Report of the Workshop on Cetaceans and Climate Change*

The Workshop was held at the Certosa di Pontignano dal Rettore dell Università degli Studi de Siena, Italy from 21-25 February 2009. The list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Welcome and introduction

Simmonds (Convener) opened the meeting, welcomed the participants and summarised the background to the Workshop.

It was in 1973 that the first regular environmental agenda item - 'Effect of pollution on whale stocks, including small cetaceans' - was placed on the agenda of the Scientific Committee. Since then there had been a number of relevant Commission resolutions and responses or initiatives from the Scientific Committee, one of which (IWC, 1997a) established the Standing Working Group on Environmental Concerns (SWGEC) and also requested the development of methods to predict effects of climate change on cetaceans.

In 1993, the Commission had requested (IWC, 1994) that the Committee should convene a special workshop on the effects of global change on cetaceans; that was duly held in Hawaii in March 1996 and convened by Reilly (IWC, 1997b). Several participants at the present workshop, including Simmonds, also attended the Hawaii workshop. The background to the first workshop was the work of the Intergovernmental Panel on Climate Change (IPCC), which had just completed its second assessment (*http://www.ipcc.ch/*). Reports were also received from CCAMLR, GLOBEC, SCAR/APIS, SCOPEX and the Palmer LTER (Long Term Ecological Research) Programme. The workshop then went on to consider the relevant temporal and spatial scales that it was concerned with and direct and indirect effects at the level of the organism. It noted that health problems associated with thermal change were unlikely for cetaceans. Much consideration was given to impacts on prey. The interplay between global climatic change, chemical pollution and pathogens was also considered – with broad areas of concern being identified, including the potential that some recent epizootics had been exacerbated by climate change. At that time, a number of species were identified as potential subjects for the study of climate change: the minke whale; the humpback whale; right whales; the blue whale; the bowhead whale; the gray whale; the white whale; *Tursiops* spp.; the harbour porpoise; and killer whales; as well as species of particular concern, including the vaquita.

The Hawaii Workshop (CC1) 'recognised 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'. Despite this, the Workshop 'believed that the available evidence is sufficient to warrant some general concern for cetaceans'. CC1 concluded that a considerable amount of fundamental research would be needed to make predictions of the effects of climate change on cetaceans' and made reference to a conceptual model of linkages. It recommended a multidisciplinary, multinational focused programme of research on those species or populations where there is the best chance of success. The Workshop strongly recommended that the Scientific Committee (and the Commission) should consider ways to facilitate the development and execution of such research.

In part as a result of this, in 1997 the Scientific Committee developed and the Commission endorsed (IWC, 1998), two major research programmes involving two long-term collaborative multi-disciplinary multinational research programmes, developed by the Scientific Committee. The first, on contaminants in whales, became the POLLUTION 2000+ project (Reijnders *et al.*, 2007; Reijnders *et al.*, 1999). The second, which became the SOWER 2000 field programme (IWC, 2000) and involved collaboration with CCAMLR (and their CCAMLR 2000 programme) and SO-GLOBEC, examined the influence of temporal and spatial variability in the physical and biological Antarctic environment on the distribution, abundance and migration of whales. The Commission endorsed this collaborative effort (IWC, 1999a) and IWC-funded observers led by Thiele participated in CCAMLR and SO-GLOBEC cruises. The results of this collaboration have been incorporated into special issues of Deep Sea Research (in 2004, 2008 and one in preparation) and further analyses are ongoing.

In 1998, the Scientific Committee identified two further priority areas for research: (i) effect on cetaceans of habitat degradation; and (ii) effects of environmental change on Arctic cetaceans. With respect to (i), the Committee held a workshop at the Certosa in 2005 (IWC, 2006), many aspects of which are also relevant to the present Workshop. Other relevant resolutions followed, including IWC (1999b) which asked the Committee to: (i) give high priority to implementation of the proposed research on environmental factors, and to continue to produce costed scientific proposal for non-lethal research, to identify and evaluate the effects of environmental change on cetaceans in all priority areas; (ii) ensure the participation of experts with the necessary expertise in environmental change; and (iii) include, in its ongoing programme of Comprehensive Assessments of whale stocks, an assessment of the impacts on the dynamics of cetacean populations of environmental change and other non-whaling human influences.

With respect to the present Workshop, Simmonds noted that it had been discussed by the Scientific Committee and at a scoping group meeting chaired by Moore and hosted by Reilly at the Scripps Institution of Oceanography, La Jolla,

*Presented to the meeting as SC/61/Rep4.

