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Report of the IWC Climate Change Steering Group Meeting, 19 August 2014, Glasgow, UK

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INTERNATIONAL WHALING COMMISSION

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1. Introduction

Mark Peter Simmonds, as convenor, welcomed everyone to the Steering Group meeting. He thanked Chris Parsons for his help in organising the meeting, Natalie Ashford Hodges for helping to prepare materials for the meeting and Julie Creek for excellent logistical support. A list of the Steering Group participants is given as Appendix 1. Simmonds noted that the objective of the meeting was '*To review work by the Scientific Committee to date; place this in the context of latest knowledge; and produce a plan for an ongoing work programme by the Scientific Committee'*. He then provided a brief summary of actions taken by the IWC to date to clarify expected impacts of climate change on cetaceans, based primarily on a review provided to the last Scientific Committee meeting (Hodges and Simmonds, 2014).

The first climate change workshop took place in 1995 and concluded that there was some 'general concern ' for cetaceans but also that 'given the uncertainties in modelling climate change at a suitable scale and thus modelling effects on biological processes…at present it is not possible to model in a predictive manner the effects of climate change on cetacean populations'. It added that a 'considerable further amount of fundamental research' would be required to accurately predict the impacts of climate change on cetaceans.

The IWC returned to this issue in 2007, when a second workshop was proposed. During this same year the fourth IPCC Assessment on Climate Change (IPPC, 2007) was published and, hence, when the second workshop was convened in 2009, it was to a backdrop of growing concern regarding the accelerating rate of global environmental change. From this workshop came recommendations focused on: (i) developing more accurate models to predict cetacean responses to climate change, such as habitat preference and climate envelope models of expected range shifts; (ii) quantifying the level of uncertainty implicit within these models, introduced by any assumptions regarding the relationship between observed cetacean distribution and environmental data, and the accuracy of the climate change model selected; and (iii) improving understanding of the relationship between cetacean distribution and quantifiable climatic indices (such as sea surface temperature) anticipated to change under IPCC predictions. The output of this final recommendation would in theory contribute to the development of more accurate models, reducing the level of uncertainty in (ii).

Further to this, a third IWC climate change workshop was held in Vienna in 2010. This workshop focused on small cetaceans and from this came particular concerns for those species with habitats restricted through the presence of physical barriers, e.g. riverine species, or populations residing in "ecological cul-de-sacs" such as bays, coves, ocean basins (e.g. northern Indian Ocean) or seas (e.g. Mediterranean) with limited ability to migrate along isotherms to mitigate localised climate warming.

Again, this workshop recognised that an improved understanding of how cetaceans interact with their environment is required to accurately predict responses to climate change. The importance of long-term datasets was stressed. The workshop encouraged further research, building on this 'library' of datasets, and recommended that efforts be made to identify and analyse existing datasets of relevance. The third workshop also called for a global review of 'restricted habitats', and recommended that a list of priority species be drafted in the context of the IUCN Red List, assessing their relative vulnerability or resilience to climate change.

Further to this intersessional work had focused on developing a list of restricted habitats (which is still in theory in progress). However, little other coordinated work on climate change seemed to be ongoing within the Scientific Committee at this point. Despite this, an informal survey of the members of the Scientific Committee's Standing Working Group on Environmental Concerns at its 2014 meeting had shown that roughly half of its members were involved in some way in research related to climate change.

The Steering Group also took note of the Commission resolution passed by consensus in 2009. In particular that the Commission had specifically endorsed the outcomes of the second workshop and the associated recommendations of the Scientific Committee given in IWC/61/Rep1, including:

(i) The need to expand the current international multi-disciplinary efforts and collaborative work with other relevant bodies;

(ii) That the Commission had directed the Scientific Committee to continue its work on studies of climate change and the impacts of other environmental changes on cetaceans, as appropriate; and

(iii) That it called on Contracting Governments, IGOs and NGOs to support the expansion of this important work.

The 2014 Steering Group meeting was held immediately after the Third International Marine Conservation Congress, which had been attended by most members of the Group and where various relevant papers had been presented. In addition, the Steering Group also took note of the recent workshop on climate change and cetaceans held under the auspices of ACCOBAMS (ACCOBAMS, 2014) and it also prepared a list of key recent publications given here as Appendix 2.

2. General Discussion

Further to its review of previous IWC workshops, Scientific Committee reports, and the materials outlined above, the Steering Group made some general observations and recommendations. It was agreed by members that progress on the topic may have been hindered in part by misconceptions regarding climate change as a subject area, and this could be partially resolved by clarifying and defining separate individual threats and issues currently falling under the blanket term of 'climate change'. The Steering Group agreed that climate change was not being given appropriate attention given the scale of expected impacts, and suggested that issues driven by climate change are potentially not being addressed because of an underlying assumption of futility of action, and the belief that work cannot be successfully progressed because of a lack of data and poor predictive power of available tools.

