Cetaceans and Climate Change – Assessing the Risks.

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Abstract

Here we provide an overview of the methods used to date to compare the likely sensitivity of animal species to climate change and test some potential sensitivity indicators for cetaceans.

This initial test indicated that indices should be applied on a population, rather than a species, basis, and that such assessments will require experts in the taxa concerned to work in co-operation with experts on the likely impacts in the relevant regions. The cetaceans may offer some unusual challenges in such assessments as some are highly migratory and, for others, there may not be adequate data to support assessment.

Consultation with a range of experts was used as a way to further assess and potentially develop indicators and the results of this consultation are also presented here.

Introduction

There is now unequivocal evidence that climate change is happening (IPCC, 2007). One of the irreversible changes that the International Panel on Climate Change has predicted is species loss and they estimate that 20-30% of the plant and animal species assessed so far are at an increased risk of extinction if global temperatures rise by 1.5-2.5^{o}C. This figure swiftly increases as temperature rises.

However, the precise implications of climate change for particular taxa are not clear and various initiatives are now underway to access likely impacts for particular species and to help identify the most sensitive ones. For example the World Conservation Union (IUCN) has started a process to consider this. They state that the “Species that are in greatest danger of climate-change driven extinction are those with high susceptibility to climatic changes, that also have distribution ranges that will experience large climatic changes and where their adaptive capacity is low" (IUCN, 2008). They have gathered such 'trait information' for the world's birds (9,856 species), amphibians (6,222 species) and reef-building corals (799 species). Preliminary analyses of life history and ecological traits of these groups suggest that up to 35% of birds, 52% of amphibians and 71% of reef-building corals have traits that are likely to make them particularly susceptibly to climate change. The IUCN intends to use biological traits indices in combination with spatial projections of future climate from General Circulation Models to produce assessments of "climate-change susceptibility" and use these to complement their Red List assessments of extinction risk. These combined assessments will be used as 'warning flags' to highlight the need for intensive monitoring and conservation action for the affected species.

Several authors have produced reviews considering the susceptibility of cetaceans to climate change, including MacGarvin and Simmonds (1996), Learmonth *et al*. (2006), Simmonds and Isaac (2007), Moore and Huntington (2008), Kovacs and Lydersen (2008), Laidre *et al*. (2008), and Simmonds and Elliot (2009). There seems reasonable consensus that species with restricted geographical distributions would be especially vulnerable and, similarly, those for which polar regions are key habitats. Laidre *et al*. (2008) comment that 'long term unidirectional changes, as opposed to large-scale interannual variation, present a particularly difficult challenge to the conservation of large polar marine mammals because such changes are likely to result in permanent habitat change, if not complete habitat loss, in some cases'. They also noted that 'habitat change or loss is critical when a species is highly specialized or dependent upon particular ecological conditions at specific times of the year.'

The International Whaling Commission is also considering this matter this year (2009) and will be holding a special intersessional workshop on climate change in Siena, Italy in February. The primary aim of the workshop is to determine how climate change is or may already be affecting cetaceans and how best to determine these effects (IWC, 2008). The Climate Change Workshop will bring together - and intends to enhance collaborations amongst - experts in cetacean biology, modelling, marine ecosystems and climate change, as well as reviewing current understanding and seeking to improve conservation outcomes for cetaceans under climate change scenarios described in the IPCC 4th report.

Developing criteria

The IUCN (2008) has identified five groups of biological traits that it believes will make species most susceptible to climate change. These are presented in Table 1.

Table 1. Biological traits that make species most susceptible to climate change - after IUCN (2008) with potential examples for cetaceans added.

- Specialized habitat and/or microhabitat requirements
  e.g. requirement for sea-ice as essential part of foraging habitat or of shallow, protected seas for breeding;
- Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle;
- Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change
  e.g. the trigger for migration;
- Dependence on interspecific interactions that are likely to be disrupted by climate change
  e.g. changes in prey type, abundance or distribution; changes in temporal/spatial overlap with competitors; increased prevalence of disease or parasites; and
- Poor ability to disperse to or colonize a new or more suitable range
  e.g. low genetic diversity or geographic containment.

Furness and Tasker (2000) have considered the biological traits that affect the vulnerability of bird species to changes in their prey and have attempted to quantify the sensitivity of seabirds to reductions in sandeel, *Ammodytes marinus*, abundance in the North Sea. (The recent fluctuations of sandeels are having a marked affect on seabird colonies and may be linked to climate change.) They used a five point scale for the following six variables: i. small size; ii. cost of foraging (with flapping flight at one end of the scale and ‘economical gliding’ at the other); iii. foraging range; iv. diving ability; v. ‘lack of spare time in diving ability’; and vi. low ability to switch diet. Scores were based on assumed vulnerability. For example, a small species being more vulnerable than a bigger one, a species with more energetic flight demands more vulnerable than one with lesser and so on. To make their assessments less subjective Furness and Tasker (2000) sent the first iterations of their vulnerability table to 10 seabird ecologists and made changes if two of more of this review panel suggested them. They also tested their indices against empirical data by looking at the breeding success of seabirds during periods of reduced food supply and found the results to be close to predictions. The kind of approach used by Furness and Tasker (2000) may be useful in application to cetaceans.

