existing habitat suitability models that rely on the statistical analysis of point data as input, we sought to generate our predictions based on the synthesis of existing and often general qualitative observations about spatial and temporal relationships between basic oceanographic conditions and a given species' presence. The resulting maps we produced represent a visualization of the complex relationships between some basic environmental parameters that may describe potentially suitable habitat or main aspects of a species' fundamental ecological niche, as defined by Hutchinson (1957). We tested and evaluated our model predictions using marine mammal sightings and catch data to establish the extent to which this approach may be able to capture actual patterns of species' occurrence. Finally, we explored the merits and limitations of the model as a useful supplement to existing habitat suitability modeling approaches.

MATERIAL & METHODS

Model structure, definitions, scope & resolution

We derived the geographic ranges for 115 marine mammal species and predicted the relative suitability of the environment (RES) for each of them throughout this range. RES predictions were based on the synthesis of the existing, often qualitative observations about the relationship between a species' presence and some basic oceanographic conditions. Species were assigned to broad ecological niche or habitat preference categories, which were then related to locally averaged environmental parameters in a global grid system with 0.5 degree latitude by 0.5 degree longitude cell dimensions (see Fig. 1 for model flow chart). Consequently, model outputs represented a spatially explicit index of suitability of a given location for a given species in terms of this species' preference with respect to the incorporated environmental parameters. Objective geographic ranges of species can then be determined based on predictions of low or non-suitability of areas for a given species to occur in.

Following Gaston (1994), we defined geographic range as the maximum area between the known outer-most limits of a species' regular or periodic occurrence. While this definition is inclusive of all areas covered during annual migrations, dispersal of juveniles etc, – it specifically excludes extralimital sightings, which are sometimes difficult to distinguish from the core range (Gaston 1994). We chose to use the term ‘environmental suitability’ rather than ‘habitat suitability’ to describe the heterogeneous patterns we generated for each species, as our model often more closely describes a species fundamental rather than its realized niche (Hall et al. 1997).

General patterns of occurrence of larger, long-living animals, such as marine mammals, are unlikely to be affected by environmental heterogeneity over small temporal and spatial scales (Turner et al. 1995, Jaquet 1996). This may be especially true for species living in the marine environment, as pelagic systems show greater continuity in environmental conditions over evolutionary time, than terrestrial environments (Platt & Sathyendranath 1992). We chose to model at global geographic scope to accommodate the wide-ranging annual movements and cosmopolitan occurrence of numerous marine mammal species. To match the geographic scope, we used long-term averages of temporally varying oceanographic input parameters to minimize the impacts of inter-annual variation.

Independent variables

Selection of oceanographic proxies that served as independent variables in our model was based on the availability of data at appropriate scales. Moreover, predictors were chosen based on the availability of matching habitat preference information that were obtainable for all or at least the majority of all species. All oceanographic data were interpolated and rasterized using a custom GIS software package (SimMap) and stored as attributes of individual grid cells in the global raster (Watson et al. 2004) (Fig. 2 A-C).

Bottom depth.

Strong correlations between bathymetry and patterns in inter- or intraspecific species occurrences have been noted for many species of cetaceans and pinnipeds in different regions and ocean basins (Payne & Heinemann 1993, Moore et al. 2000, Baumgartner et al. 2001, Hamazaki 2002), making seafloor elevation an ideal candidate as an oceanographic proxy for a generic habitat suitability model.

Bathymetric data were taken from the ETOP02 dataset available on the U.S. National Geophysical Data Center’s ‘Global Relief’ CD (www.ngdc.noaa.gov/products/ngdc_products.html) which provides elevation in 2-minute intervals for all points on Earth (Fig. 2 A).

Mean annual sea surface temperature (SST).

In addition to temporally fixed parameters, such as bathymetry, marine mammal distributions are influenced by a host of variable environmental factors, such as water temperature. Changes in sea surface temperature may be indicative of oceanographic processes that ultimately determine marine mammal occurrence across a number of different temporal scales (Au & Perryman 1985) and significant correlations of marine mammals species with sea surface temperatures have been demonstrated in different areas and for a variety of different species (e.g. Davis et al. 1998, Baumgartner et al. 2001, Hamazaki 2002). Although surface temperature may not serve as a good predictor for all marine mammals, given the substantial foraging depths of some species (Jaquet 1996), we nevertheless chose to use SST as a proxy, because of the general availability of observations or quantitative measurements of surface temperature conditions associated with marine mammal occurrences.

Global annual sea surface temperature data, averaged over the past fifty years, were extracted from the NOAA World Ocean Atlas 1998 CD (NOAA/NODC 1998) (Fig. 2 B).

Mean annual distance to ice edge.

The shifting edge of the pack ice is a highly productive zone (Brierley et al. 2002, Hewitt & Lipsky 2002) and represents important feeding grounds for many species of marine mammals (Murase et al. 2002). A number of studies have shown that sea ice concentration and ice cover, in combination with depth, play a key role in ecological niche partitioning for many species (Ribic et al. 1991, Moore & DeMaster 1997). We chose to include the distance to ice edge as an additional predictor in our model, as the distribution of species in the polar zones may not be captured sufficiently using only SST. This is due to the fact that, although ice extent is strongly spatially correlated with SST, the actual edge of the sea ice does not directly coincide with any single isotherm throughout the year (Fig. 2 B & C). Moreover, the ability of different marine mammal species to venture into the pack-ice varies substantially.

Spatial information about the average monthly ice extent (1979-1999) – defined by the border of minimum 50 % sea ice coverage – was obtained from US National Snow & Ice Data Center web site (http://nsidc.org/data/smmr_ssmi_ancillary/trends.html#gis). We smoothed the ice edge border to correct some obvious misclassification and/or re-projection errors. After rasterizing the ice extent data, we calculated monthly distances from the nearest ice edge cell for each cell in the raster and computed annual average distances based on these monthly distances (Fig. 2 C).

Distance to land.

Some pinniped species – specifically the eared seals (otariids) – appear to be restricted to areas fairly close to their terrestrial resting sites – haulouts and rookeries (Costa 1991, Boyd 1998). The maximum distances away from these land sites are determined by a combination of species-specific life history and physiological factors, such as the maximum nursing intervals based on the ability of pups to fast (Bonner 1984) and maximum swimming speed of adults (Ponganis et al. 1992). Global data sets identifying pinniped rookery sites do not appear to exist. However, distance from landmasses in general was deemed to be an appropriate proxy in the context of this model. For each cell, distance to land was calculated in the same manner as distance to the ice edge.

Dependent variables

Marine mammal species.

Our model encompassed 115 species of marine mammals that live predominantly in the marine environment (Table 1/Appendix 1), but did not consider exclusively freshwater cetacean or pinniped species or sirenians, sea otters or the polar bear. Taxonomically, we largely followed Rice (1998); except for right whales, for which, we recognized three separate species as supported by most recent findings (Bannister et al. 2001). In addition, we included a recently described additional species, Perrin's beaked whale (*Mesoplodon perrini;* Dalebout et al. 2002).

Definition of habitat preference categories.

Habitat categories were defined to represent broad predictor ranges, which roughly describe real marine physical/ecological niches inhabited by different marine mammal species. While ecologically meaningful bottom-depth and ice edge-association niches are variable in width/breadth and were defined accordingly, SST categories were described by regular 5° C steps, based on the average intra-annual variation of 5-10° C in most areas of the world (Angel 1992). Quantitative definitions and corresponding qualitative descriptions of potential niches of the resulting 17 bottom depth ranges, 27 broad temperature ranges and 12 ice edge association categories are shown in Table 2. Habitat preference categories were described by means of an assumed trapezoid probability distribution that we defined as a resource selection function (RSF) (Fig. 1), although we recognize that all our independent variables represent indirect ecological gradients rather than actual resource gradients (Guisan & Zimmermann 2000). The RSF was selected as the simplest and broadly appropriate option in view of the absence of data that could be used to derive generic functional responses of marine mammal occurrence and environmental gradients. The selected shape of the RSF meant that the relative environmental suitability was assumed to be uniformly highest throughout a species' preferred parameter range (Min_P to Max_P in Fig. 1). Beyond this range, we assumed that suitability would decrease linearly towards the minimum or maximum thresholds for a species (Min_A or Max_A in Fig. 1). Probabilities were set to zero outside the absolute minimum or maximum values.

Marine mammal habitat preferences.

We compiled published information about species-specific habitat preferences with respect to their known association with the ice edge, as well as preferred bottom depth and temperature ranges in a database. Where appropriate, additional information about maximum likely distance from landmasses was also collected, based on information about maximum foraging trip lengths. Selected sources of information included more than a thousand primary and secondary references, all screened for relevant information on habitat preferences. Data extracted from these sources ranged from statistically significant results of quantitative investigations of correlations between species' occurrence and environmental predictors (e.g., Gregr & Trites 2001, Moore et al. 2002, Baumgartner et al. 2003, Cañadas et al. 2003), opportunistic observations (e.g. Carlström et al. 1997), maps of sightings or distribution outlines, to qualitative broad descriptions of habitat preferences such as "oceanic, subtropical species" (e.g. Jefferson et al. 1993). A level of confidence was assigned to each record to reflect the origin, reliability and detail of the data, with quantitative investigations of environmental factors and species' occurrence ranking highest and qualitative descriptions ranking lowest. Data were entered with high spatial and temporal resolution to allow for future analyses at different geographic and seasonal scales.

We assigned each species to habitat preference categories for depth, temperature and ice edge association (and in some case distance to land) based on the most reliable information available (Table 3/Appendix 2). If the available information was inconclusive, or different conclusions could be drawn from the data, the species was assigned to multiple alternative habitat categories representing different hypotheses. Distance from land preferences were used as an additional constraining factor for all species marked by an asterisk in Table 3/Appendix 2. For three species (vaquita, Galapagos fur seal, Juan Fernandez fur seal), the general temperature categories were adjusted to reflect the apparent extreme narrowness of their niche.

Area restrictions.

Information on the main known distributional areas (i.e., North Atlantic or southern hemisphere) served as a rough first geographical constraint in the prediction model for each species. If generated RES predictions did not reflect documented species' absences from certain areas, further geographical restrictions were imposed (Table 3). It should be noted, however, that such restrictions were only imposed when known areas of non-occurrence were clearly definable, such as ocean basins (e.g. Red, Mediterranean or Baltic Seas) or RES predictions showed signs of bi- or multimodality, meaning that areas of high suitability were separated by long stretches of less suitable habitat. We attempted to minimize introductions of such additional constraints so as not to impede the assessment of the ability of the RES model to describe, on its own, patterns of species' presence and absence.

Model algorithm.

In our global raster, we predicted the species-specific relative environmental suitability of each individual grid cell based on its physical attributes and how well these matched the species' habitat preferences, assuming the trapezoid resource selection function described above. Using:

$$RES_C = RES_{C_D} * RES_{C_T} * RES_{C_I} * RES_{C_{Dis}} \qquad (1)$$

we computed a categorical index of the overall relative environmental suitability for each cell *c* – ranging between 0 to 1 – as a joint probability based on the RES of each cell *c* for depth (*D*), SST (*T*), distance from the ice edge (*I*) and, in some cases, from land (*Dis*), respectively. A multiplicative approach was chosen to allow each predictor to serve as an effective knock-out criterion (i.e., if a cell's average depth exceeded the absolute maximum of a species' absolute depth range, the overall RES should be zero, even if annual STT temperature and distance to ice edge of the cell were within the species preferred or overall habitat range).

Multiple hypotheses about species distributions were generated using different combinations of predictor category settings if a species had been assigned to multiple, equally plausible, options of habitat preference categories based on available data. We then selected the hypothesis considered to represent the best model fit through an iterative process and by qualitative comparison of outputs with all available information about the species' distribution and occurrence patterns within its range.

Model testing - input parameter settings.

We used the long-term data set of commercial whaling records to validate both our choice in habitat preference category for specific species as well as the shape of our selected RSF. The data set contained commercial catches of member states of the International Whaling Commission (IWC) between 1800-2001 and was compiled by the Bureau of International Whaling Statistics (BIWS) and the Museum of Natural History, London, UK (IWC 2001b). Whaling operations did not adhere to any of the particular sampling schemes that dedicated surveys follow. Consequently, whaling effort distribution and catch per unit effort (CPUE) were likely strongly biased. Nevertheless, long-term catch data sets may still serve as good indicators of annual average species distribution and may thus provide some quantitative insight into general patterns of occurrence (Whitehead & Jaquet 1996, Gregr 2000). To test our input parameter selections, we analysed whaling data following a similar approach as chosen by Kasamatsu et al. (2000) and Cañadas et al. (2002). As a first step, we assigned all catches recorded with reliable, accurate positions to the corresponding cell in our global raster, thus obtaining information about mean depth, temperature and distance to ice edge associated with each catch position. In the absence of specific effort information, we then derived a relative index of CPUE per individual raster cell by assuming that whalers would have caught any species of whale where and whenever they encountered it. CPUE was thus calculated as a proportional catch rate based on the proportion of total catch in each cell that consisted of the specific species in question. We subsequently computed average CPUE across all cells within a specific environmental stratum, defined to correspond to breakpoints in our habitat categories, and plotted these as histograms to compare with predictor probability distributions.

We included measures of uncertainty associated with mean encounter rates obtained for each stratum. In a spatial context, two types of biases in effort distributions may affect the level of confidence in CPUE values. Customary standard error calculation only captures the extent of variability of CPUE within one environmental stratum – reflected by the standard deviation – and the proportion of effort spent in each stratum in comparison to the total effort across all strata as reflected by $\sqrt{n}$ or $\sqrt{n/\sum n}$). This approach fails, however, to address the problem of non-representative effort distribution with respect to total available habitat. Generally, the amount of area covered by effort in each strata is not equally representative of the total habitat available in a particular stratum when compared across all environmental strata and for all predictor variables (Compare Fig. 3 A & B). This sampling bias will be more pronounced in opportunistic data sets obtained through non-dedicated surveys or whaling operations. Nonetheless, it should be noted that most of the dedicated marine mammal surveys, generally designed for abundance estimation purposes, are rarely stratified with respect to more than one environmental parameter (if at all). To account for these biases in effort distribution, we modified standard error calculations by weighting errors by the proportion of total available habitat that was covered by effort within each environmental stratum.

Finally, to assess the overall importance of effort considerations in the context of habitat suitability modelling, we also generated histograms of catch frequency distributions, based on the cumulative catches reported from all cells within a specific environmental stratum.

Model evaluation – RES model outputs.

We evaluated the generated RES predictions by testing the extent to which these may be representative of actual species' occurrence for a number of marine mammal species found in different parts of the world's oceans using sightings and catch data collected during dedicated surveys. Species for which we tested predictions included harbor porpoises, northern fur seals, sperm whales and Antarctic minke whales. We selected species to cover a wide taxonomic, geographic and ecological range to test the robustness of the generic RES approach. In addition, we chose test data sets that varied widely in geographic and temporal scope to assess at which temporal or spatial scale RES predictions may prove to be insufficient to capture patterns of species' occurrences. To minimize risks of circularity, we troed tp ascertain that test data had not been used to contribute directly or indirectly towards any of the studies or species reviews used to select input parameter settings. Test data sets included (1) the SCANS data collected during a dedicated line-transect survey in the North Sea and adjacent waters in the summer of 1994, (2) a long-term catch/sighting data set of northern fur seals collected during annual dedicated sampling surveys in the north-eastern Pacific that were conducted as a collaboration of US and Canadian federal fisheries agencies between 1958-1974 and (3) the long-term IWC-DESS data set collected during the IDCR-SOWER line-transect surveys in the Antarctic conducted annually over the past two and a half decades (Table 4).

Similar to the treatment of whaling data, species-specific catch/sighting frequencies were obtained by binning records from each data set by raster cells, using only those records with sufficient spatial and taxonomic accuracy (i.e., catch or sightings positions of reliably identified species reported to, at least, the nearest half degree lat/long). We used the minke whale sightings reported in the IWC-DESS database to test the predictions for the Antarctic minke whales, although the closely related sister species occurs sympatrically in some areas and the two species are not distinguished in the data set.

To convert the different types of spatial effort information available for the different test data sets to the same raster format (e.g. regularly recorded absence/presence or on-effort/off-effort transect or leg-starting-points), we developed two different types of effort proxies. The first, used for the northern fur seal and IWC-DESS survey data sets, was based on an approach similar to that applied to the IWC whaling data (i.e., we assumed that, on average, the total number of on-effort, reliable sighting records reported for one cell was representative of the effort spent surveying a cell). Species-specific relative encounter rates or SPUE (sightings per unit of effort) per raster cell were then calculated as the proportion of total sightings in a cell consisting of reports of the given species. We used an alternative approach in the case of the much smaller SCANS data set because the total number of animals sighted in one cell did not appear representative of the number of transects per cell, given a visual comparison of plotted sightings data with a map of survey transects (Hammond et al. 2002). Instead, using only the ship-based data, we derived a categorical effort proxy based on the number of leg-starting-points per cell provided in the available effort data files. Relative encounter rates of harbor porpoises per cell were then calculated relative to this proxy.