The Steering Group concluded that this was no longer the case. Predictive powers have improved for climate models. The fifth IPCC assessment report (AR5) was completed last year, with the Working Group II Report 'Impacts, Adaptation and Vulnerability' published on 31 March 2014. AR5 relies on the Coupled Model Intercomparison Project Phase 5 (CMIP5), an international effort among the climate modelling community to coordinate climate change experiments, and the Report concluded that climate models have improved since AR4 was released in 2007. Improved modelling methods predicting species- and ecosystem-level responses to climate change are being developed, and existing terrestrial models such as the bioclimatic envelope model have been refined to include demographic parameters and population dynamics, and applied to the marine environment. For examples see: Polczanska et al. (2013); Pinsky et al. (2013); Bates et al. (2014); Cheung et al. (2015); Quieros et al. (2015). In addition, our understanding of the physiology, behaviour, and trophodynamics of oceanic top predators in response to climate change has also improved in recent years (Hobday et al. 2015).

The Steering Group considered that Climate change is an issue that cuts across all the interests of the IWC and still needs to be given due priority and support, as has previously been recommended. Climate change is also expected to exacerbate existing threats such as habitat loss, pollution, human interaction, disease and malnourishment. Whilst there has been some progress made by the Scientific Committee, especially via the three workshops, climate change has not yet been successfully embedded as a core element of the work of the Commission or the Scientific Committee. In order to achieve this, and to progress this area of endeavour, the following steps were **recommended**:

1. The Scientific Committee should hold a joint session of all its relevant sub-committees to consider this topic and agree a two-year work programme. This should include a review of existing workstreams to consider where climate change related matters might best fit. The matters that should be considered in this work programme are identified in section 2 below; and

2. Every effort should be made to work expeditiously and in concert with other international multilateral bodies that are also trying to progress this topic including *inter alia* the Convention for Migratory

Species (which has a comprehensive work programme on climate change, which this Steering Committee meeting considered), the Convention for Biological Diversity and the IUCN Species Survival Commission's Cetacean Specialist Group as well as their Red List sub-group.

3. Recommendations for further research

The Steering Group discussed the recommendations coming from the previous workshops of the Scientific Committee and **reiterated,** in particular, the importance of maintaining long-term studies and giving consideration to defining and identifying restricted habitat.

Particular attention was given to the research recommendations coming from the 2009 workshop, including the datasets identified by that workshop which remain relevant. The Steering Group adapted these recommendations in the light of new work and the Steering Committee **recommends** that the new IWC work stream should include:

(a) a review of recently developed statistical models that can integrate the demographic consequences of climate change.

This could include consideration of dynamic bioclimatic envelope models (e.g. Queirós et al. 2014) and suitable datasets from existing long-term studies (e.g. Guisan and Zimmerman 2000) should be sought. This could build also on the recent progress in modelling population consequences of noise (New et al. 2013; New et al. 2014); contaminants (Hall et al. 2006); prey/environment/sea surface temperature (Leaper et al. 2006; Cooke 2007; Williams et al. 2013) and so forth. Many of these analytical tools (e.g. Pollution 2020[1]; CONCEAL[2]; some PCoD models; AquaMaps[3]) are open-source, and the Group encouraged their modification to answer questions relating to climate change and cetaceans to be addressed;

(b) There should be liaison in this work forming a cross-cutting theme with various of the Scientific Committee's working groups including, but not necessarily limited to, Ecosystems Modelling (EM), Environmental Threats (E) and Human Induced Mortalities (HIM).

(c) There should be further synthesis and meta-analysis applications on existing data sets to investigate plausible climate change scenarios

Hazen et al. (2013) provide an example of a synthesis study that took a large tracking data set to make projections of redistributions under climate change scenarios for a wide variety of marine top predators (including cetaceans) in the North Pacific Ocean. The aim would be to help better understand and predict changes in movements and distribution in response to predicted changes in prey, SST, ocean

[1] https://iwc.int/group-pollution2000sg
[2] http://cordis.europa.eu/project/rcn/96009_en.html
[3] http://www.aquamaps.org/

acidification and so forth. This should be done using a set of testable hypotheses, e.g. species migrations tracking climate velocity (Burrows et al. 2014; Pinsky et al. 2013) and taking note of relevant work as presented at IMCC (i.e. 'Ecological traits and climate velocity range shifts in a climate warming hotspot') and niche envelope models (Kaschner et al. 2011; Lambert el al. 2014; MacLeod 2009; Selig et al. 2014).

The Steering Group also observed that shifts in plastic behavioural responses such as species distribution and phenology are likely to be observed ahead of longer-term impacts affecting the total population density or average body size of a species. To effectively monitor and detect these climate-driven shifts, continuous, long-term monitoring programs such as multi-species electronic tagging and tracking as well as large-scale surveys at key sites will be critical. Examples of such surveys would include the SCANS surveys of the northeast Atlantic (Hammond et al. 2013[4]) and Antarctic surveys (Williams et al. 2014) or the Tagging of Pacific Pelagics (TOPP) program (Block et al. 2011). However, the Steering Group cautioned that in order to detect climate-mediated effects, existing and future monitoring programs require sampling designs capable of robustly capturing such shifts.