19-20 February 2008 (IWC, 2008). The plan from the Scoping Group was reviewed at the last Scientific Committee meeting and from this came the terms of reference for this workshop, which were to bring together and enhance collaborations amongst experts in cetacean biology, modelling, marine ecosystems and climate change, as well as to review the current understanding and to improve conservation outcomes for cetaceans under climate change scenarios described in the IPCC 4th report of November 2007 (*http://www.ipcc.ch/*) by:

(1) identifying existing long-term cetacean environmental datasets that can be analysed and included in models in relation to climate change variables;
(2) determining patterns that may be attributable to climate change via analyses of these datasets;
(3) modelling mechanisms to consider cause and effect relationships, provide predictions and identify data gaps that, if filled, would improve our understanding of the effects of climate change on cetaceans; and
(4) providing timely scientific advice related to cetacean research, conservation and management via peer-reviewed publications.

Simmonds concluded his remarks by thanking the governments of Australia, Germany, the UK and the USA for their sponsorship of the workshop and, similarly, the Humane Society International and the Whale and Dolphin Conservation Society for their support. He gave his personal thanks to the workshop steering committee for their guidance, and especially to Sue Moore, who in effect had been a co-convener, for her wit and wisdom. He also thanked the IWC Secretariat, particularly Jemma Miller, for their efficient assistance. He also noted the support in-kind from Costa Rica and the other sponsors of their climate change workshop earlier this month which would provide helpful and timely information to this workshop.

Sue Moore (Chair of the SWGEC) thanked the participants and the steering committee for their contributions. She commented that this is an exciting time to re-examine the subject as we are now in a much improved position than we had been at CC1, with improved predictive abilities and better investigative tools.

Gales (the Workshop Chair) thanked Simmonds and Moore for their considerable work in getting the workshop ready and the University of Siena and Cristina Fossi for the invitation to hold this meeting at the beautiful and historic Certosa. He asked participants to focus on the production of the best possible advice on whale populations and the need to make the outputs from this workshop relevant to the work of the wider Scientific Committee.

1.2 Terms of reference

The terms of reference for the Workshop as described above were noted.

1.3 Election of Chair and appointment of rapporteurs

Gales was elected Chair. A number of participants acted as rapporteurs including Aguilar, Bjørge, Brandon, Donovan, Ferguson, Laidre, Leaper, Moore, Punt and Simmonds.

1.4 Meeting procedures and time schedule

The Workshop agreed to a time schedule proposed by the Chair.

1.5 Adoption of agenda

A draft agenda was discussed, amended and approved (Annex B). The Workshop noted that it did not have time to fully consider the implications for cetaceans of climate-mediated changes in human behaviour that might impact them but noted that SC/F09/CC7 provides a short review. Würsig *et al.* (2001) had defined the tertiary effects of climate change as those which would manifest at the population or community level and 'involve a feedback loop that includes the initiator of the problem (humans in the present scenario of global warming)'. Such tertiary effects have been looked at recently by Burek *et al.* (2008), Hovelsrud *et al.* (2008) and Simmonds and Elliot (2009). The Workshop **agrees** that this subject warrants attention in the future.

1.6 Documents available

The list of documents available is given as Annex C. This includes original papers developed for the Workshop, PowerPoint presentations developed for the Workshop and a series of papers that had been already published or had been presented elsewhere noted as 'For Information' papers.

2. REVIEW OF OUTCOMES FROM RELEVANT MEETINGS

2.1 Workshop on Climate Change and Adaptation in the Eastern Pacific

Simmonds, one of the organisers, provided an overview of the Workshop on Climate Change and Adaptation in the Eastern Pacific held at the Bougainvillea Hotel, Heredia, Costa Rica, 9-11 February 2009. He noted that this was a well attended meeting attracting many scientists from Central, Southern and North America and beyond. He presented the agenda of the meeting. Simmonds noted the work by Jennifer Hoffman on 'climate change adaptation' (available to this meeting as SC/F09/CC3). He briefly described how this philosophy of 'adaptation' might apply in the case of marine turtles, for example via the relocation of nest sites (currently exhibiting high mortality because of high temperatures) to cooler sands and planting of vegetation on the shore to also provide conditions of lower temperature at the next sites. Simmonds commented that 'adaptation' for cetaceans was conceptually more problematic. There had been considerable discussion in Costa Rica about the development of sensitivity indicators, primarily for cetaceans but also for other species, and this is discussed further under Item 3.1.1. The full report from the Costa Rica meeting, including presentation summaries will be available later in the year.

2.2 CCAMLR-IWC workshop

Gales, who co-convened the CCAMLR-IWC workshop presented a summary of the workshop background, its terms of reference, the meeting format and key recommendations and outcomes. He noted the substantial areas of common interest in modelling ecological relationships in the southern ocean (particularly in predator-prey relationships) and the importance of collaborative modelling efforts to best inform the management and conservation obligations of both conventions. Several important recommendations resulted from the CCAMLR-IWC workshop that are relevant for

considerations of the relationship between climate processes and whales. In particular:

- The value of further, integrated analyses of existing datasets and series (e.g. CCAMLR 200, SOWER, GLOBEC) to explore the relationships of predators, prey and environmental correlates.
- The importance of research into the characterisation of linkages and influences of environmental and seasonal features on the distribution and density of predators and their prey.
- The importance of appropriate, coordinated long-term data series of key features of the environment (e.g. remote sensed data) and the predators and their prey (e.g. time series of relative abundance).
- The expansion of data series to include winter.
- The development of common analytical tools and modelling approaches, and access to appropriate data archives.