Laidre *et al*. (2008) developed a climate change sensitivity index specifically for Arctic cetaceans via a number of stages. First they looked at the species’ biology and habitat requirements. For example, in the case of the narwhal, they noted that it was the most specialised of the Arctic cetaceans and most restricted in distribution. In summer the whales spend approximately two months in High-Arctic ice-free shallow bays and fjords and they overwinter in offshore, deep, ice-covered habitats along the continental slope. These seasonal distributions are linked by lengthy migrations (>1000 km) of two month’s duration. Laidre *et al*. (2008) also noted a partitioning between the narwhals and belugas with the former preferring deep or offshore waters and the latter shallower waters.

Narwhals from Canada and West Greenland have a high site fidelity to the winter pack ice of Davis Strait and Baffin Bay in regions along the continental shelf which have particular features – high gradients in bottom temperatures, predictably open water (<5%), and relatively high densities of Greenland halibut (Laidre *et al*., 2004). (The overwintering grounds of some narwhal populations remain unknown.)

Laidre *et al*. (2008) go on to suggest that that the most critically important habitat for narwhals is their overwintering grounds. The low feeding activity in the summer has been contrasted with the high level of annual energy uptake likely in winter in Baffin Bay (Laidre and Heide-Jørgensen, 2005). It is clear that narwhals are highly adapted to pack ice habitat with limited open water in the winter period and 'no other cetacean species occupies such dense winter sea ice cover for such a long period of time' (Laidre *et al*., 2008). The narwhal was hence given a 1 rating for its sensitivity in terms of habitat specificity on a scale going from 1-3 (with three being the least sensitive).

In order to construct their sensitivity index, Laidre *et al*. (2008) looked at nine variables they deemed were likely to have the greatest influence on response and vulnerability of Arctic marine mammals to climate change. In each case, the variable and the score given to the narwhal are noted below:

1. Population Size: the current global population size is used: <100,000 = 1; 100,000-500,000 = 2; and a population size of greater that 500,000 was rated as a 3. The narwhal scored 1.

2. Breadth/extent of geographic range: the Arctic was divided into eight equivalent areas and if a species occurred in less than 5 it was given a 1 rating, 7-8 octants a two and those with a complete circumpolar distribution were awarded a three. The narwhal scored 1.

3. Habitat specificity: relating to the capacity of a species to use different habitats in the Arctic. Species were rated based on winter/spring habitat use and a species using seven or fewer types was given a 1; 8-9 a 2; and 9+ a 3. The narwhal scored 1.

4. Diet diversity: A species was given a 1 if only one prey species comprised >20% of its diet; a 2 if 2 prey species each comprised >20% of its diet; and a 3 if 3 or more prey types each comprised >20%. 'Prey types' in some cases were considered to be individual species and in others functional groups such as copepods. The narwhal scored 1.

5. Migrations: 1 was the score where the whole population undertook an annual migration of >1000 km along defined routes and with specific sites used through the year; 2 meant the population undertook smaller migrations or substantial region shifts; and a 3 related to the situation where the population stayed in the same general region through the year. The narwhal scored 1.

6. Individual Site Fidelity: a rating of one meant that individuals used the same site year after year; 2 represented fidelity to many different sites; and 3 was the case where some periods of the life cycle lacked any site fidelity. The narwhal scored 1.

7. Sea ice changes: 1 meant the species was critically dependent on sea ice to complete its life cycle or to feed; 2 meant changes in the sea ice would ‘moderately’ affect feeding success or life cycle but also that in the absence of ice other alternatives would be available; and 3 related to the situation where there was no dependence on sea ice. The narwhal was given a 3.

8. Influences of changes in trophic web: A species was given a rating of 1, if its carrying capacity would be expected to be reduced as a consequence of a warming ocean affecting its trophic web; 2 meant its carrying capacity would likely remain the same; and 3 meant there could be an increased availability of food and carrying capacity. The narwhal was given 2.

9. Maximum rate of population increase R max: R max ≤ 5% was rated 1; R max between 6 and 10% was classified as 2; and R max >10%, 3. The narwhal scored 1.

Overall the narwhal was given a combined score of 12, the lowest of the 11 species considered. By comparison the polar bear scored 14, the bowhead whale 16 and the ringed seal had the highest score at 25. The authors noted that the trophic web category (8) was a ‘speculative classification based on available knowledge of food chain relationships and possible alterations’.

Other criteria or traits might include the potential for climate to bring increased inter-specific competition, as for example highlighted by Kovacs and Lydersen (2008). The same authors raised the issue of increased human activities causing noise and pollution resulting from reduced ice cover in the Arctic and that the potential for this in a region could also be used to help gauge vulnerability.

The IUCN’s criteria were developed as the result of a workshop held in the UK in October 2007 (IUCN, 2007) and, in addition to the criteria mention so far, the workshop also drew attention to some others. These included ‘environmental tolerances’, relating to whether the species’ physiological tolerances might be exceeded due to climate change. Examples of environmental tolerance would include a species temperature range or pH range. The workshop also identified the presence of barriers to dispersal to a new range as an issue and also the genetic diversity of a species. Genetic diversity (usually assessed for ‘neutral’ genetic markers such as control region sequences or microsatellite profiles) may be important, since a species with reduced genetic diversity might have lost some of the breadth of specialized adaptations useful in particular times or area and, for example, be less able to respond to a changing environment or more susceptible to a novel pathogen or parasite.