In addition, the Steering Group **urged** that the Scientific Committee should review and agree upon a short list of focal species, habitats and regions, and that this list should be based on both the vulnerability of these features and probability of successful progress in a reasonable timeframe during this first phase of the IWC's work plan. A list of potential indicator species and research situations was included in the report of the second climate change workshop (Table 1) and the Steering Group advised that this list be referred to as a starting point, and updated or refined where appropriate. The hypothesis proposed at this workshop that "species in restricted habitat with little or no capacity to redistribute will be exposed to thermal, nutritional and health related stress" remains applicable given current understanding of climate change. Suggested regions to focus on relating to this hypothesis in the 2011 report were: riverine sites and the Black Sea, Adriatic Sea, Bay of Bengal and Gulf of California.

Table 1*: Potential candidate species, study locations and surveys which may be useful in studying the effects of climate change on cetaceans. Taken from 'Report of the Workshop on Cetaceans and Climate Change' (IWC 2010).*

Hypothesis	Summary	Candidate species / location / survey
FW1	Changes in precipitation and hydrological regimes will impact the preferred habitat for riverine and estuarine species. The direction of these impacts is dependent upon undetermined impacts on flow regimes.	Riverine: *Inia geoffrensis, Platanista gangetica, Sotalia fluviatilis* Estuarine: *Orcaella brevirostris*
T1	Shifts in distribution identifiable through changes to northern/southern edges of species range.	Large scale oceanic surveys (e.g. SWFSC/IATTC/ETP and Northeast Atlantic SCANS and NASS surveys, only when combined with other datasets)

[4] See: http://www.sciencedirect.com/science/article/pii/S0006320713001055

T2	Temperature-driven modification of ecosystem structure and productivity entailing shifts in distribution of pelagic small cetacean populations.	The long-term SWFSC/IATTC/ETP programmes and the Norwegian Barents Sea Ecosystem surveys are possible candidates for such studies.
T3	For populations with small ranges in restricted habitats that cannot relocate due to lack of suitable habitat or other constraints we might expect to see behavioural alterations, changes in life history parameters, and/or changes in health and body condition status, and species or population disappearance.	Riverine sites, Black Sea, Adriatic Sea, Bay of Bengal, Gulf of California.
SL1, 2 & 3	Sea level rise impact will primarily be experienced by coastal and estuarine populations and riverine populations in the lower parts of rivers. Possible responses are aggregation of animals in core preferred habitats (shrinkage of distribution leading to increased density).	Riverine and estuarine species (cf. FW1) and marine species occurring in shallow, nearshore or semi-enclosed coastal waters *Neophocaena phocaenoides, Phocoena sinus, Phocoena phocoena, Tursiops truncatus, Tursiops aduncus, Cephalorhynchus spp., Sousa chinensis*.

The report of the second workshop also included a table of possible data sources that could be used to explore climate change impacts, which the Steering Group recommend be reviewed and updated (Table 2).

Table 2*: Examples of some possible data sources that may be suitable to explore climate change impact on small cetacean distribution and habitat use for each of four broad habitat categories. Note this is not an exhaustive list and a more formal examination of available datasets and their applicability for such studies is required. Taken from 'Report of the Workshop on Cetaceans and Climate Change' (IWC 2010).*

Habitat	**Area**	**Type of data**	**Scale, spatial and temporal**	**Examples**
Freshwater & Estuarine	Bangladesh	Survey	Habitat wide, decade	Bangladesh cetacean diversity project
	Hong Kong	Survey	Habitat wide, decade	TBC
	Amazon River, Brazil, Colombia	Survey	Habitat wide, decade	TBC
Coastal (< 2nm)	Sarasota Bay, Florida USA	Survey, health, stranding	Local, decades	Chicago Zoological Society programme
	British Columbia (killer whales)	Survey	Local, decades[5]	TBC
	British Isles	Stranding	British Isles, decades	TBC
	Mediterranean	Survey	Local, decades	e.g. Adriatic Sea ('Blue World'), Ionian Dolphin Project (Tethys)
	Moray Firth, UK	Survey	Local, decades	University of Aberdeen
Neritic	European Atlantic	Survey	Habitat wide (North Sea, Irish Sea), decade	SCANS I (not Irish Sea); SCANS II
	Mediterranean	Survey	Local, decades	Alboran Sea (Alnitak); Adriatic (Blue World)
	British Isles	Stranding	British Isles, decades	TBC
	Barents Sea	Survey	Habitat wide (Barents Sea)	Norwegian NASS
Pelagic	Eastern Tropical Pacific	Survey	Large scale, decades	SWFSC/IATTC
	NE Atlantic	Survey (NASS)	Large scale, decades	NASS; Norwegian NASS
	Mediterranean	Survey (several)	Local, decades	Strait of Gibraltar (CIRCE); Alboran Sea (Alnitak)
	British Isles	Stranding	British Isles, decades	TBC

The Scientific Committee could also help develop the concept of ecological refugia (Keppel et al. 2012) and identify such areas. These might include submarine canyons with cold-water upwelling, such as the Swatch-of-No-Ground (SoNG) in the Bay of Bengal. The third climate change workshop report suggested that the SoNG may present an opportunity to evaluate the potential role of submarine canyons as ecological refugia, and

[5] See e.g. http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2004.00669.x/abstract

included details of a proposed case study to investigate this. The Steering Group recommend that this case study be reviewed, and if still considered appropriate and likely to produce data of value, then the resources and funding be secured to carry out this work plan.