Gales noted that members of both Committees now have a far greater appreciation of each other's function, activities and range of expertise, and that this represents an excellent basis for further, targeted and strategic collaborations. He further noted that the reports of the expert groups represent an excellent status report on contemporary knowledge across the range of key model inputs. Reports from this meeting will go to the Scientific Committees of both conventions and discussions in these fora will determine the future function of the joint steering committee and the need for further work in the shared metadata archive.

In discussion it was noted that the report from the CCAMLR-IWC workshop, which will be presented at the IWC Scientific Committee's 2009 Annual Meeting (SC/61/Rep2), will emphasise that various groups are at quite different stages as to their ability to provide data for modelling. In some cases it is difficult or impossible to grasp uncertainty in various components of ecosystem. For example, it is currently impossible to estimate abundance of squid – a key prey item for many cetacean species. Instead, a 'proxy' for squid abundance is derived from estimates of abundance of their predators. In sum, while good quality data are essential for developing predictive models, acquiring those data is at present the biggest challenge. Obviously, collaboration across disciplines is required to achieve this goal. A positive outcome of the workshop was the recognition that whales should be a key component of modelling work focused on the Southern Ocean ecosystem.

2.3 The implications of climate change for arctic marine mammals: US MMC monitoring framework and CAFF Marine Expert Monitoring Group

The implications of climate change for marine mammals that are endemic to, or that seasonally occupy, arctic waters has been the focus of two recent workshops. The first, held 4-6 March 2007, was sponsored by the US Marine Mammal Commission (MMC) and resulted in a report entitled 'A Framework for Monitoring Arctic Marine Mammals' (Simpkins *et al.*, 2009). The eight cetacean species considered in the report included three (bowhead, white whale, narwhal) that occur in the Arctic year-round and five (gray, humpback, fin, minke and killer whale) that migrate seasonally to and from arctic waters.

The MMC report serves as a reference for available data on population dynamics of the three Arctic species, including stock identity, abundance and trends. In addition, six key components are identified and collated with primary sampling tools for measuring the status of arctic marine mammal populations. A schematic showing the components of a comprehensive conservation management plan for monitoring the status of marine mammal species or stocks, including population dynamics and the factors that influence those dynamics, provides a framework for development of such plans (Fig. 1).

The blue whale was added to the list of seasonally migrant species by the participants at a subsequent workshop focused on the potential effects of climate change on arctic marine biodiversity, convened in January 2009 by the Arctic Council Conservation of Arctic Flora and Fauna (CAFF). The adoption of the marine mammal species list provided in the MMC report provided a linkage between the work of the MMC and CAFF on the topic of effects of climate change on Arctic marine mammals. The outcome of this linkage with regard to completion of monitoring or conservation management plans will result from further work to be undertaken at a working meeting and final workshop of the CAFF group planned for April and October 2009, respectively.

In discussion, the question arose of how to address anticipated deleterious anthropogenic effects associated with climate change. While 'Human Activities/Threats' (including direct harvest, commercial fishing, mining, shipping, tourism and oil and gas development) are included as one of the six components of a conservation management plan (Fig. 1), it remains unclear how to include such activities in the development of population dynamics models. It was suggested that human activities be considered in the context of measurable variables.

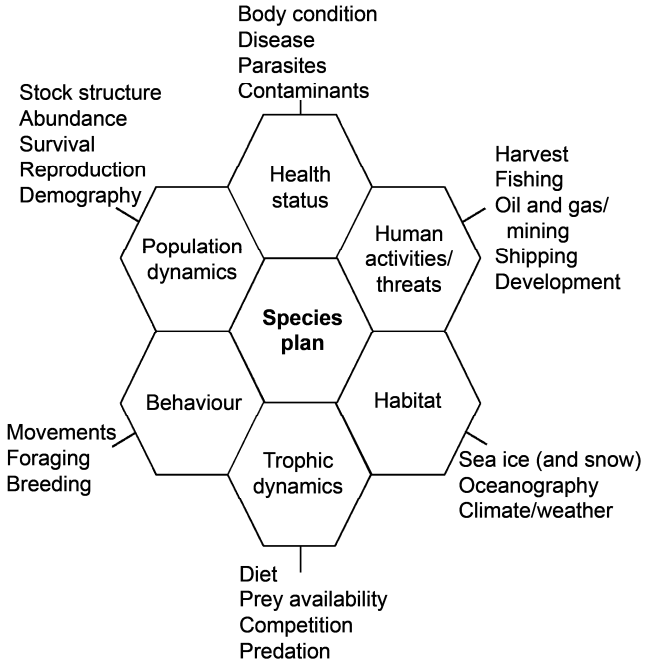

Fig. 1. The components of a comprehensive plan for monitoring the status of a marine mammal species or stock, including population dynamics, the factors that influence those dynamics, and examples of parameters that might be monitored for each factor; taken from Simpkins *et al.* (2009).