For each test data set, we compared species-specific SPUEs with the corresponding RES model output for that species by averaging encounter rates over all cells covered by any effort that fell into a specific RES class. Using a bootstrap simulation routine, we generated 1000 random data sets, similar in terms of means, ranges and distribution shapes to the observed data sets. We then used Spearman's non-parametric rank correlation test (Zar 1996, JMP 2000) to compare average observed and randomly generated encounter rates with predicted corresponding RES classes. To assess the performance of our model compared to random distributions, we obtained a simulated p-value by recording the number of times the relationship between random data sets and RES classes was as strong or stronger than that found between the observed encounter rates and our model predictions.

RESULTS

Relative environmental suitability predictions

RES modeling allows for potential habitat to be visualized on a large-scale while maintaining a high resolution of detail. Model results represent specific hypotheses about general heterogeneous occurrence patterns throughout a species' range. Examples of RES predictions for 11 pinniped, 6 toothed and 3 baleen whale species are shown in Fig. 4, A - C. These examples were selected to demonstrate the applicability of the modeling approach over a wide geographic and taxonomic range of species (compare Table 1/Appendix 1) and to illustrate the diversity of generated model outputs for species occupying different environmental niches. The colour gradient in each map represents an index of the relative environmental suitability (ranging from light = *not suitable* to dark = *very suitable*) of each raster cell for a species given its average habitat preferences. Where they existed, we included published outlines of maximum range extents (e.g. Jefferson et al. 1993, Reijnders et al. 1993) for comparison. The predicted distributions for all other species can be viewed online at www.seaaroundus.org (Watson et al. in press).

Generally, maximum extents of RES predictions for species closely matched published distributional outlines (Fig. 4). RES outputs for many species also captured distinct areas of known non-occurrence well, without the need to introduce any geographic constraints. Examples of this are the predicted absence of hooded seals from Hudson's Bay, the restriction of gray whales to the NE Bering Sea and the non-occurrence of Irrawaddy dolphins in southern Australia.

Though we only included a few very basic environmental parameters in our model, the complexity of the relationships between these parameters lead to distinctly different patterns of suitable habitat for species with slightly different habitat preferences. This is illustrated, for instance, by the predictions for hooded and harp seal *Pagophilus groenlandica* in the North Atlantic (Fig. 4 for hooded seal predictions; results for harp seals can be viewed online). Though published maximum range extents of the two species overlap to a large degree, the small difference in model parameterization resulted in substantially different RES predictions for the two species. The extent of possible spatial niche separation between harp and hooded seals that was achieved by these subtle differences in habitat preferences was interesting to see, given the similarity in physical size of the two species (Reijnders et al. 1993) and dietary preferences (Pauly et al. 1998), which is likely to result in some degree of interspecific competition.

RES predictions for different large whale species in polar waters represent similar examples for ecological niche separations based on small differences in habitat preferences (e.g., compare Fig. 4 for Antarctic minke whale with blue whale *Balaenoptera musculus*, RES predictions online). For these species, it has also been proposed that niche partitioning may have evolved to reduce food competition (Kasamatsu & Joyce 1995).

Model validation

Evaluation of RES input parameter choices

Results from the analysis of whaling data to evaluate our input parameter choices illustrated the importance of considering effort in the context of habitat suitability modeling. Without considering effort, total catches by environmental strata generally diverged from the habitat preference categories we had assigned each species to, based on the syntheses of available, non-point data (Fig. 5). In contrast, the histograms of species-specific average CPUE by environmental strata mostly provided good support for the selected categories, indicating that whaling data distributions do indeed reflect the general perception of a species' habitat preference. The fit of assigned habitat preference categories with the observed distribution of average CPUE was particularly good in case of depth preferences, whereby the shape of the RSF matched the shape of the CPUE histogram quite closely (see examples in Fig. 5), supporting our choice of the trapezoid probability distribution to describe the habitat preference categories. Fit of selected habitat preference categories with whaling data was also satisfactory for the mean annual distance to ice parameter settings, but generally not as good for the mean annual SST settings (both not shown). Sub-optimal fit for SST and ice are probability due the large concentration of the whaling effort in the summer months, which introduced a strong seasonal bias (IWC 2001b).

In general, our comparisons provided a useful feedback mechanism to identify discrepancies between whaling data distributions and assigned habitat preference categories. Decisions about changes in parameterization of the model for a given species were then made by carefully weighting known biases of all available data for that species, re-running the model for all possible combinations of predictor setting and selecting what was regarded to be the most parsimonious hypothesis for each species.

Evaluation of RES results

Relative environmental suitability modeling captured a significant amount of the variability in observed species' occurrences – corrected for effort – in all test cases (Table 5). Average species' encounter rates were correlated positively with predicted suitability of the environment for each species. While the positive correlations detected were relatively weak, particularly in the case of Antarctic minke whale, in each case < 3 % of the random datasets produced results more strongly correlated with observed encounter rates than the RES predictions (Table 5). Model predictions were fairly robust across a large range of temporal and spatial scales, as significant correlations were found even between RES predictions for harbor porpoise and observed relative encounter rates from the comparatively small-scale and short-term SCANS data.

DISCUSSION

Relative Environmental Suitability predictions

Our model represents a new, more objective approach for mapping large-scale distributions of marine species. RES model performance is convincing when compared to existing information about species' distributions, available in the form of descriptions of occurrences (see e.g. Rice 1998), or existing sketched outlines of distributional ranges (Jefferson et al. 1993). The fact that the RES maximum range extents closely match existing outlines may not be surprising, as the information about habitat preferences and the basic environmental parameter that drives our model is likely to have been considered and incorporated to some extent by the experts who drew these outlines. Moreover, there is some circularity operating here, since we sometimes used such outlines to infer temperature and/or ice edge category settings for species. However, the hand-drawn outlines vary considerably between different sources for the same species owing to differences in underlying assumptions or subjective – and to some extent arbitrary – decisions made by the expert who drew them. In contrast, within the RES model framework, assumptions and input parameter settings are clearly defined, thus making results reproducible and testable.

By sacrificing "detail for generality" (Levins 1966, Gaston 1994), our model was able to accommodate the frequently poor quality of available data. Consequently, the principle strength of the model lies in its greater objectivity and generic applicability. Using RES modeling, we can thus investigate different hypotheses about large-scale distributions over a broad range of species by visualizing some of the multi-dimensional relationships of environmental factors that indirectly determine the effective boundaries of range extents. Even more importantly though, RES predictions provide some information about the environmental heterogeneity described by the complex interactions between oceanographic parameters that – in part – ultimately determine the occurrence of a species throughout its maximum range.

In most cases, the predicted relative environmental suitability corresponded closely to the present ecological niche of a species. In some cases, predictions approximated a species' habitat including its historical range extension prior to human-induced depletion. For some species, however, our results diverge substantially from known distributional ranges, suggesting that other factors may play a more important role in determining some distributions. In general, RES predictions should be viewed as hypotheses about some major aspects of a species' spatial fundamental niche.

RES predictions: Limitations and biases

The predictions generated by our model are affected by various biases, operating on a number of different levels. Some biases are inherent to the present implementation of our approach, such as the absence of factors known to influence species occurrence (notably seasonality), the definition and shape of resource selection function or the model algorithm. Other biases are associated with the dependent and independent variables we use.

Other factors influencing species occurrence

In most cases, the realized niche of a species is likely to be influenced by far more factors other than the three basic oceanographic parameters we considered in our model, though the role these play will differ between species. Investigations of environmental correlates of species occurrence have identified a host of other parameters, such as warm core rings for sperm whales (Jaquet & Whitehead 1996), zones of confluence of cyclone-anticyclone eddy pairs for a number of cetacean species occurring in the northern Gulf of Mexico (Griffin 1999, Davis et al. 2002) or the depth of the bottom mixed layer for North Atlantic right whales (Baumgartner et al. 2003). Consequently, it can be expected that the incorporation of factors such as these would lead to more heterogeneous patterns of species' occurrence than implied by our model results.

Moreover, dynamic ecological factors that are not easily quantifiable, such as intra- and inter-specific competition and other behavioral interactions, greatly influence occurrence of species, especially on smaller geographic and temporal scales (Austin 2002). As a result, the spatial overlap in occurrence between different species may be, in reality, smaller than that implied by our predictions. Examples are the competitive exclusion or behavioral niche separation of species, such as can be found between harbor seals (*Phoca vitulina)* and spotted seals (*Phoca largha)* in the North Pacific (Rice 1998) or New Zealand fur seals (*Arctocephalus forsteri*) and the Australian sea lions (*Neophoca cinerea*) along the southern Australian coastline (Ling 1992) for which we provide RES predictions online.

At least some of the most obvious discrepancies between RES predictions and known regional occurrences of species are most easily explained by past or present anthropogenic impacts, such as whaling, sealing or fisheries bycatch. An example of the importance of this human-related factor is the stark contrast between the predicted distribution of the North Atlantic right whales (Fig. 4), and today's well-known absence of this species from European waters (Perry et al. 1999), likely due to the extreme reduction of its north-eastern stock by whalers in the past century (Brownell et al. 1983).

Another very important factor that impacts our results is the lack of consideration of short-term and long-term temporal variation of model parameters. Based on the long-term annual averages of environmental data, RES predictions describe the general distribution of a species averaged over the course of a whole year at any time from 1950 to 2000. Assigned habitat preference categories thus represent a compromise selected to capture as much of a 'typical' distributions of a species as possible, but ignore, therefore, much of the effects of seasonality, environmental regime shifts, such as global warming, and range depletion or expansion associated with population trends. Seasonal changes in habitat preferences are well documented for many of the baleen whales (Kasuya & Miyashita 1997, MacLeod et al. in press), and may be associated with annual migrations or other seasonal movements from feeding to breeding grounds, where parameters other than those determining food availability may be important, such as predator avoidance (Corkeron & Connor 1999, Pitman et al. 2001). It has also been suggested that habitat preferences of species may have changed over long temporal scales, especially in highly depleted, long-lived species such as the North Pacific right whale (*Eubalaena japonicus*) (Tynan et al. 2001). Such changes would explain the observed discrepancies between today's known occurrences of this species in limited regions of North Pacific and the wide-ranging presence throughout this ocean basin predicted by the RES model (available online), which is supported by historical records (Scarff 1983).

RES model predictions and actual species occurrences also diverge noticeably in areas with great inter-annual or seasonal fluctuations in environmental conditions, such as for some areas along the east coast of the United States, where inter- and inter-annual variation in SST exceeds 10°C (Angel 1992, NOAA/NODC 1998) and zones of high predicted environmental suitability will shift considerably throughout a year. RES predictions of species migrating along this coast, for instance, would greatly benefit from incorporating seasonality in our model. This would allow narrower temperature preference categories to be selected, which would improve predictions of species such as the northwestern stock of North Atlantic right whales. These feed in the Gulf of Maine and Newfoundland area and overwinter along the Florida coast, but rarely venture into the Gulf of Mexico (Jefferson & Schiro 1997, Kenney 2001) (unlike suggested by our predictions (Fig. 4)).

Biases of dependent and independent variables

Even under the assumption that the RES model incorporates the most important aspects of a species' niche, our results are affected by a number of biases associated with the input parameters and model algorithm that can help explain some of the discrepancies between our predictions and known species occurrences.

First, our model algorithm and the assumed habitat preference categories described by the shape of our resource selection function are likely overly simplistic. A linear relationship between all three oceanographic parameters is improbable, as is the assumption that their role is equally important with respect to influencing distributions across all species (as implied by our unweighted model algorithm, Equation 1). Likewise, the assumed unimodal shape of our RSF is unlikely to always describe adequately the presences of species along environmental gradients, even though symmetrical, unimodal RRFs were found to be most common during a comprehensive investigation of the shape of RSF of terrestrial plant species (Oksanen & Minchin 2002). It is questionable, whether these findings can be directly applied to the marine environment and mammal species, given that functional responses may in fact be strongly bimodal for some species that undertake long annual migrations between feeding and breeding grounds. Nevertheless, we think that the trapezoid shape represents the most parsimonious and broadly applicable choice in absence of detailed investigations of RSFs for most marine mammal species.

Other discrepancies between model predictions and known occurrences may be due to a lack of consideration of geographical differences in sea floor topography, which are not reflected in our quantitative definitions of the habitat preference categories. For instance, marine mammals are often found in high densities along the highly productive shelf edge, which represents an important transition zone between the different shelf and slope species communities. However, the shelf edge is typically much deeper (~500 m) in Antarctic waters than in other parts of the world, as the weight of the ice has caused the continental plate to sink in these areas (Knox 1994a). Consequently, our definition of 200 m bottom depth as the cut-off point for the preferred range for the shelf-edge habitat preference categories (Table 2) resulted in predicted absences of many species in areas of the Antarctic where these species are known to occur regularly in high numbers (E.g., compare Hedley et al. (1999), IWC (2001a) with RES predictions for baleen whales online)

The environmental parameters used as predictors in our model were themselves affected by biases which include direct measurement errors associated with the samples and problems introduced through interpolation and rasterization processes. Biases are reviewed in detail by the data providers [e.g., http://nsidc.org/data/smmr_ssmi_ancillary/trends.html#gis & \NOAA/NODC, 1998, 2473]. Of particular relevance to the RES model are some interpolation related biases. As interpolation is sensitive to variation in the density of the point data, the long-term averages of SST measurements will have been especially affected, as oceanographic sampling stations were much scarcer during the earlier decades of the last century than at present (NOAA/NODC 1998). Averaged over only the past twenty years, ice edge data may be less affected by this bias. However, the smoothing of ice edges, undertaken to eliminate some nonsensical results in the computation of ice edge distances, created its own set of problems. Predicted false absences or presences of species such as the harbor porpoise in the Baltic and Sea of Azov, or the beluga (*Delphinapterus leucas)* in the St. Lawrence (RES predictions online) are – at least partially – explainable based on effects of this *ad hoc* smoothing. Other problems may be related to the use of 50 %

ice coverage data to define the edge of ice, which made the distinction between fast-ice and pack-ice species impossible in the context of our model (Compare e.g., Wedell seals (*Leptonychotes weddellii*) and Ross seals (Fig. 4 & RES predictions online). Further artifacts of using this type of presence/absence ice data are areas of false predicted absences in Antarctic waters or false predicted presences very close to the North Pole for species not usually known to actually enter the pack-ice, such as e.g., the blue whale (RES predictions online). In the future, some ice data biases may be reduced by the use of sea ice concentration data instead, which would allow the setting of more flexible thresholds to define the edge of pack ice.

Unlike the independent variables, the information forming the basis for our dependent variables is less likely to be affected by interpolation issues due to its mainly qualitative nature. However, both quantitative and qualitative information about habitat preferences is probably influenced to some extent by unequal distribution of survey effort in the marine environment, which is likely to be much greater in the northern hemisphere and mostly concentrated along the continental shelves, relatively close to land.

RES model validation: Results, limitations and biases

Evaluation of input parameters and assumptions

The whaling data provided us with a helpful feedback mechanism to optimize input parameter model settings and investigate the validity of some of our model assumptions, especially our selection of the habitat preference category for a given species, and the trapezoid shape of the RSF. The fit of CPUE histograms and selected habitat preference category settings was generally best for bottom depth across almost all species and provided support for the validity of the shape of the RSF used here. Corresponding histograms for temperature and ice distance matched the distribution of whaling data less well. While a species' depth preferences are often consistent throughout its latitudinal range extent, temperature ranges and distance to ice edge will naturally vary depending on where, throughout its range, an animal is captured or sighted. Whaling effort was concentrated in the polar waters of both hemispheres during summer months (IWC 2001b), thereby only covering a part of the distributions of most species targeted. To describe a species' complete range extents including all migratory movements, temperature and ice distance categories often had to be defined much broader than would have been indicated by whaling data alone. In these cases, the discrepancies between CPUE plots and selected habitat preference category generally did not result in a re-consideration of selected model settings. Nevertheless, the visualization of catch data distributions and the subsequent evaluation process of input parameter settings proved to be a useful exercise that helped identify problems and inconsistencies.