The IUCN list also included susceptibility to capture (how valued or desired is the species or its close relatives); and to what extent (if any) the species is affected by the seasons. One aspect of this being ‘phenological cues’ (environmental triggers) that might be disrupted by climate change. It is likely that for many migratory species (which would include many cetaceans) finding particular conditions, such as adequately abundant and nutritional prey and certain temperatures for calf rearing, in certain places at certain times of year may also be of high importance (MacGarvin and Simmonds, 1996).

Methods

We have attempted to extend the methods used by Laidre *et al*. (2008) to others species using the following approach:

1. We applied their criteria to a range of cetacean species. For this initial exercise we selected species with widely differing biology: a river dolphin, the boto, *Inia geoffrensis*; a widespread oceanic dolphin species, the short-beaked common dolphin, *Delphinus delphis* (but only in its North Atlantic range); an endangered oceanic baleen whale, the blue whale, *Balaenoptera musculus*; an oceanic baleen whale where some populations are showing signs of recovery, the humpback whale, *Megaptera novaeangliae*; a highly migratory baleen whale which predominantly uses coastal waters and which has two distinctly different subpopulations, the gray whale, *Eschrichtius robustus*; a whale species that feeds in Antarctic waters and uses warm shallow waters for breeding, the southern right whales, *Eubalaena australis*. We have also included the narwhal in the same assessment.

2. As not all of these species are associated with polar ice, we added another category of 'Habitat Changes' which might be roughly equivalent to the sea-ice association trait, relating to other habitats that, like sea-ice could/will change with climate impacts, such as shallow breeding lagoons.

3. In addition we explored several other potential indicators:

i. Genetic variability – i.e. relating to low genetic diversity which may make species less able to respond to changes;

ii. Seasonal factors – seasonal movement between feeding and breeding grounds;

iii. Predicted regional intensity of climate change effects across the entire range of the species; and

iv. New competition – relating to the likelihood that other species will move into habitat areas and compete with, or otherwise adversely affect, the species in question; this could also be extended to adverse impacts of new human activities, such as the expansion of oil and gas exploration and extraction into polar regions following ice retreat.

In addition, we used the recently revised IUCN Red Data List category afforded to each species as an indicator. We note that population status and other factors used in the designation of Red List status overlap with some of the other criteria but the exhaustive process used in the development of the Red Lists appears highly relevant. (For our purposes here: Critically endangered/Endangered = 1; Vulnerable/ near threatened or data deficient = 2; Least concern = 3.)

The results of our initial assessment of these potential indicators is presented below as the first part of the results.

In addition to this, we took the opportunity afforded by the Workshop on Climate Change and Adaptation in the Eastern Pacific held in San Jose, Costa Rica, 9-11 February 2009, to seek expert opinion on the use of indicators. We did this by providing an earlier version of this paper to delegates who came from a range of marine disciplines. This version included the same descriptions of the indices given above and the same background explanations. In addition we provided them with a survey form which asked them to rank the 15 indices (as in table 2) from 1-5, with 5 being the most useful. We also asked them to recommend other indices and make any further comments that might wish too. Next, we asked them to describe their area of expertise. The survey form is included here as annex 2.

The utility of indices was also discussed in the cetacean working groups of the Costa Rican workshop and an attempt was made by experts from the region to apply the indices to a number of cetacean species from the Eastern Pacific region. Other working groups also considered the utility of these or similar indices for the taxa that they were considering.

Results

Results of initial assessment

Preliminary results are presented in Table 2 and an explanation for the scores used is provided in Annex 1.

This hasty assessment would seem to reinforce the vulnerability of the narwhal relative to other species, although there is little difference between it in this particular assessment and either the southern right whales or the western population of the gray whale.

The initial ranking here is narwhal>gray whale (western population)> southern right whale>gray whale (eastern)>humpback whale>blue whale>boto>common dolphin.

However, this initial assessment is presented for discursive purposes only and should not be used beyond this.

Results of consultation at the Costa Rican workshop

Twenty eight of the workshop participants returned the survey form completed and the primary results of their comments on the indicators are shown in Figure 1. There was a broad range of opinions about the usefulness of each. Overall there was less support for ‘Evolutionary history’ than any other indicator, followed by ‘new competition’ and ‘IUCN’ status. The relationship of the taxa to sea ice also received relatively little support but this may have been affected by the overlap between this and ‘other sensitive habitat’.

These results should not be overinterpreted, noting that even the most popular indices (Habitat Specificity) was still only ranked as '1' by 3 experts and the IUCN criterion, despite being relatively unpopular, was still rated 5 by 5 experts.

The workshop participants also recommended a range of new indicators for consideration and further to their initial identification the workshop was asked to describe their degree of support for these indicators.

The following 'new' indicators received strong support:

- A Population Health Parameter – meaning a measure of the apparent health status of the population and there was much discussion as to how this might be achieved including looking for indicators of poor body condition and/or respiratory problems that were affecting a critical percentage of the population (for example 10-30%);
- A Criterion Related to Anthropogenic Pressure – meaning some measure of overarching assessment of human impacts on the taxon, excluding fisheries removals;
- A Measure of Incidental Fisheries Take (the workshop thought this so important that it should be taken separately); and
- A Measure Related to Population Trend,

Less Strongly Supported were:

- A Factor Related to Toxic load;
- Status as Recognised in International Fora, and CITES was specifically mentioned in this context; and
- Food chain length (i.e. the longer the food chain the bigger the risk)

Also mentioned, but with limited support, were some aspect of social structure (the notion here being that some cetacean societies may be more robust to change than others), and also the recent history of vulnerability (e.g. stranding events/pathology) of a taxon.