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

IUCN traits	Cetacean example
Specialised habitat and/or microhabitat requirements	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	The trigger for migration
Dependence on interspecific interactions that are likely to be disrupted by climate change	Changes in prey type, abundance or distribution; changes in temporal/spatial overlap with competitors; increased prevalence of disease or parasites
Poor ability to disperse to or colonize a new or more suitable range	Low genetic diversity or geographic containment

Specifically, one needs to weight the parameters included in the Human Activities/Threats component, with guidance on such weighting potentially provided from power analysis or activity-specific models. A recent paper details how the development of robust conservation management plans can provide mechanisms to accomplish this (Donovan *et al.*, 2008).

2.4 Other meetings

It was noted that the theme of the European Cetacean Society (ECS) meeting, to be held two weeks hence, is *Global Climate Change*. In addition, the theme of the American Cetacean Society (ACS) annual meeting, held in November 2008, was *Whales in a Changing World*, and the annual meeting of the Mexican Marine Mammal Society (SOMEMMA) in May 2008 also contained a focus on the effects of climate change on marine mammals. Both of these meetings indicate growing public concern regarding the potential deleterious effects of climate change on marine mammals. It was **agreed** that Wells would present a brief overview of the scope of the present workshop and the IWC's interest in this topic at the ECS meeting, assisted by Donovan.

3. SETTING THE SCENE

3.1 Cetacean populations' response to direct and indirect effects of climate change

3.1.1 The development of climate change sensitivity indicators

Simmonds introduced SC/F09/CC8. This provided an overview of the methods used to date to compare the likely sensitivity of species to climate change and explored the potential of some of indicators. He noted that the World Conservation Union (IUCN) has started a process to consider this (IUCN, 2007; 2008). The IUCN 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.

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

Laidre *et al.* (2008) had developed a climate change sensitivity index specifically for Arctic marine mammals. 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: population size; breadth/extent of geographic range; habitat specificity; diet diversity; migrations; individual site fidelity; sea ice changes; influences of changes in trophic web: maximum rate of population increase (R_{max}).

SC/F09/CC8 reported an initial attempt to extend the methods used by Laidre *et al.* (2008) to others species along with some additional potential indicators ('genetic variability', 'seasonal factors', 'predicted regional intensity', 'new competition' and 'IUCN status'). In addition SC/F09/CC8 reports on a consultation exercise conducted at the Costa Rican Workshop where opinions were sought on the utility of proposed sensitivity indicators and suggestions for new ones. Simmonds stressed that this had essentially been a brainstorming exercise and that the results should not be over-interpreted or taken out of context.

Palacios reported that a working group had met to discuss conservation status and vulnerabilities of cetaceans in the eastern tropical Pacific region. That group also discussed the applicability of climate sensitivity indices to the species in this region, based on the concepts outlined in SC/F09/CC8. This exercise underscored the limited biological knowledge for most species in the region, but was useful for starting to identify the species of highest concern. Palacios and Simmonds commented that the exercise had been valuable in promoting a discussion at the workshop on how climate change scenarios might affect the different cetacean populations in the region, as low latitude regions have thus far received relatively little attention compared to the polar regions. They mentioned the findings of a recent study that has indicated that a major impact of climate change will be the redistribution of cetacean species diversity from the tropics into the mid latitudes (Whitehead *et al.*, 2008).

In a brief discussion at the present Workshop, suggestions about the further development of indicators based on 'expert opinion' included the potential use of fuzzy logic, or a Bayesian approach. Another suggestion was to look at the process developed by NCEAS in the development of their 'expert surveys' work (see Halpern *et al.*, 2007). Although this was seen as one means to develop

a way to weight criteria, it does not include aspects of evolutionary history and provides no guarantee against the development of 'false positives' (i.e. a conclusion that events are related when they are not). General concern over the use of oversimplistic scoring systems and the use of voting or similar methods to address complex scientific issues was also expressed by a number of particpants.

A broader discussion on an appropriate way to evaluate of cetacean vulnerabilities ensued. The Workshop **agreed** that the objective of establishing sensitivity indicators should be to assess vulnerability and adaptability. It was suggested that examining 'extreme pairs' of species or populations (for example Southern and Northern right whales, or elephant seals and monk seals) might shed light on developing sensitivity indicators in an evolutionary context. At this point discussion of the evaluation of cetacean vulnerabilities was deferred to discussions under Items 7 and 8.