Investigation of assumptions on effort

The impact of sampling schemes and effort biases on statistical habitat suitability model outputs is recognized and often stressed, yet little work has so far been done to investigate these effects quantitatively. Hirzel & Guisan (2002) used a virtual population model and simulation tools to investigate optimal sampling strategies for habitat suitability modeling and found that regular and equal-stratified sampling schemes provided most robust and accurate results. It is difficult to assess the extent to which these findings are transferable to the marine environment and to highly mobile organisms such as marine mammals, where the development of optimal sampling strategies needs further investigation. In the meantime, it is rarely acknowledged that survey designs optimized for abundance estimation may not be equally suitable for obtaining data for habitat suitability modeling (e.g., Kasamatsu et al. 2000). Even if effects of skewed effort distributions are acknowledged as a potential bias for marine mammal habitat predictions (Gregr & Trites 2001), such effects are rarely further investigated. In this context, comparisons of general knowledge on ecological niche preferences with frequency distributions point data and their effort-corrected derivates across environmental strata for different oceanographic parameters will be helpful. We thus recommend undertaking the analysis performed here to test input parameter settings and model assumptions as a useful starting point to visualize the extent of sampling biases in multiple dimensions (Fig. 3 and Fig. 5).

Evaluation of RES predictions

Statistical tests of RES model results indicated that our generic approach has some merit to adequately describe suitable habitat, as significant amounts of the variability in average species occurrence were captured for all species tested. Model performance contrasted with the simulated random data sets that rarely showed stronger relationships with the observed data than our predictions. Nevertheless, relationships between predicted and observed data were quite weak, particularly in the case of Antarctic minke whales. This species occurs sympatrically with its sister species, the Dwarf minke whale, in some parts of the area covered by the IDCR-SOWER surveys, and the pool of generic ‘minke whale’ observations therefore likely represents sightings of both species (IWC 2001a, Matsuoka et al. 2003). Consequently, the relationship between predictions for either minke whale species and the generic sightings is likely to be weaker than for the other tested species since both species appear to prefer slightly different habitat (Perrin & Brownell 2002).

Data independence & effort biases

The statistical testing of both our predictions and model assumptions will have been impacted by a number of biases. First, given the broad nature of our habitat preference input parameters and the type of information they were based on, we cannot be certain that our test data sets were indeed completely independent. Consequently, there is a risk of circularity, if the test data had somehow formed the basis of one of the broad ‘expert knowledge’ statements that was fed into our model. However, the process of abstraction from point data to these general statements in and of itself would probably ensure a certain degree of data independence. Furthermore, we argue that even if test data did serve as the basis for one of the broad statements used for input, such as “coastal, subtropical species”, testing the extent to which such broad statements may actually suffice to describe species’ occurrence when applied in a GIS modeling framework would be a worthwhile exercise. Nevertheless, we tried to minimize potential circularity by excluding all references that were directly based on these data from our pool of input sources for habitat preferences for the particular species tested (e.g. Kasamatsu et al. 2000, Hammond et al. 2002).

Other biases affecting the validation analysis have been introduced by relying on proxies of CPUE or SPUE such as the proportional encounter rates used here, as they are based on some major assumptions, ignore temporal components of effort distributions and do not represent real absence data. Especially in case of the IWC whaling data, the assumption of an equal catch probability for all species, which forms the basis for our proportional catch rate, is quite unrealistic, since whaling operations tended to target specific species in specific areas at specific times (e.g., Perry et al. 1999). Similarly, deriving proportional catch rates by binning catches by grid cells across all years and seasons ignores the temporal aspects of effort distributions, therefore masking effects of the well-known serial depletion of the large whale species (Pike 1968, Clark & Lamberson 1982). Also masked by this are the effects of unequal time spent in different environmental strata and the progressive expansion of whaling grounds which will result in some distortion as well (Walters 2003). While the problems associated with differential catchabilities are more difficult to address, the effects of serial depletions could be investigated through the computation and comparison of decadal or annual proportional catch rates for species. Likewise, effects of temporally or seasonally skewed effort distribution and expansion of whaling grounds can be studied by generating proportional catch rates on smaller temporal scales. Initial tests of this showed, however, that the number of ‘effort days’ spent in each environmental stratum was strongly and positively correlated with the total number of ‘effort cells’, indicating that the amount of area that whalers covered was directly related to the time they spent there. The lack of real absence data does not preclude the application and validation of habitat suitability models if pseudo-absence data can be generated (Robertson et al. 2001, Hirzel et al. 2002, Engler et al. 2004). Here, the proportional encounter rates used include adequate pseudo-absence data, as many encounter rates for a given species were frequently zero in cells where only other species had been caught. Nevertheless, it would be advisable to use direct measures of effort on a per cell basis to test RES predictions in the future to reduce or eliminate impacts of all these effort proxy biases.

Spatial autocorrelation

The spatial autocorrelation of predictor variables and test data and the resulting lack of independence of grid cells is always a problem when testing predictions generated by habitat suitability models (Burrough & McDonnell 1998). While acknowledging the impact that this will have on our results, we have not attempted to correct for effects of spatial autocorrelation. Following Gregr and Trites (2001), we argue that although the lack of independence may have affected the relative strength of the relationships found, it is unlikely to have impacted our results to an extent that invalidates our generated hypotheses.

Generic applicability and robustness of RES model

Statistical tests of RES predictions were only performed for a small proportion of species included in our model. However, for other species qualitative comparison with maps of plotted point data from different regions (e.g. Kasuya 1986, Kasamatsu & Joyce 1995, Heide-Jørgensen et al. 2003) as well as with predictions generated by smaller scale habitat models (e.g. Gregr & Trites 2001, Hamazaki 2002) provide some confidence in the general applicability of our approach. Moreover, the taxonomic diversity of the species that were tested and the broad range of our test data sets, both in terms of geographic origin as well as survey area covered and survey durations are noteworthy in this context. For instance, contrary to the long-term average occurrence patterns that may be inferred from the IWC and North Pacific data sets, both of which span several decades, our test data set for the harbor porpoise represents only a month long snapshot of species' occurrence observed during a single year in a relatively small area. This result suggested a remarkable robustness of RES model across a broad range of temporal and spatial scales. Furthermore, it suggested that the long-term averages of our basic environmental predictors play a substantial role in determining not only the fundamental, but also the realized ecological niche of a species, regardless of short-term and small-scale variability of these predictors, and of other factors that determine habitat use. Although further tests for other species and other areas are obviously required, we found the extent remarkable to which the delineation of marine species' distributions and patterns of occurrence could be quantitatively described using so few basic parameters.

Comparison with other habitat suitability modeling approaches

Despite the apparent robustness of the RES modeling approach to perform well at different scales, care should be taken when interpreting model outputs. Environmental envelop models, such as our RES model, cannot predict the real probability of species' occurrences in a specific place on a specific day or month of a given year. It should therefore not be viewed as an alternative to empirical habitat prediction approaches that are based on specific sighting data sets and directly predict species presence (e.g. Moses & Finn 1997, Hedley et al. 1999, Gregr & Trites 2001, Hamazaki 2002). Instead, RES modeling can usefully supplement such small-scale studies, by providing some general boundaries of species' distribution and by identifying potential focal areas.

Habitat suitability modeling is still a nascent field, and to date most efforts have focused on terrestrial systems and non-mobile organisms (e.g. Moisen & Frescino 2002, Zaniewski et al. 2002). At this stage, it is difficult to assess the advantages and disadvantages of different methodological approach in different contexts. It is noteworthy, however, that more sophisticated statistical models do not necessarily perform better than simpler approaches when faced with real data, especially if quality of the underlying data was poor, as shown by comparing different statistical habitat suitability modeling approaches (Moisen & Frescino 2002).

We compared the statistical results of our evaluation with those obtained by others when validating predictions of other habitat suitability approaches such as general linear models. We recognize that the differences in scale, questions asked and the associated conceptual frameworks of these different approaches may make the usefulness of a direct comparison somewhat questionable, especially since the underlying assumptions of the parametric test statistics used by others are different than those for Spearman’s rho. However, most statistics are similar enough to allow a meaningful comparison (Zar 1996) and a comparison may illustrate the extent of limitations of many currently existing models. For instance, Spearman’s rho values from our analysis were comparable to the logistic regression coefficients of tests of predicted whale habitat around Vancouver Island that were generated by GLMs (based on comparison with reported logistic coefficients of determination presented in Table 2 in Gregr & Trites 2001). More importantly, even when comparing predictions generated by GLMs which had been developed based on “perfect” data sets in a virtual population simulation with test data reported values of Pearson’s r only ranged between 0.6 and 0.7, depending on the underlying sampling scheme and sample size (Hirzel & Guisan 2002). This indicates that even empirical habitat suitability models developed based on perfect data explain only roughly half of the observed variance in the test data. Thus, RES model performance can be considered satisfactory in comparison.

Future work & applications

RES predictions would be greatly improved by incorporating seasonality, especially for the many marine mammal species that undergo large annual migrations from winter feeding to summer breeding grounds. This would require using seasonally averaged temperature and sea ice data as well as considerations of seasonal difference in habitat preferences of individual species. Predictions for species occurring in the pack- or fast-ice or in close vicinity of the ice edge may be improved if long-term sea ice concentrations were used instead of the 50% ice coverage data. In addition, it may be worthwhile to investigate what other oceanographic and/or biological factors could be fruitfully added to the model. In some cases, the exclusion of known areas of human-caused local extinctions would improve predictions about effectively utilized habitat.

Further validation of the model, for other species and using diverse data sets, would be useful. Testing should be conducted using direct measurements of effort in the form of sighting rates per km per raster cell instead of the proportional encounter rates used here. Although direct field tests of our predictions would be desirable for validation, the logistical and financial effort involved may exceed limits of realistic feasibility, given the scale at which the model operates.

In the future, RES modelling may serve as a useful tool to address both basic ecological questions as well as management and conservation related issues in situations where the paucity of data precludes the use of other more data intensive habitat modeling approaches.

The vastness and remoteness of the ocean environment contributes to a prevailing lack of comprehensive point data sets needed for statistically investigating patterns of species occurrence. Relying on more readily available types of data, such as general descriptions, RES modeling will therefore be particularly useful to study basic niche similarities and overlap between different species or groups of species in the marine environment. Here, its application may also be a worthwhile first step to investigate potential large-scale species' occurrence, including historical distributions of heavily depleted species (e.g. gray whales in the North Atlantic (Mitchell & Mead 1977)), calving grounds of endangered baleen whale species (yet unknown for species such as the North Pacific right whale Gaskin 1991) or changes in species distributions due to environmental regime shifts.

Similar to a proposed application of ecological niche factor analysis (ENFA) (Engler et al. 2004), RES modeling – though based on a somewhat different approach – may also be helpful to predict suitable habitat of rare and endangered species, such as for beaked whales species that have few if any at-sea records (D'Amico et al. 2003).

Most importantly, the extent to which RES generated hypotheses describe actual observed patterns in species occurrence allows more specific questions to be asked about the role that other factors play in determining actual distributions. Moreover, the comparison of RES predictions with outputs of point-data based statistical models will help identify discrepancies that may be symptomatic for underlying sampling biases and related issues, but can also highlight the problems of misapplications of such models using non-effort corrected data.

In a management context, RES predictions represent cost-efficient starting points to focus future research and survey efforts. This is especially practical when dealing with one of the many data-poor marine mammal species in the lesser-studied regions of the world. The usefulness of habitat prediction models to minimize anthropogenic impacts on endangered species of marine mammal through the implementation of effectively designed marine reserves has already been demonstrated on relatively small scales (Mullin et al. 1994b, Moses & Finn 1997, Hooker et al. 1999). By generating global spatially explicit indexes of biodiversity and species richness, or visualizing potential geographic hotspots of high conflict with fisheries or other human operations, RES modelling may be equally useful when attempting to delineate efficient marine protected areas or critical habitat on larger temporal and geographic scales.

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Table 1. Names, taxonomy and general distributions of the 20 selected marine mammal species included in the RES model for which we show predictions (Fig. 4) (for all other species see Appendix 1)

Common name	Scientific name	Suborder	Distribution
North Atlantic right whale	*Balaena glacialis*	Mysticeti	N Atlantic
Antarctic minke whale	*Balaenoptera bonaerensis*	Mysticeti	S hemisphere
Gray whale	*Eschrichtius robustus*	Mysticeti	N Pacific
Hourglass dolphin	*Lagenorhynchus cruciger*	Odontoceti	S hemisphere
Northern right whale dolphin	*Lissodelphis borealis*	Odontoceti	N Pacific
Irrawaddy dolphin	*Orcaella brevirostris*	Odontoceti	Indo-Pacific
Indian hump-backed dolphin	*Sousa plumbea*	Odontoceti	W Indian O.
Clymene dolphin	*Stenella clymene*	Odontoceti	Atlantic
Narwhal	*Monodon monoceros*	Odontoceti	Circumpolar N hemisphere
South African & Australian fur seal	*Arctocephalus pusillus*	Pinnipedia	S African & S Australian waters
Guadalupe fur seal	*Arctocephalus townsendi*	Pinnipedia	NE Pacific
Australian sea lion	*Neophoca cinerea*	Pinnipedia	SE Indian O., S & SW Australia
South (American) sea lion	*Otaria flavescens*	Pinnipedia	S American waters
Hooker's or New Zealand sea lion	*Phocarctos hookeri*	Pinnipedia	New Zealand waters, SW Pacific
Galapagos sea lion	*Zalophus wollebaeki*	Pinnipedia	Galapagos Islands, E Pacific
Hooded seal	*Cystophora cristata*	Pinnipedia	N Atlantic
Ribbon seal	*Histriophoca fasciata*	Pinnipedia	N Pacific
Mediterranean monk seal	*Monachus monachus*	Pinnipedia	Mediterranean & NE Atlantic
Hawaiian monk seal	*Monachus schauinslandi*	Pinnipedia	Hawaiian waters, NE Pacific
Ross seal	*Ommatophoca rossii*	Pinnipedia	Circumpolar S hemisphere

Table 2 – Quantitative & qualitative definitions of habitat preference categories

Environmental parameter	Minimum	Preferred mimimum	Preferred maximum	Maximum	Habitat category description
Depth preferences [m]	0	-1	-8000	-8000	all depths (uniform distribution)
	0	-1	-50	-200	mainly estuarine to edge of cont. shelf
	0	-1	-50	-500	mainly estuarine to beyond shelf break
	0	-10	-100	-1000	mainly coast.-up. cont. shelf to up. cont. slope
	0	-10	-200	-2000	mainly coast.-cont. shelf to end of cont. slope
	0	-10	-200	-6000	mainly coast.-cont. shelf to deep waters
	0	-10	-1000	-6000	mainly coast.-up. cont. slope to deep waters
	0	-10	-2000	-6000	mainly coast.-cont. slope to deep waters
	0	-10	-2000	-8000	mainly coast.-cont. slope to v. deep waters
	0	-10	-4000	-8000	mainly coast.-abyssal plains to v. deep waters
	0	-200	-1000	-6000	mainly up. cont. slope to deep waters
	0	-200	-2000	-6000	mainly cont. slope to deep waters
	0	-200	-2000	-8000	mainly cont. slope to v. deep waters
	0	-200	-4000	-8000	mainly cont. slope-abyssal plains to v. deep waters
	0	-1000	-2000	-8000	mainly low. cont. slope to v. deep waters
	0	-1000	-4000	-8000	mainly low. cont. slope-abyssal plains to v. deep waters
	0	-2000	-6000	-8000	mainly abyssal plains to v. deep waters
Temperature preferences [mean ann. SST in °C]	-2	-2	35	35	all temperatures (uniform distribution)
	-2	0	0	5	polar only
	-2	0	5	10	polar-subpolar
	-2	0	10	15	polar-c. temperate
	-2	0	15	20	polar-w. temperate
	-2	0	20	25	polar-subtropical
	-2	0	25	30	polar-tropical
	-2	0	30	35	polar-full tropical
	0	5	5	10	subpolar only
	0	5	10	15	subpolar-c. temperate
	0	5	15	20	subpolar-w. temperate
	0	5	20	25	subpolar-subtropical
	0	5	25	30	subpolar-tropical
	0	5	30	35	subpolar-full tropical
	5	10	10	15	c. temperate only
	5	10	15	20	c. temperate-w. temperate
	5	10	20	25	c. temperate-subtropcial
	5	10	25	30	c. temperate-tropical
	5	10	30	35	c. temperate-full tropical
	10	15	15	20	w. temperate only
	10	15	20	25	w. temperate-subtropical
	10	15	25	30	w. temperate-tropical
	10	15	30	35	w. temperate-full tropical
	15	20	20	25	subtropical only
	15	20	25	30	subtropical-tropical
	15	20	30	35	subtropical-full tropical
	20	25	25	30	tropical only
	20	25	30	35	full tropical only
Ice edge association preferences [mean annual distance from ice edge in km]	-1	0	8000	8000	no association w. ice edge (uniform distribution)
	-1	0	500	2000	mainly restricted to fast & deep pack-ice
	-1	0	500	8000	mainly in fast & deep pack-ice, but also elsewhere
	0	1	500	2000	mainly around edge of pack-ice
	0	1	500	8000	mainly around edge of pack-ice, but also elsewhere
	0	1	2000	8000	mainly around edge of pack-ice & max. ice extent, but also elsewhere
	0	1	8000	8000	reg. but not pref. around edge of the pack-ice
	0	500	2000	8000	mainly in areas of max. ice extent, but also elsewhere
	0	500	8000	8000	reg. but not pref. in areas of max. ice extent
	500	1000	2000	8000	no association w. ice edge, but seasonally close to max. ice extent
	500	1000	8000	8000	no association w. ice edge, but pref. close to areas of max. ice extent

Table 3 - Habitat preferences in terms of depth, mean annual sea surface temperature and distance to the edge of sea ice for selected marine mammal species. Superscripts denote the particular habitat preference type about which the reference provided information: ^{1} = depth preferences, ^{2} = temperature preferences, ^{3} = distance to edge of sea ice. For species marked by *, distance from land was used as an additional constraining factor, limiting species to waters < 500 km (*) or < 1000 km (**) from land.