Also noted as of relevance is an initiative of the recently established Joint IUCN Species Survival Commission (SSC)/World Commission on Protected Areas (WCPA) Task Force on Marine Mammal Protected Areas to identify Important Marine Mammal Areas (IMMAs). The IMMA concept follows the example of Important Bird Areas (IBAs) and is in response to the need to implement a standardized process for identifying globally significant areas for marine mammal conservation. This initiative is also being integrated into a larger effort to describe Ecologically Biological Significant Areas (EBSAs) in the world's oceans. Participants suggested that the results of both the IMMA and EBSA processes might serve as a useful first filter for compiling an inventory of restricted habitats that are particularly important for cetaceans. A second filter could then be to use global models of thermal change in the world's oceans to further identify restricted habitats that are both important for cetaceans and are also especially vulnerable to climate change impacts. It was also noted that in the USA, NOAA has been working on identifying Biologically Important Areas (BIAs) for cetaceans under the CetSound initiative, and a special issue in the journal *Aquatic Mammals* to appear in March 2015 will present them officially (the interim website is: http://cetsound.noaa.gov/important). In terms of addressing the adverse impacts of climate change, the Group noted that the resulting workstreams would have relevance to IMMAs[6] (Corrigan et al. 2014), EBSAs (see Dunn et al., 2014), KBAs, (IC)MMPAs, ABNJs (Aardron et al. 2014) and that the IWC should join with those ongoing efforts to identify priority marine mammal areas to protect.

The Steering Committee also recommended consideration of tertiary issues as, for example, identified in Alter et al. (2010), and summarised here in Table 3.

Table 3: *Summary of major climatological, oceanographic or ecological impacts of climate change, changes in human behaviour expected to occur as a result of these impacts, and potential effects on cetacean species, taken from 'Forecasting the consequences of climate-driven shifts in human behaviour on cetaceans' (Alter et al. 2010).*

Change in physical or biological environment	**Potential Change in human behaviour**	**Impact on cetaceans**	**Species that may be affected**
Diminishing sea ice	Increased shipping	Acoustic disturbance	Large whales inhabiting Arctic and subarctic waters

[6]For more information see: http://www.ascobans.org/en/document/proceedings-ecs-ascobans-wdc-workshop-towards-conservation-strategy-white-beaked-dolphins
http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0019653&representation=PDF
http://iwdg.ie/downloads/paper_lambert_et_al_2011.pdf

	Increased fishing pressure	Depletion of prey base; bycatch	Polar and subpolar cetaceans
	As ice-dependent pinnipeds decline, Arctic communities may shift hunting effort to cetaceans	Direct hunt	Arctic cetaceans subject to harvest
	Increase in military presence	Acoustic disturbance	Arctic cetaceans
Decline of coral reef health	Displacement of tourism to whale and dolphin-watching	Harassment, acoustic disturbance	Coastal tropical cetaceans in regions where coral reef tourism is prominent
Warming of high latitude waters	Increase in aquaculture	Coastal eutrophication; cetacean interactions with aquaculture operations may lead to harassment/culling	Coastal high latitude species, particularly small toothed cetaceans
	Increase in fisheries as target species move north	Increase in bycatch	Polar and subpolar cetaceans
Drought and decreasing precipitation	Decline in food security may result in greater reliance on marine ecosystems for food	Prey depletion; direct catch of cetaceans for food	Tropical coastal cetaceans in EEZs of drought prone nations
	Increase in human migration to coastal areas	Increase in urban and agricultural runoff, potential increases in tourism	Tropical coastal cetaceans in EEZs of drought prone nations
	Increase in desalination	Localized disturbance	Coastal cetaceans of drought-prone nations, particularly those that use shallow lagoon or bay habitat
	Increase in intensive agriculture	Increase in anoxic zones and potentially HABs	All coastal cetaceans in drought prone nations, particularly those near river mouths
Warming of high latitude terrestrial ecosystems	Increase in human densities and terrestrial activities (e.g. Agriculture)	Increase in urban and agricultural runoff, potential increases in tourism	Subpolar and polar coastal cetaceans
Increase in storm severity	Construction of breakwaters, jetties, etc. may increase coastal noise propagation	Acoustic disturbance	Coastal cetaceans
Sea level rise	Coastal construction projects (dykes etc.) to manage flooding	Habitat fragmentation	Coastal cetaceans (particularly estuarine and riverine)
	Land acquisition and creation of marsh and wetlands	Habitat loss; introduction of foreign contaminants and disease	Coastal cetaceans (particularly estuarine and riverine)
New focus on renewable energy sources	Construction of wind, wave and tidal generators	Acoustic disturbance; potential for habitat disruption or displacement; collisions	Cetaceans in areas with high potential for renewable energy

	Increase in hydroelectric power sources	Destruction of freshwater habitat for cetaceans and prey	Riverine and estuarine cetaceans; species that depend on freshwater fish prey

The Steering Group recommend that the Scientific Committee review these tertiary effects and seek to develop strategies to mediate them. The Group anticipated that the greatest tertiary impact on cetaceans will be through increased bycatch. Alter et al. (2010) expect this to be driven by changes in human fishing practices as a result of climate change affecting food security and the reliance of human populations on agriculture versus aquaculture and fisheries. The species expected to be at greatest risk according to the 2010 review were polar and subpolar cetaceans, and tropical coastal cetaceans in Economic Exclusion Zones of drought-prone nations. Species and populations falling into these categories and also under the definition of 'restricted habitat' may be of particular concern, and the Steering Group recommend that existing such high-risk shortlists be reviewed and cross checked to identify most at risk populations.