3.1.2 Impacts on cetaceans from the interaction of climate change with persistent organic pollutants (POPs)

Krahn provided an overview of this topic. Persistent organic pollutants (POPs) are chemicals that are resistant to environmental degradation and, as a result, are available for uptake and bioaccumulation in biota. Many classes of 'legacy' POPs (e.g. PCBs, DDTs, hexachlorobenzene and chlordanes) - as well as 'emerging' pollutants such as polybrominated diphenyl ethers (PBDEs) - have been reported in marine mammals. Some pollutants originate from local sources (e.g. industrial activities and pesticide use) and others are transported long distances via air and water pathways, particularly to the polar regions where they are deposited due to the 'cold condensation' effect. Given the length and complexity of the contaminant pathways to top marine predators, exposure to POPs is likely to be particularly sensitive to global climate change. Subtle effects of the POPs (e.g. disruption of the immune, reproductive and endocrine systems) can be exacerbated by nutritional stress and, together, these have the ability to adversely affect the viability of cetacean populations. However, the significance of pollutants as added stressors to predators already suffering from changes in habitat and prey availability is not well understood.

Multiple stressors acting synergistically make it more difficult to discriminate among the importance of each environmental threat. Experimental studies and time series are needed to test the potential effects of transport, transfer, and cycling of chemical pollutants on ecosystems and cetacean populations during times of climate change. To be able to make the correct decisions about future management actions, biological monitoring methods need to be improved to be more sensitive to individual stressors. In addition, coherent time series and advanced models that incorporate the impacts of multiple stressors are important themes for future research. In particular, research needs to be focused on the interactions of various risk factors to provide a better basis to understand and predict how changes in climate may affect risks from chemical pollution and other stressors.

The questions and discussion that followed addressed three overlying points: (1) mechanistic understanding of the introduction, transport, and concentration of pollutants in the environment; (2) the physiological effects of pollutants on marine mammals and the animals' subsequent responses; and (3) modelling to further our understanding of these phenomena, with the ultimate goal of forecasting the effects of pollutants under climate change scenarios.

With respect to achieving a mechanistic understanding of the relationships among pollutants and the environment, it was noted that there appears to be a direct link between harmful algal blooms (i.e. those producing demoic acid) and increasing temperatures and salinity. One piece of evidence in favour of this theory is that toxic algae tend to be increasing even in fairly pristine areas. In addition, the importance of coupling the atmospheric and oceanic systems when studying transport pathways was discussed. Finally, tropical regions were noted as a special case in that the combination of lower precipitation rates and increasing water diversion results in increased chemical concentration in freshwater outflows that may negatively affect riverine, estuarine and nearshore cetaceans. There is a smaller body of literature on pollutants in tropical ecosystems; this is partially due to small sample sizes.

The effects of pollutants on cetaceans were addressed in discussions of toxicity and animal response to the changing environment. In discussing potential cetacean responses reference was made to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007). This stated that there are three basic responses to climate change - animals may either: (1) redistribute relative to the changes; (2) adapt to the changes; or (3) become extinct. It was noted that the option of avoiding or following the changes may not be an option for some populations e.g. those polar regions or in areas surrounded by expanses of unsuitable habitat; in effect the animals could become trapped by their environment.

Several points were raised during the discussion on modelling the effects of pollutants within the context of climate change. First, it was stated that 'weight of evidence' will not be sufficient for forecasting; to forecast, we need to be able to quantify the magnitude of the effect. This is complicated for several reasons, including the synergistic effects of multiple stressors, low sample sizes, and the difficulty in measuring effects given that they are often sub-lethal. It was suggested that the first step in understanding interactions among multiple stressors is to understand univariate effects: if univariate effects and mechanisms are not well understood, it is even more difficult to understand higher-level effects. The need for power analyses to investigate whether effects could be detected given that they were occurring was identified but it was recognised that this is probably not possible given existing knowledge gaps. Furthering the understanding of fundamental mechanisms involving physiology and toxicology of cetaceans is of primary importance in furthering our efforts to understand, model and forecast the effects of multiple stressors. Paper SC/F09/CC11 provides a comprehensive list of references for this item.

3.2 Changes in the biological environment

3.2.1 Baleen whales and climate change in the Southern Ocean

Nicol and Forcada provided an overview of this topic. Climate change in the Southern Ocean will result in a number of physical, chemical and biological effects, many of which will have direct or indirect implications for cetaceans (Nicol *et al.*, 2008). Many changes to the physical environment have already been detected; these include

decreases in sea ice extent and duration, increases in sea surface temperature and decreases in ocean pH as a result of increased CO^2 concentrations. Biological changes in certain populations have also been detected but these cannot be linked as unequivocally to climate change as the physical and chemical shifts that have been observed (Smith *et al.*, 1999).