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
North Atlantic right whale	mainly coast.-cont. shelf to deep wat.	subpolar-tropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Atlantic - (Med., Black S., Hudson's Bay & Strait, Baltic)	Baumgartner et al, 2003^{1}; Evans, 1980^{1}; Gaskin, 1991^{2}; Jefferson et al, 1993^{3}; Kenney, 2002^{2}; Knowlton et al, 1992^{1}; Mitchell et al, 1983^{2}; Woodley & Gaskin, 1996^{1}
Antarctic minke whale	mainly cont. slope to v. deep wat.	polar-tropical	mainly around edge of pack-ice, but also elsewhere	S hemisphere	Kasamatsu et al, 2000^{1}; Murase et al, 2002^{1,3}; Perrin & Brownell, 2002^{1,3}; Ribic et al, 1991^{2}; Rice, 1998^{2,3}
Gray whale	mainly estuar. to beyond shelf break	subpolar-subtropical	reg. but not pref. around edge of the pack-ice	N Pacific	Deecke, 2003^{1,2}; Gardner & Chavez-Rosales, 2000^{2}; Jones & Swartz, 2002^{1,2,3}; Moore & DeMaster, 1997^{1,3}; Moore, 2000^{3}; Rugh et al, 1999^{3}; Weller et al, 2002^{1,2}
Hourglass dolphin	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-w. temperate	mainly in areas of max. ice extent, but also elsewhere	S hemisphere	Gaskin, 1972^{2}; Goodall, 2002^{1,2}; Goodall, 1997^{1,2,3}; Jefferson et al, 1993^{1,3}; Kasamatsu et al, 1988^{2}; Kasamatsu & Joyce, 1995^{3}
Northern right whale dolphin	mainly low. cont. slope-abyss. plains to v. deep wat.	subpolar-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	N Pacific - (Lat: < 10°N)	Bjørge et al, 1991^{1,2}; Forney & Barlow, 1998^{1}; Jefferson & Newcomer, 1993^{1}; Jefferson et al, 1993^{1}; Jefferson et al, 1994^{3}; Rice, 1998^{3}; Smith et al, 1986^{2}
Irrawaddy dolphin	mainly estuar. to end of cont. shelf	full-on tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Lon: > 156°E & < 80°E)	Arnold, 2002^{1,2}; Freeland & Bayliss, 1989^{1}; Mörzer Bruyns, 1971^{2}; Parra et al, 2002^{1,2}; Rice, 1998^{3}; Stacey, 1996^{1,2}
Indian hump-backed dolphin	mainly estuar. to end of cont. shelf	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.; Lon > 90°E & < 14°E)	Findlay et al, 1992^{1}; Jefferson et al, 1993^{2}; Jefferson & Karczmarski, 2001^{1}; Karczmarski et al, 2000^{1}; Rice, 1998^{3}; Ross, 2002^{1,2}
Clymene dolphin	mainly cont. slope-abyss. plains to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	Atlantic - (Lon: > 15°E & > 70°W)	Davis et al, 1998^{1,2}; Mullin et al, 1994^{1,2}; Perrin et al, 1981^{1}; Rice, 1998^{3}

Table 3 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Narwhal	mainly up. cont. slope to deep wat.	polar only	mainly restricted to fast & deep pack-ice	N hemisphere	Dietz & Heide-Jørgensen, 1995[1]; Heide-Jørgensen, 2002[1,3]; Heide-Jørgensen et al, 2003[1]; Jefferson et al, 1993[2]; Martin et al, 1994[1]; Rice, 1998[3]
Guadalupe fur seal*	mainly low. cont. slope to v. deep wat.	w. temperate-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N & Lon: > 150°W)	Belcher & Lee, 2002[2]; Lander et al, 2000[1]; Reijnders et al, 1993[2]; Rice, 1998[3]
South African & Australian fur seal*	mainly coast.-up. cont. shelf to up. cont. slope	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 160°E & > 20°W)	Arnould & Hindell, 2001[1]; Reijnders et al, 1993[2]; Rice, 1998[3]; Thomas & Schulein, 1988[1]
Australian sea lion	mainly coast.-up. cont. shelf to up. cont. slope	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 155°E & < 75°E)	Costa, 1991[1]; Gales et al, 1994[2]; Jefferson et al, 1993[1]; Ling, 2002[2]; Rice, 1998[3]
South (American) sea lion*	mainly estuar. to end of cont. shelf	polar-subtropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lat: > 60°S & Lon: < 40°W & > 120°W)	Campagna et al, 2001[1]; Jefferson et al, 1993[2]; Reijnders et al, 1993[2]; Rice, 1998[3]; Thompson et al, 1998[1]; Werner & Campagna, 1995[1]
Hooker's or New Zealand sea lion	mainly coast.-cont. shelf to end of cont. slope	subpolar-c. temperate	reg. but not pref. in areas of max. ice extent	W Pacific - (Lat: > 0°N)	Costa & Gales, 2000[1]; Crocker et al, 2001[1]; Gales, 2002[1,2]; Jefferson et al, 1993[2]; Rice, 1998[1,3]
Galapagos sea lion*	mainly coast.-cont. shelf to deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	E Pacific - (Lat: > 10°N & Lon: > 100°W)	Dellinger & Trillmich, 1999[2]; Heath, 2002[1]; Jefferson et al, 1993[1]; Rice, 1998[3]
Hooded seal	mainly low. cont. slope to v. deep wat.	polar-c. temperate	mainly around edge of pack-ice, but also elsewhere	N Atlantic	Folkow & Blix, 1995[1,3]; Folkow et al, 1996[1,3]; Folkow & Blix, 1999[1]; Kovacs & Lavigne, 1986[1,2,3]; Reijnders et al, 1993[2]; Rice, 1998[3]
Ribbon seal	mainly coast.-cont. slope to deep wat.	polar-subpolar	mainly in areas of max. ice extent, but also elsewhere	N Pacific	Fedoseev, 2002[1,2]; Jefferson et al, 1993[1,2]; Mizuno et al, 2002[1,2]; Reijnders et al, 1993[1]; Rice, 1998[3]
Hawaiian monk seal*	mainly coast.-cont. shelf to deep wat.	subtropical-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N & Lon: < 140°W)	Gilmartin & Forcada, 2002[1]; Parrish et al, 2000[1]; Parrish et al, 2002[1]; Reijnders et al, 1993[2,3]; Schmelzer, 2000[2]
Mediterranean monk seal	mainly coast.-up. cont. shelf to up. cont. slope	subtropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	N hemisphere - (Pacific, Indian O.; Lon: > 20°W)	Duguy, 1975[1]; Kenyon, 1981[1]; Reijnders et al, 1993[1,2,3]
Ross seal	mainly coast.-cont. slope to deep wat.	polar only	mainly restricted to fast & deep pack-ice	S hemisphere	Bengtson & Steward, 1997[1]; Bester et al, 1995[3]; Jefferson et al, 1993[2]; Knox, 1994[3]; Rice, 1998[3]; Splettstoesser et al, 2000[1]; Thomas, 2002[3]

Table 4. Sighting and catch data sets used for RES model testing

	IWC-BIWS catch data	IDCR-DESS/SOWER sighting data	SCANS survey data	Northern fur seal distribution data
Agency/Source	International Whaling Commission, UK; Bureau of International Whaling Statistics, Norway; Natural History Museum of London, UK	IWC Member State collaboration / International Whaling Commission	EU collaboration / Sea Mammal Research Unit	Arctic Unit, Canada & NOAA, USA collaboration
Time period	1800-1999	1978-2001	June/July 1994	1958-1974
Ocean basin	World	Antarctica (S of 60° S)	ASCOBANS area & adjacent waters	Northeastern Pacific
Survey focal species	Large whales	Minke whales	Harbour porpoise	Northern fur seal
No. of marine mammal species reported	~ 20	~ 50	~ 5	1
No. of sighting/catch records	~ 2 000 000	~35000	1940	~ 18000
Used for testing of	RES assumptions & input parameter settings: minke whales, blue whale, humpback whale	RES model output: minke whales, sperm whale	RES model output: harbour porpoise	RES model output: northern fur seal

Table 5. Statistical results of model testing for different species including relevant information about test data sets to illustrate robustness of RES model over a wide range of temporal and spatial scales. Relationships between RES categories and average observed proportional encounter rates were tested using non-parametric rank correlation analysis. Simulated p-values represent the percentage of random data sets, generated using bootstrap simulation, that were more strongly correlated with observed data than RES predictions for given species. Note that generic "minke whale" sightings were used to test RES predictions for Antarctic minke whales.

Common name	Survey area	Size of survey area (effort cells) [1000 km^2]	Time period covered by survey	No. of reported encounters	Spearman's non-parametric rank correlation analysis of RES vs mean SPUE		Comparison with random data sets
					rho	p	Simulated p-value
Northern fur seal	Northeastern Pacific	2011	~ 20 years	10254	0.54	< 0.0001	0
Harbour porpoise	Greater North Sea	741	~ 1 month	1265	0.57	< 0.0001	0.027
Sperm whale	South of S 60	5489	~ 20 years	951	0.42	< 0.0001	0
Antarctic minke whale	South of S 60	5489	~ 20 years	12288	0.28	0.01	0.014

LIST OF FIGURES

Figure 1

Relative Environmental Suitability (RES) prediction model – flow chart of model structure and evaluation approach used for individual marine mammal species. Also shows trapezoid resource selection function describing the habitat preference categories used in the model

Figure 2 A –C

Distribution of model predictors: (A) bathymetry; (B) annual average sea surface temperature in, (C) mean annual distance to the ice edge

Figure 3 A-C

Frequency distribution of (A) globally available habitat and (B) amount of habitat covered by whaling effort as percent of cells per available environmental strata for depth, mean annual sea surface temperature (SST) and (C) mean annual distance to ice edge

Figure 4 A–C

Examples of RES model outputs: Predicted relative environmental suitability (ranging from less suitable (light) to very suitable (dark)) based on habitat preference information for (A) eleven pinniped, (B) six odontocete and (C) three mysticete species. Outlines of proposed maximum range extent (Jefferson et al, 1993) are included for comparison. Note that, when viewed on a global scale, RES predictions for many coastal species are difficult to see in narrower shelf areas such as e.g., along the western coast of South America and east coast of Africa and apparent absences from certain areas may just be artefacts of viewing scale. RES predictions of narwhal distribution in Sea of Okhotsk are masked to some extent by those for the Northern right whale dolphin. RES maps for all marine mammal species can be viewed on-line at www.seaaroundus.org.

Figure 5

Frequency distribution of IWC-BWIS whaling data set (1800-2001) plotted against depth strata to illustrate the importance of effort considerations when using point data for habitat suitability modeling and the extent to which the catch data supported our choice of habitat preference category for each species. Graphs on top show the total number of catches reported in cells falling into the specified depth stratum, graphs on the bottom show the same data after effort corrections using average relative encounter rates per stratum. Lines represent the resource selection function describing the depth preference category that the species was assigned to based on available information (Table 3/Appendix 2). Information about depth at catch locations was obtained by assigning records to corresponding 0.5 latitude/longitude cells in a global raster with associated environmental data. Only records with adequate geographic accuracy and unequivocal species identification were used. Standard errors of relative encounter rates shown in the graphs have been modified to reflect two types of effort biases: (1) the heterogeneous distribution of effort coverage across all strata and (2) the different proportions of total available habitat that was covered by whaling within each stratum. Note that frequency distributions were scaled to touch highest bar for better visualization of fit of habitat preference range

Figure 1

RELATIVE ENVIRONMENTAL SUITABILITY (RES)
PREDICTION MODEL

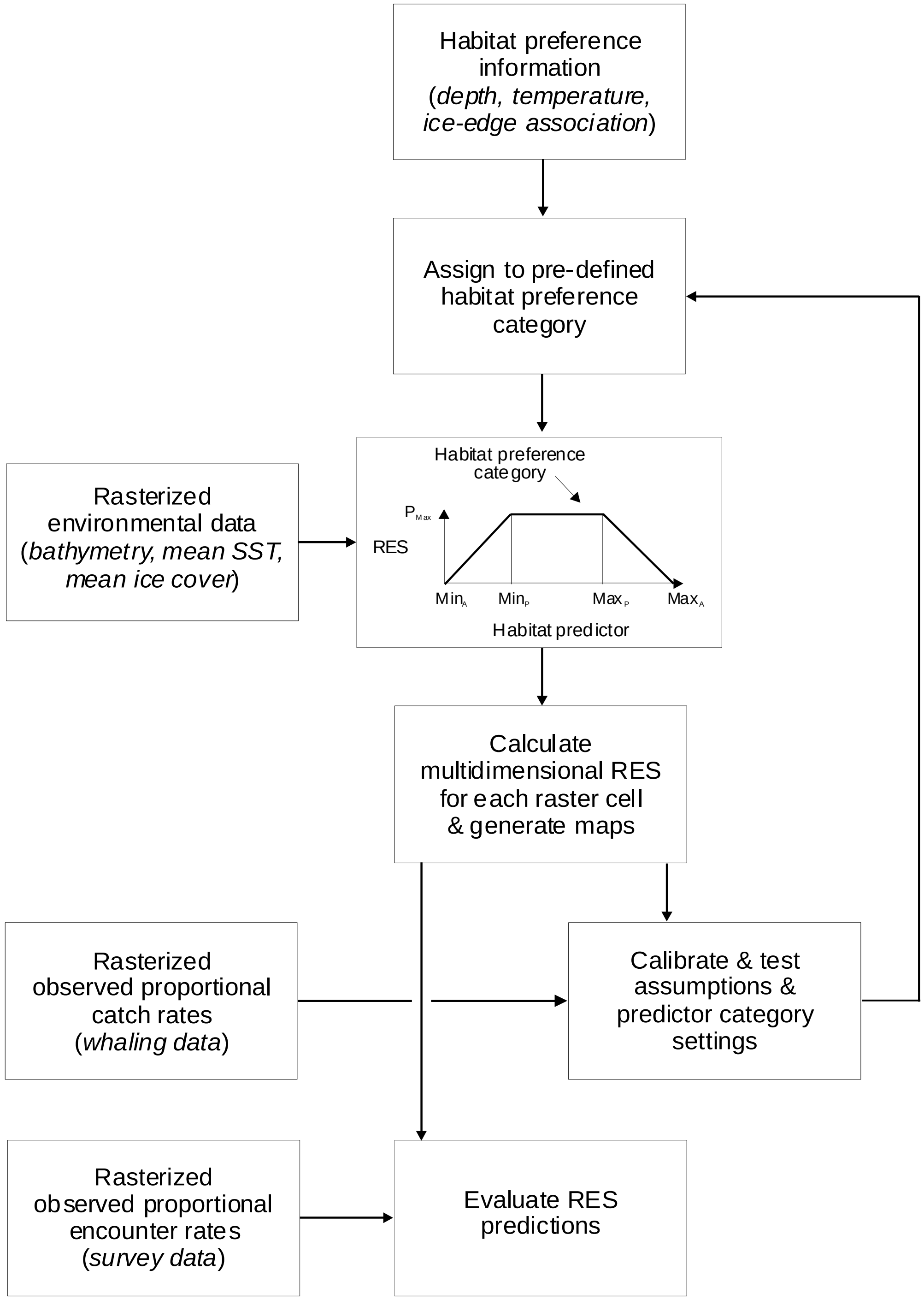


Figure 2 A –C.