The workshop participants also offered other comments about the development of criteria for assessment:

- They suggested that the criteria could be weighted relative one to another (i.e. some being more important than others);
- They felt that the criteria should be applied and interpreted with intelligence and care (a 'one size fits all' approach may not be appropriate);
- There was concern about the situations where data did not exist and it was not clear how the index might be applied where there was incomplete information for some taxa;
- There was considerable discussion about genetic indicators and a general conclusion that they would be useful but there was less clarity on which might be applied;

- It was noted that there was overlap in some potential criteria and the suggestion that some might be amalgamated. For example consideration of whether or not the taxon is migratory might be combined with site fidelity;
- Similarly could diet-related factors be combined;
- Workshop participants noted that the interpretation of many variables was subjective and that objectivity should be sought along with indicators which can be applied across many populations;
- Participants suggested that some affects might be cumulative and wondered if this could be worked into the index;
- Could acidification be taken into account?:
- Some noted that population determination – size and range - is affected by methodology; and finally
- Participants suggested that other parts of the world might benefit from a similar workshop to this one.

Table 2. Draft Sensitivity Table for cetacean species
*For the critically endangered western population of the gray whale scores are in square brackets.

Species	*Monodon monoceros*	*Inia geoffrensis*	*Balaenoptera musculus*	*Megaptera novaeangliae*	*Delphinus delphis*	*Eschrichtius robustus**	*Eubalaena australis*
	Narwhal	Boto	Blue whale	Humpback Whale	Common dolphin	Gray whale	S. Right whale
Population size	1	1	1	1	3	1[1]	1
Geographic distribution	1	2	2	3	3	2[2]	3
Habitat specificity	1	1	3	2	3	2[2]	1
Diet diversity	3	3	1	1	3	3[3]	2
Migrations	1	2	2	1	2	1[1]	1
Site fidelity	1	2	3	1	3	1[1]	1
Sea Ice Changes	3	-	-	-	-	-	-
Habitat changes	-	2	2	2	2	1[1]	1
Trophic web changes	3	3	2	2	3	3[3]	2
Rmax	1	1	1	1	1	1[1]	1
Genetic variability	1	2	3	2	3	1[1]	1
Seasonal factors	1	2	2	1	2	1[1]	1
Predicted regional intensity	1	3	1	2	2	2[2]	2
New competition	1	3	3	3	3	2[2]	3
IUCN status	2	2	1	3	3	3[1]	3
SUM	21	29	27	25	36	24[22]	23

Discussion

This is only a very preliminary test of the utility of some potential assessment criteria for a range of species and populations and was originally presented to facilitate discussion of this kind of approach by the Costa Rican climate change workshop.

The initial exercise highlighted for the authors a number of difficulties involved in making judgments about the sensitivities of cetacean species even beyond the subjectivity involved in some of the decision-making used here.

Issues included:

1. The need for a strict interpretation of criteria to minimize subjectivity, which may include elaboration of the indices to facilitate this;

2. Obtaining adequate data on which to make judgments (in the case of some species or populations there may not be inadequate information and this then raises the question of how this should be addressed);

3. That attempting to make single assessments for species which are composed of populations with differing status and/or other circumstances is difficult at best, misleading and unhelpful at worst. (Note that we did not even attempt this for the two gray whale populations);

4. We also experienced particular difficulty in trying to assess the river dolphin species relative to the others because of its particular habitat (and our lack of knowledge); and

5. Whether, or not, all traits/criteria/indices should be treated as having similar values or in some way weighted relative to each other. For example should the vulnerability of critical habitat be ascribed the same weighting as genetic diversity? (It has been suggested to us that the genetic diversity indicator may be misleading as some marine mammal populations with seemingly low genetic diversity appear to be robust (Cipriano, pers comm..)).

Note also that we have made many assumptions in this assessment that further research may or may not prove right. For example we are unsure if the common dolphin in the north Atlantic has high genetic variability but, as it is a wide ranging and relatively numerous species, we have assumed that this is the case. (See annex 1 for further details of the assumptions and resources used.)

Consulting with a large group of experts via the Costa Rican workshop proved to be a useful exercise. There is general support for the application of a sensitivity index, although much debate over the precise criteria that it might be composed of and how they should be applied. Generally it was felt that more indicators were better than fewer but also that some were more important than others and they should those be weighted relative to each other.

If a set of strictly interpretable criteria for assessment of cetaceans worldwide can be established, then experts on particular cetacean taxa might usefully be recruited to evaluate them for particular populations (as done by Laidre *et al*. (2008) for Arctic species). Their work would need to be carefully combined with that of experts in the impacts of climate changes in the regions where the population occurs to ensure the most robust outcomes and such assessment would probably need to be repeated on a regular basis as conditions may change unpredictably. Highly migratory species will occur across a range of regions requiring assessment of the likely changes in each.

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The notional evaluations of species/populations presented here should not be used for any management or conservation purposes.