Baleen whales are most likely to be directly affected by changes in the sea ice environment, which will subsequently result in changes to the distribution and abundance of their primary food source, krill. Sea ice affects biological productivity through the growth of algae on the base of floes which provides food for grazers, particularly krill larvae, through the melting sea ice seeding the spring bloom and through its role as a platform and as an excluder of particular species (Arrigo and Thomas, 2004). Because sea ice is intimately linked to biological production, any changes in the extent and duration of sea ice cover will have significant ecological effects. Satellite measures of sea ice concentration and extent have been available since the late 1970s and these have indicated that there has been no net decrease in the seasonal sea ice cover in the Southern Ocean; however, there has been a marked recent decrease in the extent and concentration of sea ice in the Antarctic Peninsula region (Parkinson, 2004). Suggested changes in sea ice cover prior to the availability of satellite data are controversial but at least three proxy datasets (from the location of whaling fleets, sea ice records at the South Orkney Islands, and MSA records in ice cores) suggest that there was as much as a 20% decrease in winter sea ice cover in the 1950s and 1960s (de la Mare, 2009).

Antarctic krill are distributed throughout the sea ice zone and in the ice-free waters around South Georgia, but they are not uniformly distributed throughout their range (Atkinson *et al.*, 2008). Declines in krill populations in the southwest Atlantic and a reduction in overall range have been suggested from time series of scientific net surveys, and these have been linked to declines in sea ice cover in this area (Atkinson *et al.*, 2004). Long-term time series of acoustic surveys of krill are limited and are too localised to make generalisations on trends. There have been four large scale quasi-synoptic acoustic surveys of krill but these have covered different regions or have used dissimilar techniques so are unsuitable for examining change. Three of these surveys (CCAMLR 2000 in the SW Atlantic, BROKE in the SE Indian and BROKE West in the SW Indian) collected data on krill, oceanography, and cetacean distributions. It would be beneficial to further study the data from these three surveys to examine the relationships between cetaceans and their physical and biological environment. Among krill consumers, seals and penguins are currently estimated to consume the most krill (Priddle *et al.*, 1998). Populations of these land-based krill feeding predators show a number of trends but there is no general pattern that might accompany a dramatic decline in their prey (Croxall *et al.*, 2002).

Changes in the Southern Ocean ecosystem are also driven by cyclic variability on the scale of years to decades (Murphy *et al.*, 2007). In the Southwest Atlantic sector of the Southern Ocean, environmental autocorrelation is evident with frequent SST anomalies, correlated with ENSO indices. More direct forcing is likely to be driven by the Southern Annular Mode (SAM), which interacts with ENSO and has been associated with sea ice contraction and expansion in the Antarctic Peninsula and the Ross Sea regions respectively. Disentangling climate change effects from other types of variability including periodic physical forcing requires time series of data and these are scarce in the Southern Ocean (Quetin *et al.*, 2007). At present only a few available long term data sets of whale productivity allow detection of responses to climatic fluctuation.

The responses of the Southern Ocean ecosystem to climate change are likely to be complex. Sea ice decreases may actually enhance overall primary production but could reduce ice algae production which occurs at a critical time of year for krill larvae (Arrigo and Thomas, 2004). The location of upwelling of nutrient-rich deep water may change and result in enhanced primary production in areas that are otherwise unfavourable to krill (Prezelin *et al.*, 2000). The distribution of krill predators might change in response to changes in the distribution of their prey (Atkinson *et al.*, 2004). Baleen whales may have had a significant role in iron recycling in surface waters and their decline may have led to a drop in overall ecosystem productivity (Smetacek, 2008). Ocean acidification might change community structure in unpredictable ways (McNeil and Matear, 2008). Progress in understanding the effects of climate change on the Southern Ocean will require the development of conceptual and predictive models, the maintenance and enhancement of long-term datasets and further process studies to understand ecosystem linkages. Ecosystem-based models are likely to be useful to understand cetacean responses to climate change and other anthropogenic pressures, but improvements in measuring relative and absolute abundance of key species will be essential for creating and validating these models.

In the discussion that followed, it was noted that some species such as salps have been shown to increase in abundance in the absence of krill (Atkinson *et al.*, 2004). Other species such as copepods could also increase if Antarctic krill abundance were to decrease and these could provide an alternative food source if krill were to decline but this would depend upon the population density and energy content of alternate prey species.

It was noted that there currently exists a spectrum of opinions in our ability to estimate krill abundance and distribution (e.g. see SC/61/Rep2). The two techniques used to estimate abundance are net tows and acoustic surveys. Net tow analyses are complicated by the ability to estimate a scaling factor to extrapolate to absolute abundance from the net sample. Acoustic methods require estimates of a scaling factor and of target strength in order to produce a density estimate (Hewitt and Demer, 2000). Net tows and acoustics cannot currently be used to provide precise estimate of density or abundance, but they can estimate relative density and age/size distribution. It was also noted that krill off South Georgia are exclusively adults that spend their larval stages in other areas (Tarling *et al.*, 2007).