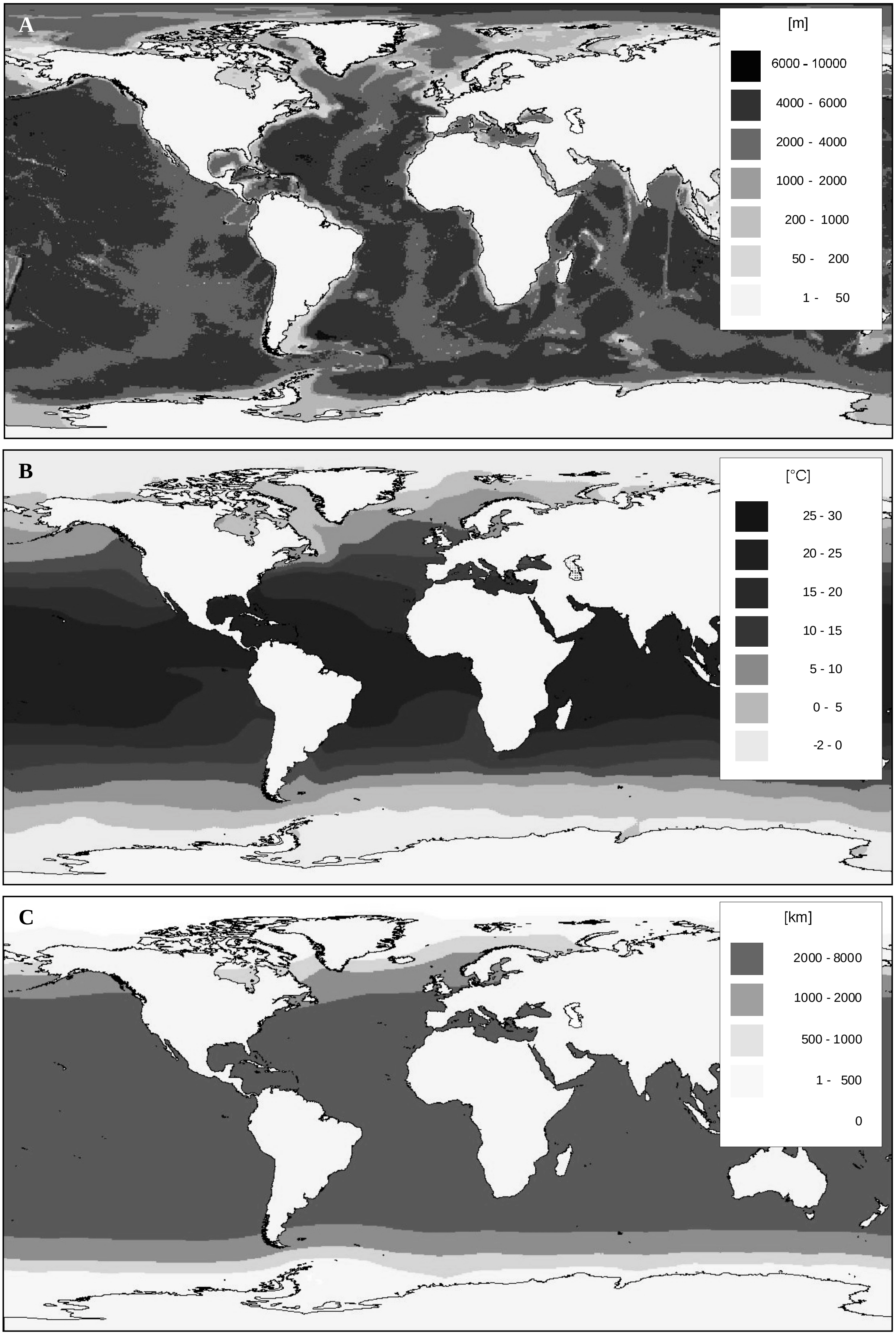

A
[m]
6000 - 10000
4000 - 6000
2000 - 4000
1000 - 2000
200 - 1000
50 - 200
1 - 50
B
[°C]
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
-2 - 0
C
[km]
2000 - 8000
1000 - 2000
500 - 1000
1 - 500
0

Figure 3

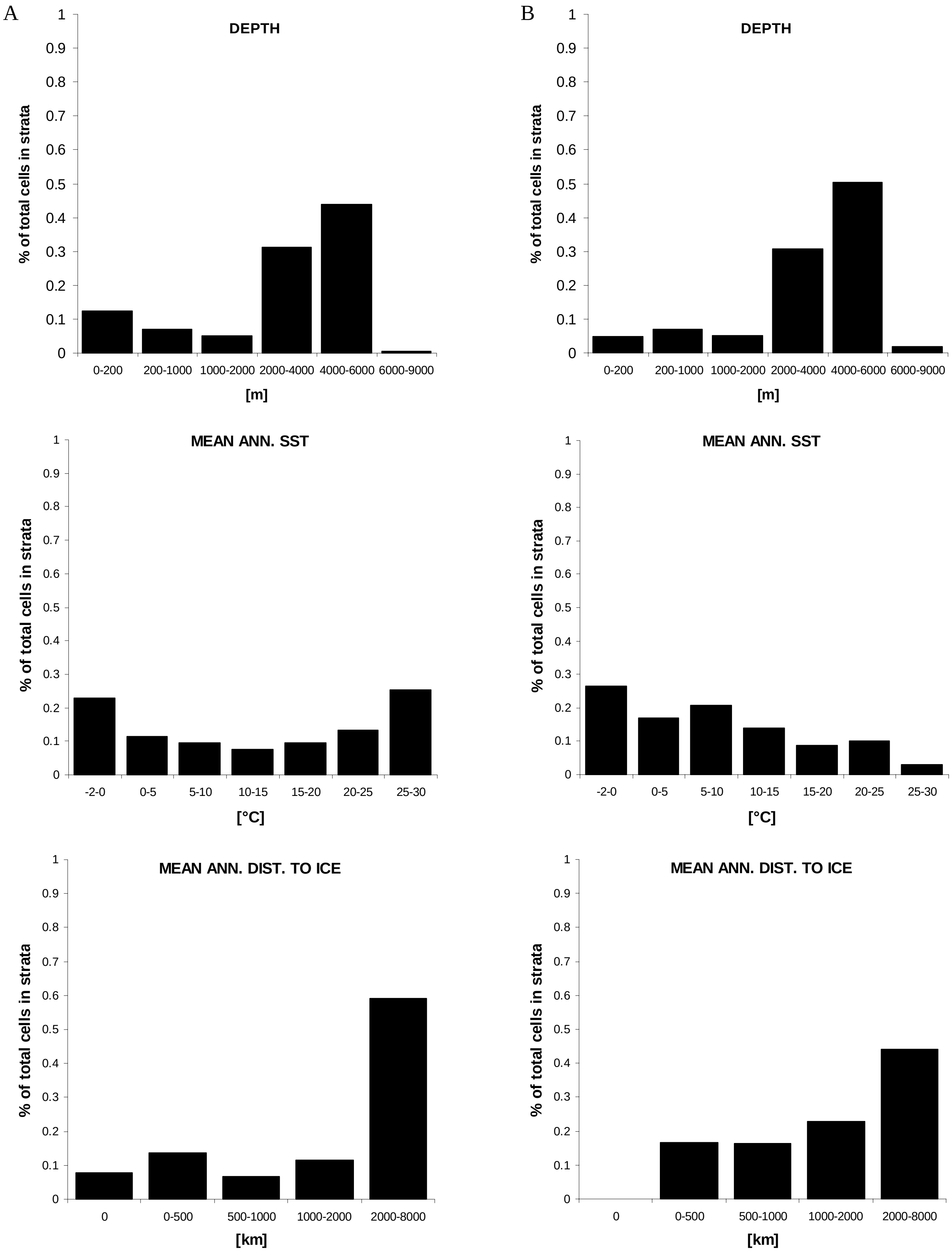

A
B
DEPTH
% of total cells in strata
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-200
200-1000
1000-2000
2000-4000
4000-6000
6000-9000
[m]
MEAN ANN. SST
-2-0
0-5
5-10
10-15
15-20
20-25
25-30
[°C]
MEAN ANN. DIST. TO ICE
0
0-500
500-1000
1000-2000
2000-8000
[km]

Figure 4 a –c.

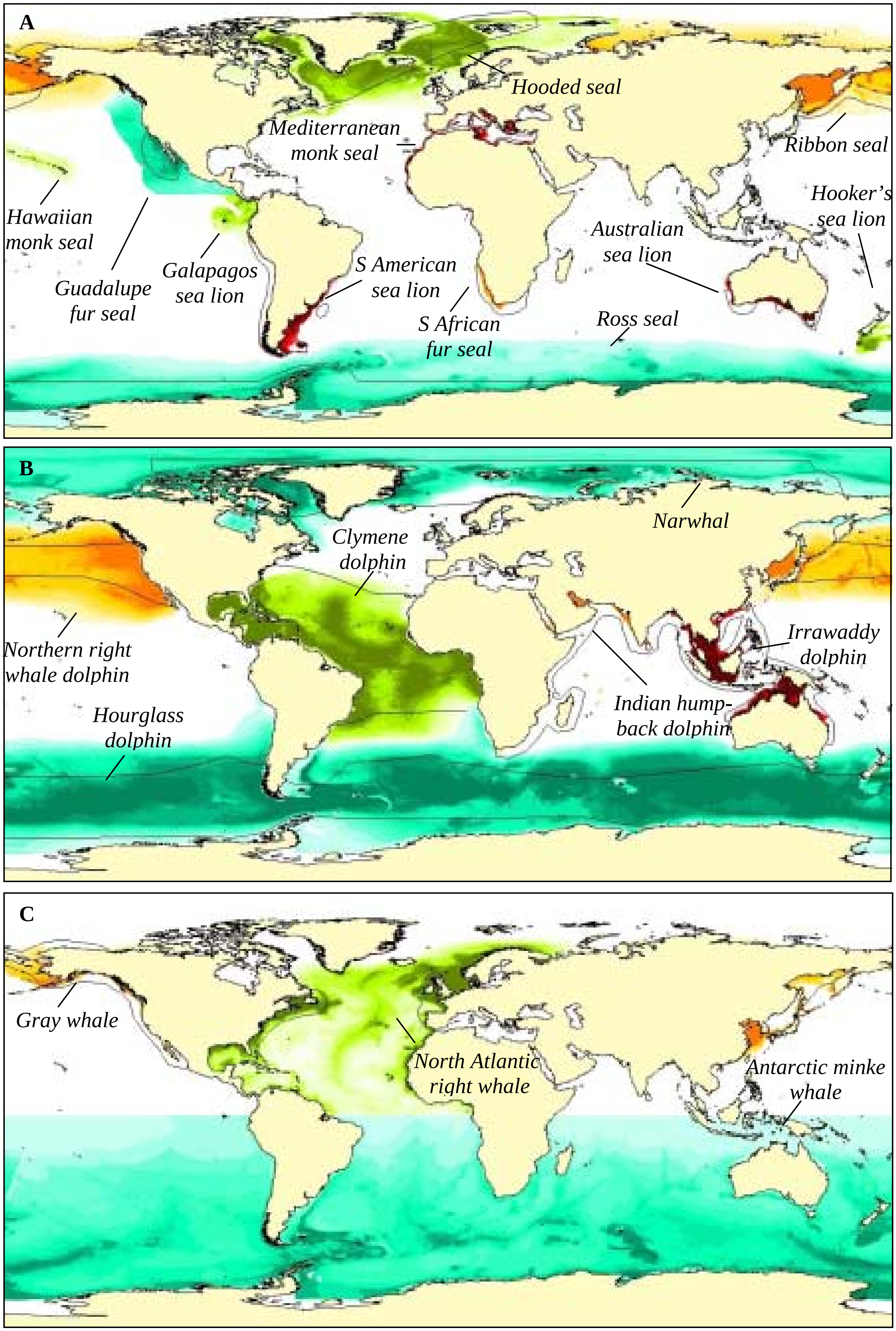
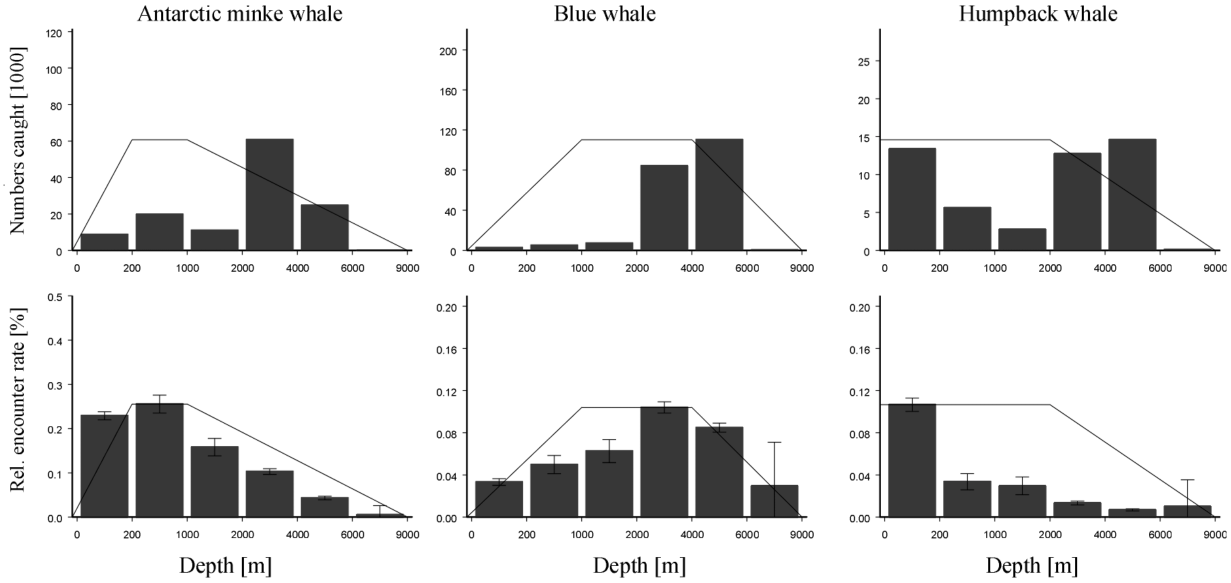

A
Hooded seal
Mediterranean monk seal
Ribbon seal
Hooker's sea lion
Hawaiian monk seal
Guadalupe fur seal
Galapagos sea lion
S American sea lion
Australian sea lion
S African fur seal
Ross seal
B
Narwhal
Clymene dolphin
Northern right whale dolphin
Irrawaddy dolphin
Hourglass dolphin
Indian hump-back dolphin
C
Gray whale
North Atlantic right whale
Antarctic minke whale

Figure 5.