The Steering Group expressed concern that some researchers may currently be in possession of relevant datasets and biological materials, but unable to analyse them due to lack of funding. The Steering Group **recommended** that such data sets and collections should urgently be identified, added to updated versions of Table 2 above, and efforts made to secure funding to support analyses. The use of historical collections to inform research on climate change impacts was discussed at length at the second climate change workshop, and potential methods are outlined in the report. Biochemical indicators such as blubber lipid content and fatty acid signatures can be applied to samples collected from dead specimens, and can allow retrospective monitoring of trends over a large timescale, determined by the age of the specimens. It was agreed at the 2010 workshop that these techniques present a valuable alternative to observational data in providing insight into cause-effect relationships in changes observed in populations under environmental pressure from climate change.

It was also noted that behavioural data (such as that obtained by digital tags) might be used to tell us something about how foraging is affected by prey abundance, which is in turn affected by climate (Lusseau et al., 2004). Finally, the Steering Group recommended that in order to expedite research the focus provided by a special edition of a journal on the effects of climate change on cetaceans might be he helpful and therefore **recommended** that efforts were made to find a suitable journal and editor.

These recommendations are intended for consideration by the IWC Scientific Committee in 2015.

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References

ACCOBAMS, 2014 Report of the ACCOBAMS expert workshop on the impact of Climate Change on Cetaceans of the Mediterranean and Black Seas. Monaco 20th June 2014. 24 pages. Available online HERE

Alistair J. Hobday, Haritz Arrizabalaga, Karen Evans, Simon Nicol, Jock W. Young, Kevin C. Weng. 2015. Impacts of climate change on marine top predators: Advances and future challenges. Deep Sea Research Part II: Topical Studies in Oceanography, doi:10.1016/j.dsr2.2015.01.013.

Ardron, J. A., R. Rayfuse, K. Gjerde and R. Warner. 2014. The sustainable use and conservation of biodiversity in ABNJ: What can be achieved using existing international agreements? Marine Policy:1–11.

Barros, V. R., Field, C. B., Dokke, D. J., Mastrandrea, M. D., Mach, K. J., Bilir, T. E., ... & White, L. L. (2015). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
Bates, A. E., Pecl, G. T., Frusher, S., Hobday, A. J., Wernberg, T., Smale, D. A., ... & Watson, R. A. (2014). Defining and observing stages of climate-mediated range shifts in marine systems. *Global Environmental Change*, *26*, 27-38.

Block, B. A., I. D. Jonsen, S. J. Jorgensen, A. J. Winship, S. A. Shaffer, S. J. Bograd, et al. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature 475:86–90.

Burrows, Michael T., David S. Schoeman, Anthony J. Richardson, Jorge García Molinos, Ary Hoffmann, Lauren B. Buckley, Pippa J. Moore et al. (2014) "Geographical limits to species-range shifts are suggested by climate velocity." *Nature* 507, no. 7493, 492-495.

Burrows, Michael T., David S. Schoeman, Lauren B. Buckley, Pippa Moore, Elvira S. Poloczanska, Keith M. Brander, Chris Brown et al. (2011) "The pace of shifting climate in marine and terrestrial ecosystems." *Science* 334, no. 6056, 652-655.

Cheung, W. W., Brodeur, R. D., Okey, T. A., & Pauly, D. (2015). Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. *Progress in Oceanography*, *130*, 19-31.

Cooke, J. G. (2007). *The influence of environmental variability on baleen whale sustainable yield curves* (Vol. 7). Paper SC.

Corrigan, C. M., Ardron, J. A., Comeros‐Raynal, M. T., Hoyt, E., Notarbartolo Di Sciara, G., & Carpenter, K. E. (2014). Developing important marine mammal area criteria: learning from ecologically or biologically significant areas and key biodiversity areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(S2), 166-183.

Dunn, D. C., J. Ardron, N. Bax, P. Bernal, J. Cleary, I. Cresswell, et al. 2014. The Convention on Biological Diversity's Ecologically or Biologically Significant Areas: Origins, development, and current status. *Marine Policy* 49 (2014): 137-145.

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological modelling*, *135*(2), 147-186

Hall AJ, McConnell BJ, Rowles TK, Aguilar A, Borrell A, Schwacke L, Reijnders PJ, Wells RS (2006). Individual-based model framework to assess population consequences of polychlorinated biphenyl exposure in bottlenose dolphins. *Environmental Health Perspectives* 114 Suppl 1:60-64

Hammond, P. S., Macleod, K., Berggren, P., Borchers, D. L., Burt, L., Cañadas, A., ... & Vázquez, J. A. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biological Conservation*, *164*, 107-122.