The Workshop noted the technical complexities of estimating krill biomass in three dimensional space and that this is even more difficult for squid. Currently, estimation of squid abundance is achieved through back-calculations, starting from squid predators. It was suggested that correlations between annual breeding success of different land-based predators such as seals and penguins, could give an indication of the spatial scale of interannual changes. It

was acknowledged that estimation of absolute abundance of these important prey species is very important to understanding ecological linkages in the Southern Ocean.

The Workshop noted that while the Southern Ocean is generally regarded as one of the simplest ecosystems to understand due to the short length of the food chain, there are still problems in even estimating basic parameters such as prey abundance. Nevertheless, understanding the effects of climate change on the ecosystem requires understanding of complex relationships, including the functional relationships between predators and prey. As emphasised at the recent CCAMLR-IWC joint workshop (SC/61/Rep2), further effort will be required to understand the ecosystem dynamics of the Southern Ocean and the implications for climate change.

3.2.2 Baleen whales and climate change in the Pacific Arctic Region: bowhead and gray whale focus

Ashjian introduced this topic. Ice cover is particularly important in structuring ecosystems in seasonally covered regions of the Pacific Arctic. Regions with abundant seasonal sea ice (Chukchi Sea, Northern Bering Sea) are characterised by low water column grazing so that a high proportion of total primary production (ice algae and phytoplankton) reaches the seafloor and supports a high benthic biomass (benthic dominated), while regions with less sea ice (the Southern Bering Sea) are characterised by higher water column grazing, reduced flux of organic material to the sea floor, and lower benthic biomass (pelagic dominated) (e.g. Bluhm and Gradinger, 2008).

Potential ecosystem responses to climate change include changes in seasonality, changes in production, and changes in the distribution and composition of biological communities. The most obvious manifestations of marine climate change in the Western Arctic are reduced sea ice extent and increased water temperature, demonstrated in particular by conditions in 2007. Other physical consequences of climate change include: (1) changes in the timing of sea ice advance, retreat, and seasonality; (2) changes in atmospheric characteristics and ensuing changes in weather patterns and meteorology. Recent changes such as earlier ice retreat and warming of the southern Bering Sea, northern Bering Sea cold pool, and air temperature (e.g. Grebmeier *et al.*, 2006b; Stabeno *et al.*, 2007) are associated with changes in the abundances of large vs. small copepods and of krill in the southern Bering Sea (Coyle *et al.*, 2008; Pinchuk and Coyle, 2008) and of northern Bering Sea benthic biomass (e.g. Grebmeier *et al.*, 2006b; Moore *et al.*, 2003).

Gray whales primarily consume benthic prey including amphipods and clams, although they also may consume krill, invertebrates that are found usually in the water column or occasionally just above the sea floor. By contrast, bowhead whales consume primarily krill and copepods that are usually thought of as pelagic (water column), although both can be found near the seafloor where they also appear to be consumed by bowheads. The distribution of prey for both whale species is strongly dependent on the regional circulation. Gray whales are found at sites of elevated benthic biomass in the Chirikov Basin, southern Chukchi Sea, and near Barrow, Alaska (e.g. Moore *et al.*, 2003; Stafford *et al.*, 2007). These productive benthic communities are associated with elevated water column productivities (represented by standing chlorophyll) that in turn are dependent on elevated nutrients advected from south to north through the Bering and Chukchi Seas (e.g. Dunton *et al.*, 2005; Grebmeier *et al.*, 2006a), as well as on the formation of local fronts that promote localised regions of elevated chlorophyll with associated aggregations of pelagic prey (krill) (e.g. Bluhm and Gradinger, 2008). Gray whale observations in the Chirikov Basin are lower in recent years (e.g. 2002) relative to the 1980s, but higher in the southern Chukchi Sea, associated with an accompanying decline in the biomass of their ampeliscid amphipod prey in the Chirikov Basin (e.g. Coyle *et al.*, 2007; Moore *et al.*, 2003).

Bowhead whale copepod prey consists primarily of large species of the genus *Calanus* that are found over the Slope and in the Arctic Basin rather than on the Chukchi and Beaufort Shelves. These species follow a two- or three-year life history, undergoing ontogenetic migration to depth (400m) during winter, and store lipids for overwintering during the productive season. During summer and fall, *Calanus* spp. are a lipid rich food source for bowhead whales. Krill are relatively rare in the Western Arctic proper and must be advected into the Chukchi/Beaufort Seas from Bering Strait in the prevailing circulation. Modelling of krill trajectories and transit times demonstrates that krill advected through Bering Strait in the spring can easily reach Barrow and the Beaufort Shelf in time to be utilised by the bowheads during their fall southerly migration (Berline *et al.*, 2008). Both *Calanus* and krill are brought onto the Beaufort and Chukchi Shelves through wind-driven upwelling of deeper water (and intrinsic plankton) onto the shelf during winds from the east, even during periods of ice cover (Pickart, unpub.). This mechanism is particularly effective near Barrow where sustained upwelling winds from the east followed by low winds or winds from the south produce elevated abundances of krill on the shelf at the 15-20m isobath (Ashjian, Campbell, Okkonen, unpub.).