Antarctic minke whale
Blue whale
Humpback whale
Numbers caught [1000]
Rel. encounter rate [%]
0
20
40
60
80
100
120
160
200
5
10
15
25
0.0
0.1
0.2
0.3
0.4
0.5
0.00
0.04
0.08
0.12
0.16
0.20
0
200
1000
2000
4000
6000
9000
Depth [m]
Depth [m]
Depth [m]

Appendix 1. Names, taxonomy and distributional range of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Bowhead whale	*Balaena mysticetus*	Mysticeti	Circumpolar N hemisphere
North Pacific right whale	*Balaena japonicus*	Mysticeti	N Pacific
Southern right whale	*Balaena australis*	Mysticeti	S hemisphere
North Atlantic right whale	*Balaena glacialis*	Mysticeti	N Atlantic
Sei whale	*Balaenoptera borealis*	Mysticeti	Circumglobal
Blue whale	*Balaenoptera musculus*	Mysticeti	Circumglobal
Eden/Bryde's whale	*Balaenoptera edeni*	Mysticeti	Indo-Pacific
Bryde's whale	*Balaenoptera brydei*	Mysticeti	Circumglobal
Fin whale	*Balaenoptera physalus*	Mysticeti	Circumglobal
Antarctic minke whale	*Balaenoptera bonaerensis*	Mysticeti	S hemisphere
Dwarf minke whale	*Balaenoptera acutorostrata*	Mysticeti	Circumglobal
Humpback whale	*Megaptera novaeangliae*	Mysticeti	Circumglobal
Gray whale	*Eschrichtius robustus*	Mysticeti	N Pacific
Pygmy right whale	*Caperea marginata*	Mysticeti	S hemisphere
Heaviside's dolphin	*Cephalorhynchus heavisidii*	Odontoceti	SW African waters
Hector's dolphin	*Cephalorhynchus hectori*	Odontoceti	New Zealand waters
Commerson's dolphin	*Cephalorhynchus commersonii*	Odontoceti	SE S American waters & Kerguelen
Black dolphin	*Cephalorhynchus eutropia*	Odontoceti	SW S American waters
Long-beaked common dolphin	*Delphinus capensis*	Odontoceti	Circumglobal (exc. N Indian O.)
Arabian common dolphin	*Delphinus tropicalis*	Odontoceti	N Indian O. & S China Sea
Short-beaked common dolphin	*Delphinus delphis*	Odontoceti	Circumglobal (exc. S Atlantic & Indian O.)
Pygmy killer whale	*Feresa attenuata*	Odontoceti	Circumglobal

Appendix 1 (cont.). Names, taxonomy and general distributions of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Short-finned pilot whale	*Globicephala macrorhynchus*	Odontoceti	Circumglobal
Long-finned pilot whale	*Globicephala melas*	Odontoceti	Circumglobal
Risso's dolphin	*Grampus griseus*	Odontoceti	Circumglobal
Fraser's dolphin	*Lagenodelphis hosei*	Odontoceti	Circumglobal
White-beaked dolphin	*Lagenorhynchus albirostris*	Odontoceti	N Atlantic
Hourglass dolphin	*Lagenorhynchus cruciger*	Odontoceti	S hemisphere
Dusky dolphin	*Lagenorhynchus obscurus*	Odontoceti	S hemisphere
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	Odontoceti	N Atlantic
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*	Odontoceti	N Pacific
Peale's dolphin	*Lagenorhynchus australis*	Odontoceti	S American waters
Northern right whale dolphin	*Lissodelphis borealis*	Odontoceti	N Pacific
Southern right whale dolphin	*Lissodelphis peronii*	Odontoceti	S hemisphere
Irrawaddy dolphin	*Orcaella brevirostris*	Odontoceti	Indo-Pacific
Killer whale	*Orcinus orca*	Odontoceti	Circumglobal
Melon-headed whale	*Peponocephala electra*	Odontoceti	Circumglobal
False killer whale	*Pseudorca crassidens*	Odontoceti	Circumglobal
Tucuxi	*Sotalia fluviatilis*	Odontoceti	NE S American waters
Indian hump-backed dolphin	*Sousa plumbea*	Odontoceti	W Indian O.
Atlantic hump-backed dolphin	*Sousa teuszii*	Odontoceti	NW African waters
Pacific hump-backed dolphin	*Sousa chinensis*	Odontoceti	Indo-Pacific
Pantropical spotted dolphin	*Stenella attenuata*	Odontoceti	Circumglobal
Atlantic spotted dolphin	*Stenella frontalis*	Odontoceti	Atlantic
Striped dolphin	*Stenella coeruleoalba*	Odontoceti	Circumglobal

Appendix 1 (cont.). Names, taxonomy and distributional range of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Clymene dolphin	*Stenella clymene*	Odontoceti	Atlantic
Spinner dolphin	*Stenella longirostris*	Odontoceti	Circumglobal
Rough-toothed dolphin	*Steno bredanensis*	Odontoceti	Circumglobal
Indian Ocean bottlenose dolphin	*Tursiops aduncus*	Odontoceti	Indo-Pacific
Bottlenose dolphin	*Tursiops truncatus*	Odontoceti	Circumglobal
Pygmy sperm whale	*Kogia breviceps*	Odontoceti	Circumglobal
Dwarf sperm whale	*Kogia simus*	Odontoceti	Circumglobal
Beluga or white whale	*Delphinapterus leucas*	Odontoceti	Circumpolar N hemisphere
Narwhal	*Monodon monoceros*	Odontoceti	Circumpolar N hemisphere
Finless porpoise	*Neophocoena phocaenoides*	Odontoceti	Indo-Pacific
Burmeister's porpoise	*Phocoena spinipinnis*	Odontoceti	S American waters
Harbour porpoise	*Phocoena phocoena*	Odontoceti	N hemisphere
Vaquita	*Phocoena sinus*	Odontoceti	Gulf of California, NE Pacific
Spectacled porpoise	*Phocoena dioptrica*	Odontoceti	S hemisphere
Dall's porpoise	*Phocoenoides dalli*	Odontoceti	N Pacific
Sperm whale	*Physeter macrocephalus*	Odontoceti	Circumglobal
Franciscana	*Pontoporia blainvillei*	Odontoceti	E S American waters
Arnoux's beaked whale	*Berardius arnuxii*	Odontoceti	S hemisphere
Baird's beaked whale	*Berardius bairdii*	Odontoceti	N Pacific
Northern bottlenose whale	*Hyperoodon ampullatus*	Odontoceti	N Atlantic
Southern bottlenose whale	*Hyperoodon planifrons*	Odontoceti	S hemisphere
Longman's beaked whale	*Indopacetus pacificus*	Odontoceti	Indo-Pacific

Appendix 1 (cont.). Names, taxonomy and distributional range of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Gray's beaked whale	*Mesoplodon grayi*	Odontoceti	S hemisphere
True's beaked whale	*Mesoplodon mirus*	Odontoceti	Atlantic & Indian O.
Andrews' beaked whale	*Mesoplodon bowdoini*	Odontoceti	S hemisphere
Gervais' beaked whale	*Mesoplodon europaeus*	Odontoceti	Atlantic
Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens*	Odontoceti	Indo-Pacific
Stejneger's beaked whale	*Mesoplodon stejnegeri*	Odontoceti	N Pacific
Hector's beaked whale	*Mesoplodon hectori*	Odontoceti	S hemisphere
Spade-toothed beaked whale	*Mesoplodon traversii*	Odontoceti	S Pacific
Pygmy beaked whale	*Mesoplodon peruvianus*	Odontoceti	E Pacific
Sowerby's beaked whale	*Mesoplodon bidens*	Odontoceti	N Atlantic
Strap-toothed whale	*Mesoplodon layardii*	Odontoceti	S hemisphere
Perrin's beaked whale	*Mesoplodon perrini*	Odontoceti	NE Pacific
Hubb's beaked whale	*Mesoplodon carlhubbsi*	Odontoceti	N Pacific
Blainville's beaked whale	*Mesoplodon densirostris*	Odontoceti	Circumglobal
Tasman or Shepherd's beaked whale	*Tasmacetus shepherdi*	Odontoceti	S hemisphere
Cuvier's beaked whale	*Ziphius cavirostris*	Odontoceti	Circumglobal
Walrus	*Odobenus rosmarus*	Pinnipedia	Circumpolar N hemisphere
Guadalupe fur seal	*Arctocephalus townsendi*	Pinnipedia	NE Pacific
South American fur seal	*Arctocephalus australis*	Pinnipedia	S American waters
Galapagos fur seal	*Arctocephalus galapagoensis*	Pinnipedia	Galapagos Is., E Pacific
South African & Australian fur seal	*Arctocephalus pusillus*	Pinnipedia	S African & S Australian waters
Subantarctic fur seal	*Arctocephalus tropicalis*	Pinnipedia	Circumpolar S hemisphere (exc. SE Pacific)
Antarctic fur seal	*Arctocephalus gazella*	Pinnipedia	Circumpolar S hemisphere (exc. SE Pacific)

Appendix 1 (cont.). Names, taxonomy and distributional range of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Juan Fernandez fur seal	*Arctocephalus philippii*	Pinnipedia	Juan Fernandez Islands, SE Pacific
New Zealand fur seal	*Arctocephalus forsteri*	Pinnipedia	New Zealand & S Australian waters
Northern fur seal	*Callorhinus ursinus*	Pinnipedia	N Pacific
Steller's sea lion	*Eumetopias jubatus*	Pinnipedia	N Pacific
Australian sea lion	*Neophoca cinerea*	Pinnipedia	SE Indian O., S & SW Australia
South (American) sea lion	*Otaria flavescens*	Pinnipedia	S American waters
Hooker's or New Zealand sea lion	*Phocarctos hookeri*	Pinnipedia	New Zealand waters, SW Pacific
Galapagos sea lion	*Zalophus wollebaeki*	Pinnipedia	Galapagos Islands, E Pacific
California sea lion	*Zalophus californianus*	Pinnipedia	NE Pacific
Hooded seal	*Cystophora cristata*	Pinnipedia	N Atlantic
Bearded seal	*Erignathus barbatus*	Pinnipedia	Circumpolar N hemisphere
Gray seal	*Halichoerus grypus*	Pinnipedia	N Atlantic
Ribbon seal	*Histriophoca fasciata*	Pinnipedia	N Pacific
Leopard seal	*Hydrurga leptonyx*	Pinnipedia	Circumpolar S hemisphere
Weddell seal	*Leptonychotes weddellii*	Pinnipedia	Circumpolar S hemisphere
Crabeater seal	*Lobodon carcinophagus*	Pinnipedia	Circumpolar S hemisphere
Southern elephant seal	*Mirounga leonina*	Pinnipedia	Circumpolar S hemisphere
Northern elephant seal	*Mirounga angustirostris*	Pinnipedia	NE Pacific
Hawaiian monk seal	*Monachus schauinslandi*	Pinnipedia	Hawaiian waters, NE Pacific
Mediterranean monk seal	*Monachus monachus*	Pinnipedia	Mediterranean & NE Atlantic
Ross seal	*Ommatophoca rossii*	Pinnipedia	Circumpolar S hemisphere
Harp seal	*Pagophilus groenlandica*	Pinnipedia	N Atlantic & Russian Arctic

Appendix 1 (cont.). Names, taxonomy and distributional range of 115 marine mammal species covered by RES model

Common name	Scientific name	Suborder	Distribution
Largha or spotted seal	*Phoca largha*	Pinnipedia	N Pacific
Harbour seal	*Phoca vitulina*	Pinnipedia	N hemisphere
Ringed seal	*Pusa hispida*	Pinnipedia	Circumpolar N hemisphere

Appendix 2 - Habitat preferences in terms of depth, mean annual sea surface temperature and distance to the edge of sea ice for 115 marine mammal species. Superscripts denote the particular habitat preference type about which the reference provided information: ^{1} = depth preferences, ^{2} = temperature preferences, ^{3} = distance to edge of sea ice. For species marked by *, distance from land was used as an additional constraining factor, limiting species to waters < 500 km (*) or < 1000 km (**) from land.

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Bowhead whale	mainly coast.-cont. shelf to end of cont. slope	polar only	mainly around edge of pack-ice	N hemisphere - (Baltic)	Jefferson et al, 1993^{2}; Klinownska, 1991^{2}, Krutzikowsky & Mate, 2000^{3}; Mate et al, 2000^{1,3}; Moore & DeMaster, 1997^{1,3}; Moore, 2000^{1}; Treacy, 2000^{3}
North Pacific right whale	mainly coast.-cont. slope to v. deep wat.	subpolar-subtropical	reg. but not pref. in areas of max. ice extent	N Pacific - (Lat < 10°N)	Angliss & Lodge, 2002^{3}; Jefferson et al, 1993^{2}; Kenney, 2002^{1,2,3}; Moore et al, 2000^{1,2}; Scarff, 1983^{1,3}; Tynan et al, 2001^{2}
Southern right whale	mainly coast.-cont. slope to v. deep wat.	polar-subtropical	reg. but not pref. around edge of the pack-ice	S hemisphere	Hamner et al, 1988^{1,2,3}; IWC, 2001^{3}; Kenney, 2002^{1}; Moore et al, 1999^{1}; Ohsumi & Kasamatsu, 1983^{2}; Payne, 1983^{1}; Tormosov et al, 1998^{3}
North Atlantic right whale	mainly coast.-cont. shelf to deep wat.	subpolar-tropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Atlantic - (Med., Black S., Hudson's Bay & Strait, Baltic)	Baumgartner et al, 2003^{1}; Evans, 1980^{1}; Gaskin, 1991^{2}; Jefferson et al, 1993^{3}; Kenney, 2002^{2}; Knowlton et al, 1992^{1}; Mitchell et al, 1983^{2}; Woodley & Gaskin, 1996^{1}
Sei whale	mainly cont. slope-abyss. plains to v. deep wat.	subpolar-tropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	World - (Black S., Med., Red S.)	Best & Lockyer, 2002^{1}; COSEWIC, 2003^{1,2}; Horwood, 1987^{2,}3; Kawamura, 1974^{2}; MacLeod et al, 2003^{1}; Ohsumi, 1977^{2}; Rice, 1998^{3}; Sigurjonsson, 1995^{1}
Blue whale	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-full tropical	mainly around edge of pack-ice, but also elsewhere	World - (Black S., Med., Red S.)	Heide-Joergensen, 2001^{1}; Hooker et al, 1999^{2}; Kasamatsu et al, 1996^{3}; Kasamatsu et al, 2000^{1,2,3}; Mate et al, 1999^{1}; Murase et al, 2000^{1}; Perry et al, 1999^{2}; Tynan, 1998^{3}; Yochem & Leatherwood, 1985^{3}; Zerbini et al, 1997^{2}
Eden/Bryde's whale	mainly coast.-cont. shelf to deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S., Med., Rea S., Persian Gulf, N Atlantic, SW Atlantic)	Best et al, 1984^{1}; Cummings, 1985^{2}; Jefferson et al, 1993^{3}; Kato, 2002^{1}; Klinowska, 1991^{2}; Nemoto, 1959^{2}; Ohsumi, 1977^{2}; Rice, 1998^{3}; Tersy, 1992^{1}