Hazen, E. L., Jorgensen, S., Rykaczewski, R. R., Bograd, S. J., Foley, D. G., Jonsen, I. D., ... & Block, B. A. (2013). Predicted habitat shifts of Pacific top predators in a changing climate. *Nature Climate Change*, *3*(3), 234-238.

Kaschner, K., Tittensor, D. P., Ready, J., Gerrodette, T., & Worm, B. (2011). Current and future patterns of global marine mammal biodiversity. *PLoS One*, *6*(5), e19653.

Keppel, G., Van Niel, K. P., Wardell-Johnson, G. W., Yates, C. J., Byrne, M., Mucina, L., ... & Franklin, S. E. (2012). Refugia: identifying and understanding safe havens for biodiversity under climate change. *Global Ecology and Biogeography*, *21*(4), 393-404.

Lambert, E., Pierce, G. J., Hall, K., Brereton, T., Dunn, T. E., Wall, D., ... & MacLeod, C. D. (2014). Cetacean range and climate in the eastern North Atlantic: future predictions and implications for conservation. *Global change biology*, *20*(6), 1782-1793.

Leaper, R., J. Cooke, P. Trathan, K. Reid, V. Rowntree and R. Payne. (2006). Global climate drives southern right whale (Eubalaena australis) population dynamics. Biology Letters 2:289–292.

Lusseau, D., Williams, R., Wilson, B., Grellier, K., Barton, T. R., Hammond, P. S. and Thompson, P. M. (2004), Parallel influence of climate on the behaviour of Pacific killer whales and Atlantic bottlenose dolphins. Ecology Letters, 7: 1068–1076

MacLeod, C. D. (2009). Global climate change, range changes and potential implications for the conservation of marine cetaceans: a review and synthesis. *Endangered Species Research*, *7*(2), 125-136.

New L.F., Clark J.S., Costa D.P., Fleishman E., Hindell M.A., Klanjšček T., Lusseau, D., Kraus, S., McMahon, C. R., Robinson, P. W., Schick, R. S., Schwarz, L. K., ... & Harwood, J. (2014). Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. *Mar Ecol Prog Ser*, *496*, 99-108.

New, L. F., Moretti, D. J., Hooker, S. K., Costa, D. P., & Simmons, S. E. (2013). Using energetic models to investigate the survival and reproduction of beaked whales (family Ziphiidae). *PloS one*, *8*(7), e68725.

Pachauri, R. K., & Reisinger, A. (2007). IPCC fourth assessment report. *IPCC, Geneva*.

Pinsky, M. L., Worm, B., Fogarty, M. J., Sarmiento, J. L., & Levin, S. A. (2013). Marine taxa track local climate velocities. *Science*, *341*(6151), 1239-1242.

Poloczanska, E. S., Brown, C. J., Sydeman, W. J., Kiessling, W., Schoeman, D. S., Moore, P. J., ... & Richardson, A. J. (2013). Global imprint of climate change on marine life. *Nature Climate Change*, *3*(10), 919-

Queirós, A. M., Fernandes, J. A., Faulwetter, S., Nunes, J., Rastrick, S. P., Mieszkowska, N., ... & Widdicombe, S. (2015). Scaling up experimental ocean acidification and warming research: from individuals to the ecosystem. *Global change biology*, *21*(1), 130-143.

Selig, E. R., Turner, W. R., Troëng, S., Wallace, B. P., Halpern, B. S., Kaschner, K., ... & Mittermeier, R. A. (2014). Global priorities for marine biodiversity conservation. *PloS one*, *9*(1), e82898.

Sunday, J.M. (2014) ‘Ecological traits and climate velocity range shifts in a climate warming hotspot’ Presentation at the International Marine Conservation Congress. Glasgow. 2014 Unpublished.

Williams, R., Kelly, N., Boebel, O., Friedlaender, A. S., Herr, H., Kock, K. H., ... & Brierley, A. S. (2014). Counting whales in a challenging, changing environment. *Scientific reports*, *4*.

Williams, R., Vikingsson, G. A., Gislason, A., Lockyer, C., New, L., Thomas, L., & Hammond, P. S. (2013). Evidence for density-dependent changes in body condition and pregnancy rate of North Atlantic fin whales over four decades of varying environmental conditions. *ICES Journal of Marine Science: Journal du Conseil*, fst059.

Appendix 1. Steering Group Participants

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Appendix 2. Some key recent publications relevant to better understanding the effects of climate change on cetaceans.

This list is not intended to be exhaustive.