References

Furness, R.W. and Tasker, M.L. 2000. Seabird-fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. *Marine Ecology Progress Series* 202: 253-264.

IPCC 2008 Climate change 2007: Synthesis Report. Summary for Policymakers. Intergovernmental Panel for Climate Change.

IUCN 2007. Report – Workshop: Species Vulnerability Traits. 14 pages unpublished.

IUCN 2008 Species susceptibility to climate change impacts. Fact sheet. 4 pages. Available at: http://cmsdata.iucn.org/downloads/climate_change_and_species.pdf

Kovacs, K.M. and Lydersen, C. 2008. Climate Change impacts on seals and whales in the North Atlantic Arctic and adjacent sea areas. *Science Progress* 91(2): 117-150

Laidre, K.L., Heide-Jørgensen, M-P., Jørgensen, O.A. and Treble, M.A. 2005. Deep ocean predation by a high Arctic cetacean. *ICES journal of Marine Science* 61:430-440.

Laidre, K.L., Stirling, I., Lowry, L.F., Øystein Wiig, Heide-Jørgensen, M-P., Ferguson, S.H. 2008. Quantifying the sensitivity of Arctic Marine Mammals to Climate-Induced habitat change. *Ecological Applications* 18(2) Supplement: S97-S125

Laidre, K.L. and Heide-Jørgensen, M-P. 2005 Winter feeding intensity in narwhals (Monodon monoceros). *Marine Mammal Science* 21: 45-57.

Moore, S.E. and Huntington, H.P. 2008. Arctic marine mammals and climate change impacts and resilience. *Ecological Applications* 18(2): S157-S165

MacGarvin M. and Simmonds, M.P. 1996 Whales in a changing ocean. In: Simmonds M.P. & Hutchinson J.D. (Editors) '*The Conservation Of Whales and Dolphins: Science and Practice'*. John Wiley, London.

Simmonds, M.P. and Elliot, W.J. 2009. Climate change and cetaceans: concerns and recent developments. *Journal of the Marine Biological Association of the United Kingdom* (in press).

Simmonds, M.P. and Isaac, S.J. The impacts of climate change on marine mammals: early signs of significant problems. *Oryx* 41: 19-26

Annex 1. Rationale for sensitivity criteria shown in Table 2.

Information used in the scoring process is from the IUCN Red List (http://www.iucnredlist.org/) unless otherwise specified. * marks highly subjective judgments based on own understanding.

Rmax was judged as '1' for all species being considered.

1. Short-beaked Common Dolphin, Delphinus delphis (North Atlantic population only)

Population

Worldwide > 4 million. In the Atlantic, abundance in European continental shelf waters was estimated at 63,400 (95% CI=27,000-149,000) in 2005. Offshore, abundance in a block bounded by 53-57ºN and 18-29ºW was estimated at 273,000 (95%CI=153,000-435,000) in 1995. West of the Bay of Biscay, 62,000 common dolphins were estimated in the fishing grounds of the albacore tuna driftnet fishery in 1993. In the western North Atlantic, 121,000 (CV=0.23) were estimated to occur.

Total: 519,400 (Score 3)

Geographic Distribution
Widespread in the North Atlantic (Score 3)

Habitat Specificity
Distribution is mainly widespread but offshore; a shallow diving species. (Provisionally 3).

Diet Diversity
The prey of common dolphins consists largely of small schooling fishes and to a lesser extent squid. Pusineri *et al*. (2007) suggest that the common dolphin forages preferentially on small schooling, vertically migrating mesopelagic fauna in the surface layer at dusk and early night. (Provisionally 3).

Migrations
*Not typically regarded as highly migratory but does make seasonal movement seemingly following prey (for example into the English Channel in the winter). (Provisionally 2).

Site fidelity
*Wide-ranging. (3)

Habitat change
*Arguably vulnerable to changes in the North Atlantic Gulf stream. (Provisionally 2).

Trophic Web changes
Varied habitats and diet; populations could adapt (3).

Genetic variability
* Assumed high (3)

Seasonal Factors
*Some movement seemingly tied to diet.(2)

Predicted Regional Intensity
*Gulf stream changes (2)

New Competition
* Probably not (3)

IUCN status
Least concern (3)

2. Narwhal *Monodon monoceros* (Only occurs in specific region – world population)

First nine critera scored as per Laidre *et al*. (2008)

Genetic variability
Extremely low nucleotide diversity (0.0017 – one of the lowest ever recorded for cetaceans) with low average pair-wise genetic distances suggesting recent (i.e. past several tens of thousands of years) expansion from a small bottlenecked population.

Despite the low levels of genetic variation, frequency differences among the most common haplotypes between areas were identified. These data suggest some site philopatry, with the possibility of mixing of pods with different haplotypic compositions in a single breeding ground (Weider and Hobaek, 2000). (Score 1).

Seasonal Factors
Strong seasonal movements. (1)

Predicted Regional Impact
Changes in Arctic sea ice marked. (1)

New Competition
Influx of other whales species possible and considerable concern about new human activities in the region (e.g. Moore and Huntingdon, 2008) (1)

IUCN Status
Near threatened (2).