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Bryde's whale	mainly cont. slope-abyss. plains to v. deep wat.	subtropical-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S., Med.)	Best et al, 1984[1]; Cummings, 1985[2]; Jefferson et al, 1993[3]; Jefferson& Schiro, 1997[1]; Kawamura & Satake, 1976[2]; Kawamura, 1982[1]; Miyashita et al, 1996[2]; Rice, 1998[2,3]; Shimada & Pastene, 1995[1]
Fin whale	mainly cont. slope-abyss. plains to v. deep wat.	polar-tropical	predom. in areas of max. ice extent, but also elsewhere	World - (Black S., Red S., Persian Gulf)	Aguilar, 2002[2]; Kasamatsu et al, 2000[1,2]; MacLeod et al, 2003[1]; Moore et al, 2000[1]; Notarbartolo-di-Sciara et al., 2003[1]; Rice, 1998[2,3]; Zerbini et al, 1997[2]
Antarctic minke whale	mainly cont. slope to v. deep wat.	polar-tropical	mainly around edge of pack-ice, but also elsewhere	S hemisphere	Kasamatsu et al, 2000[1]; Murase et al, 2002[1,3]; Perrin & Brownell, 2002[1,3]; Ribic et al, 1991[2]; Rice, 1998[2,3]
Dwarf minke whale	mainly coast.-cont. slope to v. deep wat.	polar-tropical	predom. in areas of max. ice extent, but also elsewhere	World - (Baltic, Black S., Hudson's Bay & Strait, Red S., Persian Gulf)	Hamazaki, 2002[1]; IWC, 2001[1]; Jefferson et al, 1993[3]; Klinowska, 1991[3]; Moore et al, 2002[1]; Rice, 1998[2,3]; Sigurjonsson, 1995[1]
Humpback whale	mainly coast.-cont. slope to v. deep wat.	polar-tropical	reg. but not pref. in areas of max. ice extent	World - (Med., Black S., Baltic, Hudson's Bay & Strait, Red S.)	Benson et al, 2001[2]; Clapham, 2002[2]; Gregr & Trites, 2001[1]; Hamazaki, 2002[1,2]; Kasamatsu et al, 2000[3]; Moore et al, 2000[1]; Nicol et al, 2000[1,3]; Rice, 1998[3]; Winn & Reichley, 1985[2]; YoNAH, 2001[3]
Gray whale	mainly estuar. to beyond shelf break	subpolar-subtropical	reg. but not pref. around edge of the pack-ice	N Pacific	Deecke, 2003[1,2]; Gardner & Chavez-Rosales, 2000[2]; Jones & Swartz, 2002[1,2,3]; Moore & DeMaster, 1997[1,3];
Pygmy right whale	mainly coast.-cont. slope to v. deep wat.	subpolar-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere	Jefferson et al, 1993[1,2]; Kemper, 2002[1,2]; Matsuoka et al, 1996[2]; Rice, 1998[3]
Heaviside's dolphin	mainly estuar. to end of cont. shelf	c. temperate-w. temperate	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 50°E & > 20°W)	Best & Abernethy, 1994[1,2]; Dawson, 2002[1], Jansen van Vuuren et al, 2002[1,2]; Jefferson et al, 1993[1]; Rice, 1998[3]
Hector's dolphin	mainly estuar. to end of cont. shelf	c. temperate-w. temperate	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 180°E & < 150°E)	Dawson, 2002[1], Jefferson et al, 1993[1]; Slooten & Dawson, 1994[2]; Rice, 1998[3]
Commerson's dolphin	mainly estuar. to beyond shelf break	subpolar-c. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: > 120°E & > 72°W)	Dawson, 2002[1], Goodall, 1994[1,2]; Goodall et al, 1988[3]; Jefferson et al, 1993[1]; Rice, 1998[3]
Black dolphin	mainly estuar. to end of cont. shelf	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: < 70°W & < 180°E)	Aguayo, 1975[2]; Dawson, 2002[1], Goodall, 1994[1,2]; Goodall et al, 1988[1,2]; Jefferson et al, 1993[1]; Rice, 1998[3]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Long-beaked common dolphin	mainly coast.-cont. shelf to deep wat.	subtropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.)	Findlay et al, 1992[1]; Perrin, 2002[1,2]; Rice, 1998[1,2,3]
Arabian common dolphin	mainly coast.-up. cont. shelf to up. cont. slope	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	N hemisphere - (Med., Black S.; Lon > 180°E & < 30°E)	Balance & Pitman, 1998[1]; Perrin, 2002[2]; Rice, 1998[3]
Short-beaked common dolphin	mainly cont. slope to deep wat.	c. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Indian Ocean, S Atlantic)	Evans, 1994[1]; Griffin, 1997[1]; Hooker et al, 1999[1]; Perrin, 2002[2]; Selzer & Payne, 1988[2]; Rice, 1998[1,2,3]
Pygmy killer whale	mainly cont. slope to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S., Red S.)	Donahue & Perryman, 2002[2]; Findlay et al, 1992[1]; Jefferson et al, 1993[1,2]; Miyazaki & Wada, 1978[2]; Rice, 1998[3]; Ross & Leatherwood, 1994[2]
Short-finned pilot whale	mainly cont. slope to v. deep wat.	subtropical-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.)	Davis et al, 1998[1,2]; Jefferson et al, 1993[1]; Mullin et al, 1994[1]; Payne & Heinemann, 1993[1,2]; Rice, 1998[3]; Smith et al, 1986[2]; Wade & Guerrodette, 1993[2]
Long-finned pilot whale	mainly cont. slope to v. deep wat.	polar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	World - (Hudson's Bay, N Pacific)	Bernard & Reilly, 1999[1]; Findlay et al, 1992[2]; Hamazaki, 2002[1]; Hooker et al, 1999[2]; Jefferson et al,
Risso's dolphin	mainly up. cont. slope to deep wat.	c. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Baltic)	Baird, 2002[1]; Davis et al, 1998[1]; Jefferson et al, 1993[2]; Rice, 1998[3]; Ross, 1984[1]
Fraser's dolphin	mainly low. cont. slope-abyss. plains to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S., Red S.)	Dolar, 2002[1,2]; Jefferson et al, 1993[2]; Jefferson & Leatherwood, 1994[1,2]; Jefferson & Schiro, 2000[1]; Perrin
White-beaked dolphin	mainly coast.-cont. shelf to deep wat.	polar-c. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Atlantic - (Baltic, Hudson's Bay & Strait)	Kinze, 2002[1,2]; Northridge et al, 1997[1,3]; Reeves et al, 1999[1,2;] Rice, 1998[1,2]
Hourglass dolphin	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-w. temperate	mainly in areas of max. ice extent, but also elsewhere	S hemisphere	Gaskin, 1972[2]; Goodall, 2002[1,2]; Goodall, 1997[1,2,3]; Jefferson et al, 1993[1,3]; Kasamatsu et al, 1988[2]; Kasamatsu & Joyce, 1995[3]
Dusky dolphin	coast.-cont. slope to deep wat.	c. temperate-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere	Brownell & Cipriano, 1999[1]; Ciprian, 1992[2]; Goodall et al, 1997[1,3]; Kasamatsu et al, 1990[2]; van Waerebeek & Würsig, 2002[1,2]; Würsig & Würsig, 1980[2]; Würsig et al, 1997[1]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Atlantic white-sided dolphin	mainly low. cont. slope to v. deep wat.	subpolar-w. temperate	reg. but not pref. in areas of max. ice extent	N Atlantic - (Hudson's Bay & Strait)	Cipriano, 2002[1]; Hamazaki, 2002[2]; Hooker et al, 1999[1]; Leopold & Couperus, 1995[2]; Northridge et al, 1997[3]; Reeves et al, 1999[1]; Selzer & Payne, 1988[1,2]; Sergeant et al, 1980[2]
Pacific white-sided dolphin	mainly cont. slope to v. deep wat.	c. temperate-subtropcial	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Pacific	Barlow, 1995[1]; Brownell et al, 1999[2]; Buckland et al, 1993[1]; Dahlheim & Towell, 1986[2]; Forney & Barlow, 1998[1]; Green et al, 1992[1]; Heise, 1997[3]; Rice, 1998[3]; Smith et al, 1986[2]; van Waerebeek & Würsig, 2002[2]
Peale's dolphin	mainly estuar. to beyond shelf break	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: <20°W & >140°W)	Brownell et al, 1999[1]; Crespo et al, 1997[1]; Goodall et al, 1997[1,2,3]; Goodall, 2002[1]; Lescrauwaet, 1997[2]; Oporto; 1984[2,3]
Northern right whale dolphin	mainly low. cont. slope-abyss. plains to v. deep wat.	subpolar-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	N Pacific - (Lat: < 10°N)	Bjørge et al, 1991[1,2]; Forney & Barlow, 1998[1]; Jefferson & Newcomer, 1993[1]; Jefferson et al, 1993[1]; Jefferson et al, 1994[3]; Rice, 1998[3]; Smith et al, 1986[2]
Southern right whale dolphin	mainly cont. slope to v. deep wat.	polar-subtropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere	Cruickshank & Brown, 1981[2]; Findlay et al, 1992[1]; Gaskin, 1968[2]; Jefferson et al, 1993[1]; Kasamatsu et al, 1988[2]; Lipsky, 2002[3]; Newcomer et al, 1996[1]; Rose & Payne, 1991[1,2]; Rice, 1998[3]
Irrawaddy dolphin	mainly estuar. to end of cont. shelf	full-on tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Lon: > 156°E & < 80°E)	Arnold, 2002[1,2]; Freeland & Bayliss, 1989[1]; Mörzer Bruyns, 1971[2]; Parra et al, 2002[1,2]; Rice, 1998[3]; Stacey, 1996[1,2]
Killer whale	mainly cont. slope-abyss. plains to v. deep wat.	polar-tropical	mainly around edge of pack-ice, but also elsewhere	World - (Hudson's Bay & Strait, Black S., Red S, Persian Gulf)	Ford, 2002[3]; IWC, 2001[1,2,3]; Jefferson et al, 1993[2]; Jefferson & Schiro, 1997[1]; Kasamatsu et al, 2000[2,3]; Pitman et al, 2001[1]; Thiele & Gill, 1999[3]
Melon-headed whale	mainly cont. slope to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.)	de Boer, 2000[2]; Gunnier, 2000[1]; Jefferson et al, 1993[1,2]; Jefferson & Schiro, 1997[1]; Perryman et al, 1994[1,2]; Rice, 1998[3]
False killer whale	mainly low. cont. slope to v. deep wat.	w. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S., Red S, Persian Gulf)	de Boer, 2002[2]; Findlay et al, 1992[1]; Jefferson et al, 1993[1]; Miyazaki & Wada, 1978[2]; Rice, 1998[3]; Shallenberger, 1981[1]; Stacey et al, 1994[2]; Wade & Gerrodette, 1993[1,2]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Tucuxi	mainly estuar. to end of cont. shelf	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	W Atlantic - (Lat: > 13°N & Lon: < 20°W & > 70°W)	Borobia et al, 1991[2]; da Silva & Best, 1996[1]; Flores, 2002[1]; Jefferson et al, 1993[2]; Rice, 1998[3]
Indian hump-backed dolphin	mainly estuar. to end of cont. shelf	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.; Lon > 90°E & < 14°E)	Findlay et al, 1992[1]; Jefferson et al, 1993[2]; Jefferson & Karczmarski, 2001[1]; Karczmarski et al, 2000[1]; Rice, 1998[3]; Ross, 2002[1,2]
Atlantic hump-backed dolphin	mainly estuar. to end of cont. shelf	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	E Atlantic - (Lat: > 27°N & Lon: >13°E & > 20°W)	Jefferson et al, 1993[1,2]; Rice, 1998[3]; Ross et al, 1994[2]; Ross, 2002[1]
Pacific hump-backed dolphin	mainly estuar. to end of cont. shelf	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Lon: > 180°E & < 90°E)	Corkeron et al, 1997[1], Dolar et al, 1997[1]; Jefferson et al, 1993[2]; Jefferson & Karczmarski, 2001[1;2]; Rice, 1998[3]; Ross, 2002[1,2]
Pantropical spotted dolphin	mainly low. cont. slope to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.)	Baumgartner et al, 2000[2]; Baumgartner et al, 2001[1]; Fiedler & Reilly, 1994[2]; Hamazaki, 2002[1,2]; Miyazaki et al, 1974[2]; Mullin et al, 1994[1]; Perrin & Hohn, 1994[1]; Rice, 1998[3]
Atlantic spotted dolphin	mainly coast.-up. cont. slope to deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	Atlantic - (Lon: > 18°E & > 70°W)	Davis et al, 1998[1,2]; Hamazaki et al, 2002[2]; Herzing, 1990[1]; Mullin et al, 1994[1]; Perrin, 2002[1]; Rice, 1998[3]
Striped dolphin	mainly cont. slope to v. deep wat.	c. temperate-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S.)	Baird et al, 1993[1]; Bloch et al, 1996[2]; Davis et al, 1998[1]; Focada et al, 1990[2]; Gannier & Gannier, 1998[1]; Hooker et al, 1999[2]; Jefferson & Schiro, 1997[1]; Rice, 1998[3]
Clymene dolphin	mainly cont. slope-abyss. plains to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	Atlantic - (Lon: > 15°E & > 70°W)	Davis et al, 1998[1,2]; Mullin et al, 1994[1,2]; Perrin et al, 1981[1]; Rice, 1998[3]
Spinner dolphin	mainly cont. slope to v. deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World	Davis et al, 1998[1,2]; de Boer, 2000[2]; Dollar et al, 2003[1]; Jefferson et al, 1997[1]; Mullin et al, 1994[1]; Miyazaki & Wada, 1978[2]; Perrin, 2002[2]; Rice, 1998[3]
Rough-toothed dolphin	mainly cont. slope to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S. S, Red S.)	Davis et al, 1998[1,2]; Gannier, 2000[1]; Jefferson et al, 1993[2]; Jefferson & Schiro, 19971; Rice, 1998[3]
Indian Ocean bottlenose dolphin	mainly estuar. to end of cont. shelf	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S.; Lon: >180°E & <15°E)	Findlay et al, 1992[1]; Hale et al, 2000[1]; Rice, 1998[3]; Ross et al, 1987[1]; Wells & Scott, 2002[2]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Bottlenose dolphin	mainly coast.-up. cont. slope to deep wat.	c. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World	Baumgartner et al, 1999[2]; Canadas et al, 2002[1]; Findlay et al, 1992[1]; Hastie et al, 2003[1]; Hooker et al, 1999[2]; Jefferson et al, 1993[2]; Rice, 1998[3]; Wells et al, 1999[1;] Wells & Scott, 1999[2]
Pygmy sperm whale	mainly cont. slope to v. deep wat.	w. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S., Red S.)	Baumgartner et al, 2001[1]; Davis et al, 1998[1]; Jefferson et al, 1993[2]; McAlpine, 2002[3]; Mullin et al, 1994[1]; Rice, 1998[1,3]
Dwarf sperm whale	mainly up. cont. slope to deep wat.	w. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S., Red S.)	Baumgartner et al, 2001[1]; Davis et al, 1998[1]; Jefferson et al, 1993[2]; McAlpine, 2002[1,2]; Mullin et al, 1994[1]; Rice, 1998[3]
Beluga or white whale	coast.-cont. slope to deep wat.	polar-subpolar	mainly restricted to fast & deep pack-ice	N hemisphere - (Baltic)	Harwood et al, 1996[3]; Moore et al, 1993[1]; Moore & DeMaster, 1997[1,3]; Moore et al, 2000[1,3]; O'Corry-Crowe, 2002[2]; Rice, 1998[1,2]; Suydam et al, 2001[3]; Watts et al, 1991[2]
Narwhal	mainly up. cont. slope to deep wat.	polar only	mainly restricted to fast & deep pack-ice	N hemisphere	Dietz & Heide-Jørgensen, 1995[1]; Heide-Jørgensen, 2002[1,3]; Heide-Jørgensen et al, 2003[1]; Jefferson et al, 1993[2]; Martin et al, 1994[1]; Rice, 1998[3]
Finless porpoise	mainly estuar. to end of cont. shelf	w. temperate-full tropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	World - (Med., Black S.; Lat: > 8° S & Lon: > 180°E & < 48°E)	Amano, 2002[1,2]; Jefferson et al, 1993[1,2]; Kasuya, 1999[2]; Rice, 1998[3]; Yoshida et al, 2001[1]
Burmeister's porpoise	mainly coast.-cont. shelf to end of cont. slope	c. temperate-subtropcial	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: < 40°W & > 125°W)	Brownell & Praderi, 1983[2]; Brownell & Clapham, 1999[1]; Jefferson et al, 1993[1,2]; Goodall et al, 1995[1]; Reyes, 2002[1]; Rice, 1998[3]
Harbour porpoise	mainly estuar. to beyond shelf break	subpolar-w. temperate	reg. but not pref. in areas of max. ice extent	N hemisphere - (Hudson's Bay & Strait)	Bjørge & Øien, 1995[3]; Dahlheim et al, 2000[1]; Gaskin et al, 1993[2]; Palka, 1995[1,2]; Raym-Suryan & Harvey et al, 2001[1,2]; Raym-Suryan & Harvey, 1998[2]; Read & Westgate, 1997[1,2]
Vaquita	mainly estuar. to end of cont. shelf	narrow subtropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific	Jefferson et al, 1993[1,3]; Rojas-Bracho & Jaramillo-Legoretta, 2002[1,2]; Silber, 1990[1]; Silber et al, 1994[2]
Spectacled porpoise	mainly coast.-cont. slope to v. deep wat.	polar-c. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lat: > 65°S)	Goodall, 1978[1]; Goodall & Schiavini, 1995[2]; Goodall, 2002[1,2,3]; Jefferson et al, 1993[1]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Dall's porpoise	mainly coast.-cont. slope to v. deep wat.	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Pacific	Jefferson, 1988[1,2]; Jefferson, 2002[1]; Jones et al, 1987[2]; Miyashita & Kasuya, 1988[2]; Moore et al, 2002[1]; Rice, 1998[3]; Smith et al, 1986[1]
Sperm whale	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-full tropical	reg. but not pref. in areas of max. ice extent	World - (Red S., Black S.)	Davis et al, 1998[2]; Gordon et al, 2000[1]; Griffin, 1999[1]; Jaquet & Gendron,2002[1,2]; Kasuya & Miyashita, 1988[2]; Rice, 1998[3]; Whitehead, 2002[3]
Franciscana	mainly estuar. to end of cont. shelf	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	Atlantic - (Lat: > 0°N & Lon: < 20°W & > 70°W)	Crespo, 2002[1,2]; Jefferson et al, 1993[1]; Rice, 1998[3]; Secchi et al, 2001[1]
Arnoux's beaked whale	mainly low. cont. slope to v. deep wat.	polar-subtropical	predom. in areas of max. ice extent, but also elsewhere	S hemisphere	Balcomb, 1989[1,2,3]; D'Amico et al, 2003[1,2,3]; Jefferson et al, 1993[1,2]; Hobson & Martin, 1996[3]; Ponganis & Kooyman, 1995[1]
Baird's beaked whale	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-subtropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Pacific - (Lat: < 10°)	D'Amico et al, 2003[1,2,3]; Fedoseev, 1984[3]; Jefferson et al, 1993[1]; Kasuya et al, 1997[1]; Kasuya, 2002[1,2,3]; Reeves & Mitchell, 1993[1,2,3]
Northern bottlenose whale	mainly low. cont. slope to v. deep wat.	polar-w. temperate	predom. in areas of max. ice extent, but also elsewhere	N Atlantic - (Black S.)	Benjaminsen, 1972[1]; Benjaminsen & Christensen, 1979[1,2,3]; D'Amico et al, 2003[1,2,3]; Hooker et al, 1999[1]; Jefferson et al, 1993[2]; Reeves et al, 1993[1,3]
Southern bottlenose whale	mainly low. cont. slope-abyss. plains to v. deep wat.	polar-subtropical	mainly around edge of pack-ice, but also elsewhere	S hemisphere	D'Amico et al, 2003[1,2,3]; Jefferson et al, 1993[1]; Gowans, 2002[1]; Kasamatsu & Joyce, 1995[1]; Mead, 1989[1,3]; Rice, 1998[3]
Longman's beaked whale	rest. to abyss. to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Atlantic, Med., Black S.)	D'Amico et al, 2003[1,2,3]; Mead, 1989[1 ,2,3]; Pitman, 2002[2]
Gray's beaked whale	mainly cont. slope to v. deep wat.	subpolar-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere	D'Amico et al, 2003[1,2,3]; Gaskin, 1971[2]; Mead, 1989[1,2,3]; Pitman, 2002[1]; Rice, 1998[2]
True's beaked whale	mainly cont. slope to v. deep wat.	w. temperate-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S., Red S., Persian Gulf; Lon: > 150°E & > 70°W)	D'Amico et al, 2003[1,2,3]; Houston, 1990[1,2,3]; MacLeod, 2000[2]; Mead, 1989[1,2]; Pitman, 2002[1,2]; Waring et al, 2001[1]
Andrews' beaked whale	mainly cont. slope to v. deep wat.	c. temperate-subtropcial	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere	Baker, 2001[2], Gaskin, 1968[2], Gaskin, 1971[2]; Mead, 1989[1,3]; Pitman, 2002[1]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Gervais' beaked whale	mainly cont. slope to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	Atlantic - (Lon: > 30°E)	D'Amico et al, 2003[1,2,3]; Davis et al, 1998[1]; Mead, 1989[2,3]; MacLeod, 2000[2]; Pitman, 2002[1,2]; Rosario-Delestro et al, 1999[2]; Waring et al, 2001[1]
Ginkgo-toothed beaked whale	mainly cont. slope to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Atlantic, Med., Black S.)	Mead, 1989[1,2,3]; Miyakazi et al, 1987[2]; Pitman, 2002[1]
Stejneger's beaked whale	mainly cont. slope to v. deep wat.	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Pacific	D'Amico et al, 2003[1,2,3]; Houston, 1990[2]; Loughlin et al, 1982[1]; Loughlin & Perez, 1985[2,3]; Mead, 1989[1]; Miyazaki et al, 1987[2]; Pitman, 2002[1]; Rice, 1998[1,2]
Hector's beaked whale	mainly cont. slope to v. deep wat.	c. temperate-subtropcial	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere	D'Amico et al, 2003[1,2,3]; Mead, 1989[1,2,3]; Pitman, 2002[1]; Rice, 1998[2]
Spade-toothed beaked whale	mainly cont. slope to v. deep wat.	c. temperate-subtropcial	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 70°W & < 30°E)	van Helden et al, 2002[2,3]; depth preference inferred from other species
Pygmy beaked whale	mainly cont. slope to v. deep wat.	subtropical-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	Pacific	D'Amico et al, 2003[1,2,3]; Jefferson et al, 1993[3]; Mead, 1989[1]; Pitman, 2002[1]
Sowerby's beaked whale	mainly cont. slope to v. deep wat.	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Atlantic - (Med., Black S., Hudson's Bay & Strait, Baltic)	Carlström et al, 1997[1]; D'Amico et al, 2003[1,2,3]; Houston, 1990[1]; Hooker & Baird, 1999[1,2]; MacLeod, 2000[2,3]; Waring et al, 2001[1]
Strap-toothed whale	mainly cont. slope to v. deep wat.	polar-subtropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere	D'Amico et al, 2003[1,2,3]; Guiler et al, 1987[2]; Mead, 1989[1,2,3]; Pitman, 2002[1]
Perrin's beaked whale	mainly cont. slope to v. deep wat.	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N)	Dalebout et al, 2002[1]; D'Amico et al, 2003[1,2,3]; Mead, 1998[2]; Miyazaki et al, 1987[2]; Pitman, 2002[1]; Rice, 1998[3]
Hubb's beaked whale	mainly cont. slope to v. deep wat.	c. temperate-subtropcial	no assoc. w. ice edge, nowhere near ice at any time of the year	N Pacific - (Lat: < 10°N)	Houston, 1990[2,3]; MacLeod, pers comm[1]; Mead, 1989[1,2]
Blainville's beaked whale	mainly cont. slope to v. deep wat.	w. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Med., Black S. S, Red S., Persian Gulf)	D'Amico et al 2003[1,2,3]; Houston, 1990[1,2,3]; Moore, 1966[1]; Pitman, 2002[2]; Ritter & Brederlau, 1999[1]; Rosario-Delestro et al, 1999[2]; Shallenberger, 1981[1]
Tasman or Shepherd's beaked whale	mainly low. cont. slope to v. deep wat.	subpolar-w. temperate	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere	D'Amico et al, 2003[1,2,3]; Gaskin, 1971[2] Jefferson et al, 1993[1,2]; Mead, 1989[2]; Mead, 2002[1,2]; Rice, 1998[3]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Cuvier's beaked whale	mainly low. cont. slope to v. deep wat.	c. temperate-full tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	World - (Black S., Red S., Persian Gulf)	D'Amico et al, 2003[1,2,3]; Dolar et al, 1997[1]; Gannier, 2000[1]; Heyning, 2002[2]; Rice, 1998[2,3]; Waring et al, 2001[1]
Walrus	mainly estuar. to beyond shelf break	polar only	mainly around edge of pack-ice	N hemisphere	Born et al, 2003[1]; Estes & Gilbert, 1978[3]; Jay et al, 2001[1]; Jefferson et al, 1993[1]; Kastelein, 2002[1,3]; Rice, 1998[2,3]
Guadalupe fur seal*	mainly low. cont. slope to v. deep wat.	w. temperate-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N & Lon: > 150°W)	Belcher & Lee, 2002[2]; Lander et al, 2000[1]; Reijnders et al, 1993[2]; Rice, 1998[3]
South American fur seal*	mainly coast.-cont. shelf to end of cont. slope	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: < 20°W & > 100°W)	Bonner, 1981[2]; Daneri et al, 1997[3]; Jefferson et al, 1993[1]; Rice, 1998[3]
Galapagos fur seal*	mainly coast.-up. cont. shelf to up. cont. slope	narrow subtropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	E Pacific - (Lat: > 10°N & Lon: < 70°W & > 140°W)	Rejnders et al, 1993[1,2]; Rice, 1998[3]
South African & Australian fur seal*	mainly coast.-up. cont. shelf to up. cont. slope	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 160°E & > 20°W)	Arnould & Hindell, 2001[1]; Reijnders et al, 1993[2]; Rice, 1998[3]; Thomas & Schulein, 1988[1]
Subantarctic fur seal	mainly coast.-up. cont. slope to deep wat.		no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: > 20°W)	depth inferred based on Antarctic fur seals; Reijnders et al, 1993[2]; Rice, 1998[3]
Antarctic fur seal	mainly coast.-up. cont. slope to deep wat.	polar-subpolar	reg. but not pref. in areas of max. ice extent	S hemisphere - (Lon: > 80°W)	Bonnadonna et al, 2000[1]; Boyd et al, 1998[1]; C. Bradshaw pers. Comm[3]; Guinet et al, 2001[1]; Reijnders et al, 1993[2]; Ribic et al, 1991[1,2,3]; Rice, 1998[3]
Juan Fernandez fur seal*	mainly low. cont. slope to v. deep wat.	narrow w. temperate only	no assoc. w. ice edge, nowhere near ice at any time of the year	E Pacific - (Lat: > 0°N & Lon: > 100°W)	Francis & Ochoa-Acuna, 1998[1,2]; Ochoa-Acuna & Francis, 1995[1]; Reijnders et al, 1993[2]; Rice, 1998[3]
New Zealand fur seal*	mainly coast.-cont. shelf to deep wat.	subpolar-w. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lon: > 180°E & < 150°E)	Bradshaw et al, 2002[1]; Jefferson et al, 1993[2]; Lalas & Bradshaw, 2001[1]; Reijnders et al, 1993[1]; Rice, 1998[3]
Northern fur seal	mainly cont. slope to deep wat.	subpolar-w. temperate	reg. but not pref. in areas of max. ice extent	N Pacific	Antonelis et al, 1990[1]; Gentry, 1981[1,2]; Gentry, 2002[2]; Jefferson et al, 1993[1]; Loughlin & Ingraham, 1999[1]; Rice, 1998[3]
Steller's sea lion	mainly coast.-cont. shelf to end of cont. slope	subpolar-c. temperate	no assoc. w. ice edge, but season. close to areas of max. ice extent	N Pacific	Baba et al, 2000[1,2,3]; Merrick & Loughlin, 1997[1]; Loughlin et al, 1987[1]; Loughlin, 2002[1]; Rice, 1998[2,3]; Trites, pers. Comm[3]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Australian sea lion	mainly coast.-up. cont. shelf to up. cont. slope	w. temperate-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	S hemisphere - (Lon: > 155°E & < 75°E)	Costa, 1991[1]; Gales et al, 1994[2]; Jefferson et al, 1993[1]; Ling, 2002[2]; Rice, 1998[3]
South (American) sea lion*	mainly estuar. to end of cont. shelf	polar-subtropical	no assoc. w. ice edge, but season. close to areas of max. ice extent	S hemisphere - (Lat: > 60°S & Lon: < 40°W & > 120°W)	Campagna et al, 2001[1]; Jefferson et al, 1993[2]; Reijnders et al, 1993[2]; Rice, 1998[3]; Thompson et al, 1998[1]; Werner & Campagna, 1995[1]
Hooker's or New Zealand sea lion	mainly coast.-cont. shelf to end of cont. slope	subpolar-c. temperate	reg. but not pref. in areas of max. ice extent	W Pacific - (Lat: > 0°N)	Costa & Gales, 2000[1]; Crocker et al, 2001[1]; Gales, 2002[1,2]; Jefferson et al, 1993[2]; Rice, 1998[1,3]
Galapagos sea lion*	mainly coast.-cont. shelf to deep wat.	full tropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	E Pacific - (Lat: > 10°N & Lon: > 100°W)	Dellinger & Trillmich, 1999[2]; Heath, 2002[1]; Jefferson et al, 1993[1]; Rice, 1998[3]
California sea lion*	mainly up. cont. slope to deep wat.	w. temperate-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	N Pacific - (Lat: < 10°N & Lon: > 150°W)	Antonellis et al, 1990[1]; Heath, 2002[2]; Jefferson et al, 1993[1]; Rice, 1998[1,3]
Hooded seal	mainly low. cont. slope to v. deep wat.	polar-c. temperate	mainly around edge of pack-ice, but also elsewhere	N Atlantic	Folkow & Blix, 1995[1,3]; Folkow et al, 1996[1,3]; Folkow & Blix, 1999[1]; Kovacs & Lavigne, 1986[1,2,3]; Reijnders et al, 1993[2]; Rice, 1998[3]
Bearded seal	mainly coast.-up. cont. shelf to up. cont. slope	polar-subpolar	mainly around edge of pack-ice, but also elsewhere	N hemisphere - (Baltic)	Gjertz et al, 2000[1]; Kingsley et al, 1985[1]; Krafft et al, 2000[1]; Kovacs, 2002[1,2,3]; Lund et al, 1997[3]; Reijnders et al, 1993[2]; Rice, 1998[3]; Wiig, 1995[3]
Gray seal	mainly estuar. to beyond shelf break	subpolar-c. temperate	reg. but not pref. in areas of max. ice extent	N Atlantic - (Hudson's Bay & Strait)	Hall, 2002[3]; Jefferson et al, 1993[1,2]; McConnell et al, 1999[1]; Rice, 1998[3]; Sjöberg & Ball, 2000[1]; Thompson et al, 1996[1]
Ribbon seal	mainly coast.-cont. slope to deep wat.	polar-subpolar	mainly in areas of max. ice extent, but also elsewhere	N Pacific	Fedoseev, 2002[1,2]; Jefferson et al, 1993[1,2]; Mizuno et al, 2002[1,2]; Reijnders et al, 1993[1]; Rice, 1998[3]
Leopard seal	mainly up. cont. slope to deep wat.	polar-w. temperate	mainly around edge of pack-ice, but also elsewhere	S hemisphere	Jefferson et al, 1993[2]; King, 1983[2]; Knox, 1994[3]; Laws, 1984[1,2,3]; Rice, 1998[3]; Rogers, 2002[3]
Weddell seal	mainly coast.-cont. slope to v. deep wat.	polar-subpolar	mainly restricted to fast & deep pack-ice	S hemisphere	Hindell et al, 2003[1]; Jefferson et al, 1993[2]; Kooyman, 1981[2]; Lake et al, 2003[1]; Rice, 1998[3]; Stirling, 1971[3]; Thomas, 2002[1,3]; Wantabe et al, 2003[1]