1. Ainley, D., Ballard, G., Blight, L. K., Ackley, S., Emslie, S. D., LESCROel, A., ... & Woehler, E. (2010). Impacts of cetaceans on the structure of Southern Ocean food webs. *Marine mammal science*, *26*(2), 482-498.
2. Albouy, C., Velez, L., Coll, M., Colloca, F., Loc'h, F., Mouillot, D., & Gravel, D. (2014). From projected species distribution to food web structure under climate change. *Global change biology*.
3. Alter,E.S., Simmonds, M. P., & Brandon, J. R. (2010). Forecasting the consequences of climate-driven shifts in human behavior on cetaceans. *Marine Policy*, *34*(5), 943-954

4. Arcangeli, A., Marini, L., & Crosti, R. (2013). Changes in cetacean presence, relative abundance and distribution over 20 years along a trans-regional fixed line transect in the Central Tyrrhenian Sea. *Marine Ecology*, *34*(1), 112-121.
5. Arcangeli, A., Orasi, A., Carcassi, S. P., & Crosti, R. (2014). Exploring thermal and trophic preference of *Balaenoptera physalus* in the central Tyrrhenian Sea: a new summer feeding ground?. *Marine Biology*, *161*(2), 427-436.
6. Ashford-Hodges, N., & Simmonds, M. P. Climate change and cetaceans: an update. Submission to the IWC Scientific Committee SC/65b/E12
7. Barnett, T. P., Pierce, D. W., AchutaRao, K. M., Gleckler, P. J., Santer, B. D., Gregory, J. M., & Washington, W. M. (2005). Penetration of human-induced warming into the world's oceans. *Science*, *309*(5732), 284-287.
8. Beaugrand, G., Goberville, E., Luczak, C., & Kirby, R. R. (2014). Marine biological shifts and climate. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1783), 20133350.
9. Bernhardt, J. R., & Leslie, H. M. (2013). Resilience to climate change in coastal marine ecosystems.
10. Bond, A. L., & Lavers, J. L. (2014). Climate change alters the trophic niche of a declining apex marine predator. *Global change biology*.
11. Borja, A. (2014). Grand challenges in marine ecosystems ecology. *Marine Ecosystem Ecology*, *1*, 1.
12. Brandon, J. R., & Punt, A. E. (2009). *Assessment of the eastern stock of North Pacific gray whales:*
13. Cheung, W. W., Lam, V. W., Sarmiento, J. L., Kearney, K., Watson, R., & Pauly, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries*, *10*(3), 235-251.
14. Coastal Management, Volume 42, Issue 2, 2014 Special Issue: Establishing a Region-wide System of Marine Protected Areas in the Coral Triangle
15. Costello, M. J. (2009). Distinguishing marine habitat classification concepts for ecological data management. *Marine ecology progress series*, *397*, 253-268.
16. Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., & Totterdell, I. J. (2000). Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature*, *408*(6809), 184-187.
17. Davidson, A. D., Boyer, A. G., Kim, H., Pompa-Mansilla, S., Hamilton, M. J., Costa, D. P., ... & Brown, J. H. (2012). Drivers and hotspots of extinction risk in marine mammals. *Proceedings of the National Academy of Sciences*, *109*(9), 3395-3400.
18. Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., ... & Talley, L. D. (2012). Climate change impacts on marine ecosystems. *Marine Science*, *4*.
19. Gaskin, D.E. 1982. *The ecology of whales and dolphins*. Heinemann Educational Books Ltd., London.
20. Greene, C. H., & Pershing, A. J. (2004). Climate and the conservation biology of North Atlantic right whales: the right whale at the wrong time?. *Frontiers in Ecology and the Environment*, *2*(1), 29-34.
21. Heikkinen, R. K., Luoto, M., Araújo, M. B., Virkkala, R., Thuiller, W., & Sykes, M. T. (2006). Methods and uncertainties in bioclimatic envelope modelling under climate change. *Progress in Physical Geography*, *30*(6), 751-777.
22. Helmuth, B., Babij, E., Duffy, E., Fauquier, D., Graham, M., Hollowed, A., ... & Wilson, C. (2013). Impacts of Climate Change on Marine Organisms. In *Oceans and Marine Resources in a Changing Climate* (pp. 35-63). Island Press/Center for Resource Economics.