3. Boto, *Inia geoffrensis* (Only occurs in specific region – world population)

Population
Unclear, but highly likely to be <100,000 (Score 1)

Distribution
Widespread and relatively common throughout the Amazon and Orinoco river basins, from the deltas upstream to where impassable rapids, waterfalls, lack of water, and possibly low temperatures block their movement. (2)

Habitat specificity
Limited to river habitat (1)

Diet diversity
Botos feed on a large variety of fishes (over 43 species), generally near the bottom Therefore highly likely 3 prey types > 20% of diet (Score 3)

Migrations

Mark/recapture studies have shown that some individuals are resident to specific areas year-round whereas others move several tens to hundreds of kilometers within the rivers, but there does not appear to be any actual seasonal migration. (3)

Habitat change

There is evidence for harmful and beneficial effects of climate change on tropical river habitats. (Nijssen *et al*. 2001) (2)

Trophic web

Exploits over 43 different species - would therefore assume adaptable to trophic web changes. (3)

Genetic variability

The overall nucleotide diversity found in *Inia* is - 2.8% control region (Banguera-Hinestroza *et al*. 2002). (3)

Seasonal Factors

Large river systems are subject to major changes between the wet and dry seasons which may be important in opening up foraging range and bringing nutrients into the river systems. (2)

Regional Intensity

Unclear (3)

New competition

Unclear (3)

IUCN Status

Data deficient (2)

4. Blue Whale, *Balaenoptera musculus* (World population)

Population

The global population of blue whales is uncertain, but plausibly in the range 10,000-25,000, corresponding to about 3-11% of the 1911 population size. (1)

Distribution

Found in all oceans except the Arctic, but absent from some regional seas such as the Mediterranean, Okhotsk and Bering seas. (2)

Habitat specificity

Worldwide distribution, but oceanic (3)

Diet

Blue whales feed almost exclusively on euphausiids (krill), with a variety of species being taken by different blue whale populations (1)

Migration
The migration patterns of blue whales are not well understood and some populations appear to be resident year-round in high productivity zones. (2)

Site fidelity
Evidence of nine different groupings, but nothing to suggest they rely heavily on particular localities. (3)

Habitat change
Oceanic distribution but reliance on high productivity zones. (2)

Trophic Web
Warming is likely to alter the spatial distribution of primary and secondary pelagic production (e.g. Richardson and Schoeman, 2004) (2)

Genetic variability
*Significant reduction in populations caused by whaling may well have reduced genetic variability (2)

Seasonal Factors
Some populations require to find certain resources seasonally, although this is not well understood. (2)

Predicted Regional Intensity
This will varying between populations (which indicates that an assessment for a wide ranging species with different populations is probably invalid). For populations that need to find food in Antarctic waters regional intensity may be high hence the score (1).

New competition
Unlikely (3)

IUCN Status
Endangered (1)

5. Humpback whale, *Megaptera novaeangliae* (World population)

Population
Estimated at over 60,000 animals and increasing. (1)

Distribution
Found in all the major ocean basins, and all but one of the subpopulations (in the Arabian Sea) migrate between mating and calving grounds in tropical waters. (3)

Diet

Limited data but varies between populations. In the Southern Hemisphere, humpbacks appear to feed mainly in the Antarctic, where the diet consists almost exclusively of krill. Humpback whales caught off Newfoundland and Labrador in the 1950s and 1960s were found to be consuming mainly capelin (Mallotus villotus) and a range of schooling fish are reported as prey from elsewhere. (2).

Migration
Extensive migrations (all but one sub-population) (1).

Site fidelity
*Fidelity to many different sites throughout lifecycle. (1)

Habitat change
Antarctic feeding grounds may be vulnerable but different populations will have different sensitivities (which brings into question trying to apply this approach to entire world populations). (2)

Trophic web changes
(Richardson and Schoeman, 2004)(2)

Genetic variability
The nucleotide diversity of humpbacks worldwide is 2.4% but less for some local *Megaptera novaeangliae* populations (0.89% for the Mexican population and 0.63% for the Hawaii population) (Banguera-Hinestroza *et al*. 2002). (2)

Seasonal Factors
Has requirements at either end of migrations (1)

Predicted Regional Intensity
Particular concern for Antarctic feeding grounds for some populations (2)

New Competition
Unlikely (3)

IUCN Status
Least concern (3)

6. Gray Whale, *Eschrichtius robustus* (Western Sub population) [Eastern Sub-population]

Population
The western subpopulation seems to have peaked around 1997/98 when a census on the southward migration indicated a population of 24,000-36,000; it may have declined since the most recent estimate is 15,000-22,000 for 2001/02. This is regarded as a fluctuation and may relate to carrying capacity.

The Eastern population is very small and regarded as critically endangered. Because the two populations are so distinctly different, we consider them separately. [Square brackets indicate comments and scores for the Eastern population.] (1)[1]

Geographic range

The larger eastern North Pacific population summers and feeds mainly in the shallow waters of the Chukchi and Beaufort seas, and the northwestern Bering Sea; a few also summer and feed along the Pacific coast from Vancouver Island (Canada) to central California (US).

Wide range but predominately in inshore waters.
(2)[2]

Habitat specificity

Gray whales are primarily bottom feeders and are thus restricted to shallow continental shelf waters for feeding. They are largely coastal although they do feed at greater distances from shore on the shallow shelf of the Bering and Chukchi seas. (2)[2]

Diet diversity

Gray whales feed primarily on swarming mysids, tube-dwelling amphipods, and polychaete tube worms in the northern parts of their range, but are also known to take red crabs, baitfish, and other food (crab larvae, mobile amphipods, herring eggs and larvae, cephalopods, and megalops) opportunistically or off the main feeding grounds.