Appendix 2 (cont.)

Common name	Depth range preference	Temperature range preference	Distance to ice edge preference	General area - (excluded areas)	Sources
Crabeater seal	mainly coast.-cont. shelf to deep wat.	polar-c. temperate	mainly around edge of pack-ice, but also elsewhere	S hemisphere	Bengtson, 1997[1]; Bengtson, 2002[1]; Jefferson et al, 1993[2]; Nordoy et al, 1995[1]; Ribic et al, 1991[1,2,3]; Rice, 1998[3]
Southern elephant seal	mainly cont. slope-abyss. plains to v. deep wat.	polar-tropical	mainly around edge of pack-ice, but also elsewhere	S hemisphere	Bennet et al, 2002[1]; Bornemann et al, 2000[3]; Boyd & Arnborn, 1991[2]; Bradshaw et al, 2002[2]; Campagna et al, 1998[3]; Hindell et al, 1991[1]; Hindell et al, 1999[2]; Hindell, 2002[1]; Ling & Bryden, 1992[2]; McConnell et al, 1992[1]; Rice, 1998[3]
Northern elephant seal	mainly low. cont. slope-abyss. plains to v. deep wat.	subpolar-subtropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N)	DeLong et al, 1992[1]; Hakoyama et al, 1994[2]; Hindell, 2002[1]; Rice, 1998[3]; Stewart & Hubert, 1993[1,2]
Hawaiian monk seal*	mainly coast.-cont. shelf to deep wat.	subtropical-tropical	no assoc. w. ice edge, nowhere near ice at any time of the year	NE Pacific - (Lat: < 10°N & Lon: < 140°W)	Gilmartin & Forcada, 2002[1]; Parrish et al, 2000[1]; Parrish et al, 2002[1]; Reijnders et al, 1993[2,3]; Schmelzer, 2000[2]
Mediterranean monk seal	mainly coast.-up. cont. shelf to up. cont. slope	subtropical only	no assoc. w. ice edge, nowhere near ice at any time of the year	N hemisphere - (Pacific, Indian O.; Lon: > 20°W)	Duguy, 1975[1]; Kenyon, 1981[1]; Reijnders et al, 1993[1,2,3]
Ross seal	mainly coast.-cont. slope to deep wat.	polar only	mainly restricted to fast & deep pack-ice	S hemisphere	Bengtson & Steward, 1997[1]; Bester et al, 1995[3]; Jefferson et al, 1993[2]; Knox, 1994[3]; Rice, 1998[3]; Splettstoesser et al, 2000[1]; Thomas, 2002[3]
Harp seal	mainly up. cont. slope to deep wat.	polar-c. temperate	mainly around edge of pack-ice, but also elsewhere	N hemisphere - (Baltic, Hudson's Bay & Strait, Black S.; Lon: > 95°W)	Joiris et al, 1996[3]; Kovacs & Lavigne, 1986[1]; Lawson et al, 1998[1]; Lacoste & Stenson, 2000[1]; Lavigne, 2002[1,3]; Reijnders et al, 1993[2]; Rice, 1998[3]
Largha or spotted seal	mainly coast.-cont. shelf to deep wat.	polar-w. temperate	predom. in areas of max. ice extent, but also elsewhere	N Pacific	Burns, 2002[2]; Jefferson et al, 1993[1]; Lowry et al, 2000[1,3]; Mizuno, 2002[1]; Reijnders et al, 1993[1]
Harbour seal	mainly coast.-up. cont. shelf to up. cont. slope	subpolar-w. temperate	reg. but not pref. in areas of max. ice extent	N hemisphere - (Med., Black S.)	Bjørge et al, 1995[1]; Burns, 2002[1,2]; Gjertz et al, 2001[1]; Lowry et al, 2001[1]; Rice, 1998[3]
Ringed seal	mainly coast.-cont. shelf to deep wat.	polar-subpolar	mainly in fast & deep pack-ice, but also elsewhere	N hemisphere	Kingsley et al, 1985[1]; Lund et al, 1997[3]; Miyazaki, 2002[2]; Reeves, 1998[1,3]; Rice, 1998[3]; Stirling et al, 1982[1]; Wiig et al, 1999[3]

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