23. Hijmans, R. J., & Graham, C. H. (2006). The ability of climate envelope models to predict the effect of climate change on species distributions. *Global change biology*, *12*(12), 2272-2281.
24. Hoffman, JR, Fonseca, A, and C Drews (eds). 2009. Cetaceans and Other Marine Biodiversity of the Eastern Tropical Pacific: Options for Adapting to Climate Change. Report from a workshop held February 9-11, 2009. MINAET/WWF/EcoAdapt/CI/IFAW/TNC/WDCS/IAI/PROMAR, San Jose, Costa Rica. ISBN: 978-9968-825-37-5
25. Intergovernmental Panel on Climate Change. 2007. Fourth assessment report, climate change 2007: synthesis report. Summary for policymakers. 24pp.
26. InternationaI Whaling Commission. 1997b. Report of the IWC Workshop on Climate Change and Cetaceans. Rep. Int. Whal. Commn 47:293-319. WC
27. InternationaI Whaling Commission. 2006. Report of the IWC Scientific Committee Workshop on Habitat
28. International Whaling Commission, 2010b. Report of the Workshop on Cetaceans and Climate Change, 21-25 February 2009, Siena, Italy. J. Cetacean Res. Manage. (Suppl.) 11(2):451-80.
29. International Whaling Commission. 2010a. Report of the Scientific Committee. J. Cetacean Res. Manage (Suppl.) 11(20:1-98.
30. International Whaling Commission. 2012. Report of the Workshop on small cetaceans and climate change. J. Cetacean Res. Manage (Suppl.) 13(319:336.
31. IPCC SAR WG1 (1996), Houghton, J.T.; Meira Filho, L.G.; Callander, B.A.; Harris, N.; Kattenberg, A., and Maskell, K., ed., *Climate Change 1995: The Science of Climate Change*, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0-521-56433-6 (pb: 0-521-56436-0) pdf.
32. Laidre, K. L., Stirling, I., Lowry, L. F., Wiig, Ø., Heide-Jørgensen, M. P., & Ferguson, S. H. (2008). Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications*, *18*(sp2), S97-S125.
33. Lescroël, A., Ballard, G., Grémillet, D., Authier, M., & Ainley, D. G. (2014). Antarctic Climate Change: Extreme Events Disrupt Plastic Phenotypic Response in Adélie Penguins. *PLOS ONE*, *9*(1), e85291.
34. Levy, J. S., & Ban, N. C. (2013). A method for incorporating climate change modelling into marine conservation planning: An Indo-west Pacific example. *Marine Policy*, *38*, 16-24.
35. MacLeod, C. D., Bannon, S. M., Pierce, G. J., Schweder, C., Learmonth, J. A., Herman, J. S., & Reid, R. J. (2005). Climate change and the cetacean community of north-west Scotland. *Biological Conservation*, *124*(4), 477-483.
36. MacLeod, C. D., Weir, C. R., Pierpoint, C., & Harland, E. J. (2007). The habitat preferences of marine mammals west of Scotland (UK). *Journal of the Marine Biological Association of the United Kingdom*, *87*(01), 157-164.
37. Magris, R. A., Pressey, R. L., Weeks, R., & Ban, N. C. (2014). Integrating connectivity and climate change into marine conservation planning. *Biological Conservation*, *170*, 207-221.
38. McClellan, C. M., Brereton, T., Dell'Amico, F., Johns, D. G., Cucknell, A. C., Patrick, S. C., ... & Godley, B. J. (2014). Understanding the Distribution of Marine Megafauna in the English Channel

Region: Identifying Key Habitats for Conservation within the Busiest Seaway on Earth. *PloS one*, *9*(2), e89720.

39. Meager, J. J., & Limpus, C. (2014). Mortality of Inshore Marine Mammals in Eastern Australia Is Predicted by Freshwater Discharge and Air Temperature. *PloS one*, *9*(4), e94849.
40. Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.*, *37*, 637-669.
41. Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37-42.
42. Perry, A. L., Low, P. J., Ellis, J. R., & Reynolds, J. D. (2005). Climate change and distribution shifts in marine fishes. *Science*, *308*(5730), 1912-1915.
43. Review of the Literature on the Links Between Biodiversity and Climate Change: Impacts, Adaptation, and Mitigation. UNEP/Earthprint, 2009 - Political Science - 124 pages
44. Simmonds, M. P., & Eliott, W. J. (2009). Climate change and cetaceans: concerns and recent developments. *Journal of the Marine Biological Association of the United Kingdom*, *89*(01), 203-210.
45. Simmonds, M. P., & Isaac, S. J. (2007). The impacts of climate change on marine mammals: early signs of significant problems. *Oryx*, *41*(01), 19-26.
46. Simmonds, M. P., & Smith, V. (2009) *Cetaceans and climate change—assessing the risks* (Vol. 9). SC.
47. Smith, B.D**.** and R. R. Reeves. 2012. River cetaceans and habitat change: generalist resilience or specialist vulnerability? *Journal of Marine Biology* 2012:1-11.
48. Smith, B.D**.,** and Mansur, E.F. 2012. Sundarbans. Pages 144-154 in Hilty, J.A., Chester, C. C., and Cross, M. (eds) *Climate and Conservation: Landscape and Seascape Science, Planning and Action*. Island Press.
49. Sorte, C. J., Williams, S. L., & Carlton, J. T. (2010). Marine range shifts and species introductions: comparative spread rates and community impacts. *Global Ecology and Biogeography*, *19*(3), 303-316.
50. Stewart, J. S., Hazen, E. L., Bograd, S. J., Byrnes, J. E., Foley, D. G., Gilly, W. F., ... & Field, J. C. (2014). Combined climate-and prey-mediated range expansion of Humboldt squid (Dosidicus gigas), a large marine predator in the California Current System. *Global change biology*.
51. Tetley, M.J. and Dolman, S.J. 2013. Towards a Conservation Strategy for White-Beaked Dolphins in the Northeast Atlantic. Report from the European Cetacean Society's 27th Annual Conference Workshop, the Casa da Baia, Setubal, Portugal. European Cetacean Society Special Publication Series No. XX, 121pp.
52. Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., ... & Williams, S. E. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145-148.
53. Whalewatcher: Journal of the American Cetacean Society, 2010. Dutton, I.(ed). Climate change: challenges to cetacean conservation. Vol 39. No.2
54. Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis Summary for Policymakers". Retrieved 21 December 2013.