Highly likely 3 prey types > 20% (3)[3]

Migrations

The population migrates in autumn along the coast to winter breeding grounds on the west coast of Baja California (Mexico) and the southeastern Gulf of California. Some calves are born during the southward migration but most are born in shallow bays and lagoons on the west coast of Baja California

Whole population annual migration > 1000km (1)[1]

Site fidelity

Exhibits fidelity to many different sites throughout lifecycle. (1)[1]

Habitat Changes

High latitude feeding grounds may be especially vulnerable.(1)[1]

Trophic web changes

Shown to be opportunistic feeders; likely to adapt. (3)[3]

Rmax

Thus, estimates of their maximum net recruitment have ranged from 0.05-0.08 in stock assessments (e.g.Wade, 2002; Wade and Perryman, 2002) and for Eastern Greys less. (1)[1]

Genetic variation
Higher levels of genetic diversity in the eastern population (mean He = 0.759) when compared with the western population (mean He=0.724) (Lang *et al*. 2004) (1)[1]

Seasonal Factors
Requirement to find resources in certain seasons in certain places. (1)[1]

Predicted Regional Intensity
Changes in high latitude feeding grounds may be pronounced (2)[2]

Competitors
A change in competing species is perhaps unlikely. However changes in industrial activities may follow in coastal waters in particular – for example renewable energy plants (2)[2]

IUCN status
Least concern/Critically Endangered (3)[1]

7. Southern Right Whale, *Eubalaena australis* (World Population)

Population
Several breeding populations (Argentina/Brazil, South Africa, and Australia) of southern right whales have shown evidence of strong recovery. Estimated total population size as of 1997 was 7,500 animals. (1)

Geographic distribution
Southern right whales have a circumpolar distribution in the Southern Hemisphere. The distribution in winter, at least of the breeding component of the population, is concentrated near coastlines in the northern part of the range. Major current breeding areas are nearshore off southern Australia, New Zealand (particularly Auckland Islands and Campbell Islands), Atlantic coast of South America (Argentina and Brazil), and southern Africa (mainly South Africa). (3)

Habitat specificity
Appears to use a range of habitats but number unclear (2).

Diet
Where feeding occurs north of 40°S, the diet consists mainly of copepods, south of 50°S mainly euphausiids (krill), and varying proportions of the two food items at intermediate latitudes

Highly likely 1 prey species > 20% diet. (1)

Migrations
Whole population annual migration > 1000km. (1)

Valenzuela *et al*. (2008) report that southern right whales show maternally inherited site fidelity to near-shore winter nursery grounds. They consume large quantities of copepods and krill, and their reproductive rates respond to fluctuations in krill abundance linked to El Niño Southern Oscillation (ENSO). The time scale of culturally inherited site fidelity to feeding grounds is at least several generations. Valenzuela *et al*. comment that 'such conservatism would be expected to limit the exploration of new feeding opportunities, and might explain why this population shows increased rates of reproductive failure in years following sea surface temperature anomalies off South Georgia'.

Site Fidelity
Strong evidence of site fidelity.(1)

Habitat change
Both cold feeding grounds and shallow breeding grounds appear vulnerable (1)

Trophic web changes
(2)

Genetic variability
Assumed affected by high hunting pressure and see Rosenbaum *et al*. (2000) (1).

Seasonal Factors
Requirement for certain features in certain places at certain times of year (1)

Predicted Intensity
Cold water feeding grounds may be particularly vulnerable (2)

New Competition
Unlikely (3)

IUCN Status
Least concern (3)

Annex References

Banguera-Hinestroza, E., Cardenas, H., Ruiz-Garcıa, M., Marmontel, M., Gaitan, E., Vazquez, R., Garcıa-Vallejo, F. 2002. Molecular Identification of Evolutionarily Significant Units in the Amazon River Dolphin Inia sp. (Cetacea: Iniidae).The American Genetic Association, 93:312–322.

IWC, 2008. Scientifc Committee Report: Annex K: Report of the Standing Working Group on Environmental Concerns.

Lang, A R; Weller, D W; Le Duc, R G; Burdin, A M; Hyde, J; Brownell Jr., R L 2004. Genetic differentiation between western and eastern gray whale populations using microsatellite markers. Report to the IWC Scientific Committee, 2004.

Nijssen, B., O'Donnell, G.M., Hamlet, A. F., Lettenmaier, D.P. 2001. Hydrologic sensitivity of global rivers to climate change. Climatic Change, 50: 143-175.

Moore, S.E. and Huntington, H.P. 2008. Arctic marine mammals and climate change impacts and resilience. Ecological Applications 18(2): S157-S165

Pusineri, C. Magnin, V., Meynier, L., Spitz, J., Hassani, S., Ridoux. V. 2007. Food and feeding ecology of the common dolphin (*Delphinus delphis*) in the oceanic northeast Atlantic and comparison with its diet in neritic areas. Marine Mammal Science, 23: 30 – 47.

Richardson, A. J. and Schoeman, D. S. 2004. Climate Impact on Plankton Ecosystems in the Northeast Atlantic. Science, 305: 1609 – 1612

Rosenbaum, HC, Brownell, RL, Brown, MW, Schaeff, C *et al*. 2000. World-wide genetic differentation of *Eubalaena* questioning the number of right whale species. Molecular Ecology, 9: 1793-1802.

Valenzuela, L.O., Sironi, M., Rowntree, V., Seger, J. (2008) Isotopic and genetic evidence for site fidelity to feeding grounds in southern right whales (*Eubalaena australis*). J. Cetacean Res. Manage.
Wade, P.R. and Perryman, W. 2002. An assessment of the eastern gray whale population in 2002. Available online at http://iwcoffice.org/_documents/sci_com/workshops/MSYR/SC-54-BRG7.pdf

Weider, L. J., Hobaek, A. 2000. Phylogeography and arctic biodiversity: a review. Annales Zoologici Fennici, 37: 217-231.

Annex 2. CRITERIA FOR EVALUATING THE SENSITIVITY OF CETACEANS TO CLIMATE CHANGE (Survey Form)

The following criteria might be used to evaluate the sensitivity of cetaceans to climate change. Please grade the usefulness of these criteria from 1-5 (1 = least useful, 5 = most useful)[1].

Criterion	**Grade**
Population size	
Extent of range	
Habitat specificity	
Diet diversity	
Extent of migration/non migratory	
Site fidelity	
Relationship to Sea Ice	
Relationship to other highly vulnerable habitat – e.g. coastal breeding lagoons.	
Habitat changes	
Likely exposure to climate change induced trophic web changes	
Reproductive Rate	
Evolutionary history	
Genetic variability	
Extent to which species/population is affected by seasonal triggers and/or exhibits seasonal behaviours	
Predicted regional intensity of climate	

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[1] For further details about these criteria and their potential application, please see the paper presented to this workshop by Simmonds and Smith.

change impact within range of species/population	
Likelihood that climate change will create new competition for species/population and/or additional negative interactions with people	
IUCN status	

Do you have any suggestions for other criteria?

Do you have any further comments about these criteria or the effects of climate change on cetaceans?

Please could you tell us your area of expertise:

Cetacean biology ☐
Marine biology ☐
Oceanography ☐

Other (please describe) ______________________________
Name and affiliation______________________________
Email address______________________________

THANK YOU

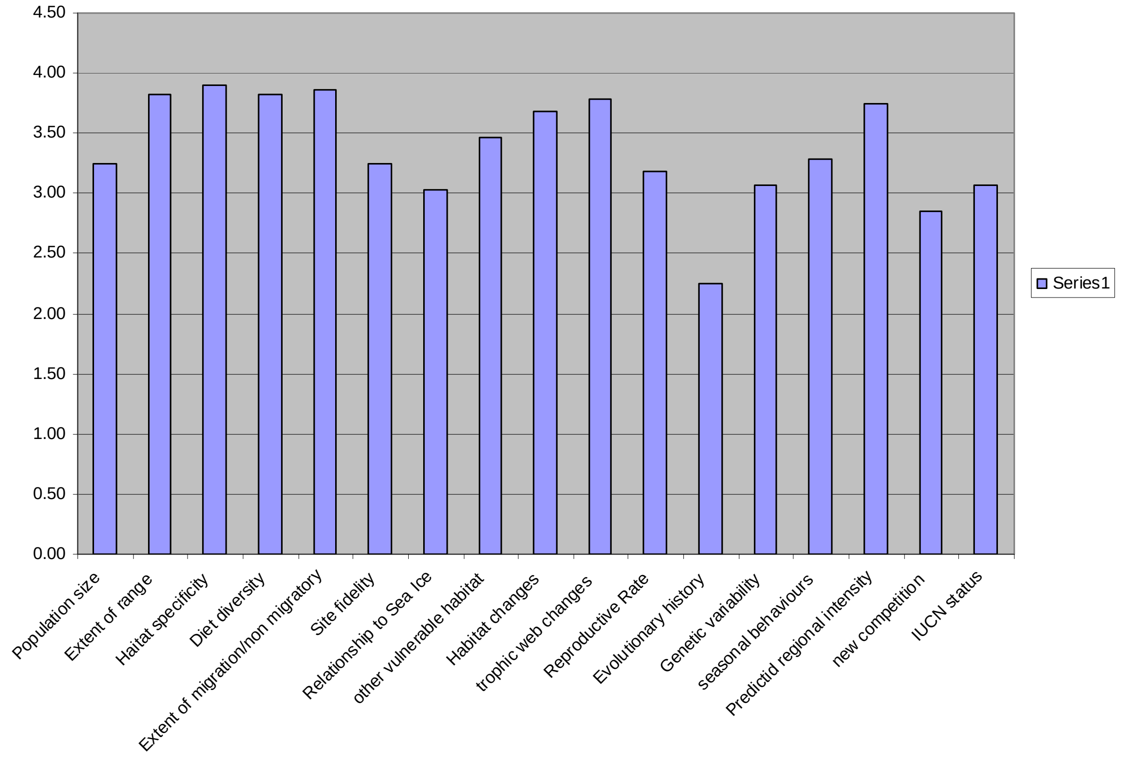

Figure 1. Results of survey of experts concerning the usefulness of the indices.