There are a number of hypotheses related to possible impacts of climate change on the prey of baleen whales, particularly bowhead whales, in the Western Arctic and northern Pacific (Bering Sea). Climate change could potentially increase or decrease the supply of bowhead whale prey in the Chukchi and Beaufort Seas through:

(1) changes in weather that modifies the frequency of upwelling along the Beaufort Shelf;
(2) the magnitude of production, circulation, or abundance of krill in the Bering Sea through food web changes or loss of sea ice; or
(3) species and size composition of zooplankton, particularly those that advect into the Chukchi and Beaufort Seas from the Bering Sea.

For gray whales, changes in the availability of their benthic prey either through changes in the supply of organic material to the benthos or through modification of sediments (Grebmeier *et al.*, 2006b), can alter preferred feeding sites. Complete understanding of Bering Sea and Arctic ecosystems is hampered by lack of information on winter conditions in these regions.

During discussion, the question as to whether bowhead whales fast during the winter was raised. It was noted that results from a stable carbon isotopic analysis (Schell *et al.*, 1989) had been used to infer that bowheads feed in the Bering Sea and that summer feeding in the Eastern Beaufort Sea was less important than previously thought (particularly

for adults). However that study overlooked the fact that bowhead summer prey consumed in the Western Arctic is advected from the Bering Sea. Direct observations, including those from aerial surveys, suggest that summer feeding is important. Bowheads are unique among other highly migratory mysticetes in that they stay at a relatively high level of nutrition, although seasonal differences in body composition and girth suggest that some fasting might occur (and might differ by age class). It was also noted that none of the workshop participants was aware of any existing prey abundance estimates suitable for quantifying ecological linkages

3.2.3 Climate change and small cetaceans

Wells introduced this topic (SC/F09/CC6). Arctic and Antarctic marine mammals are expected to exhibit the strongest climate-related signals, at least initially, but large scale changes are also likely to affect small cetaceans, especially those inhabiting shallow, inshore habitats, including estuaries and rivers. The challenge of disentangling climate change signals from other forcing factors affecting demographics is a common theme among scientists studying small cetaceans. Clear identification of whether factors affecting populations are from anthropogenic sources (direct or indirect) not related to climate or result from climate change impacts would help guide management decisions. In the absence of dramatic habitat changes, detecting the impacts on small cetaceans in shallow habitats from more subtle and gradual but progressive changes in water temperature, sea level, salinity, and other factors will require holistic, multi-variate approaches that consider synergies among climate change related impacts and other anthropogenic stressors. Research techniques and a long term dataset from Sarasota Bay, Florida, relevant to studying climate change impacts on small coastal cetaceans were described as a case study.

The collection of research tools that have been developed to provide data for examining the effects of long-term environmental change on inshore small cetaceans include:

(1) visual censuses and surveys of cetaceans and their environment;
(2) acoustic censuses and tracking;
(3) photo-identification;
(4) biopsy-tissue sampling for genetic, pollutant and diet analyses;
(5) radio and satellite-linked tagging and tracking; and
(6) remote sensing.

In shallow-water situations, it may be possible to supplement these tools with additional sources of information, including:

(7) strandings;
(8) live capture-release health and body condition assessments; and
(9) prey monitoring.

When these tools are applied consistently over time to those species that can be studied most reliably, it is possible to develop baselines with sufficiently high resolution to allow detection of trends possibly tied to climate change, which can lead to predictive hypotheses that can be tested through further research. Such a weight-of-evidence approach taking advantage of 'natural experiments' may lead to the identification of signals and impacts of climate change. The most appropriate potential 'sentinel' shallow-water small cetacean species will likely vary from site to site around the world.

Common bottlenose dolphins (*Tursiops truncatus*), which occur along many coastlines in temperate and warm waters, may serve as one sentinel of climate change as they exhibit a wide range of behavioural and physiological plasticity that may provide the basis for detectable responses to environmental changes. This species has been the subject of numerous research projects, providing potential baseline data for evaluation of changes at a number of sites. At the northern extent of the species' range on both the east and west coasts of the United States, bottlenose dolphins have demonstrated the capacity to dramatically alter spatial or temporal aspects of their ranging patterns in apparent response to changing environmental conditions. Many coastal bottlenose dolphin populations live well away from the range limits of the species, within a matrix of established, long-term resident communities. Under these circumstances, large-scale range shifts into waters already inhabited by other bottlenose dolphins may not be an option due to competitive exclusion, and indications of effects of climate change may be less visible. The datasets developed beginning in 1970 through a long-term study of resident common bottlenose dolphins on the central west coast of Florida, including sightings, reproductive histories, health and body condition, strandings, behavioural observations, and prey distribution and abundance, provide a basis for examination of possible climate change signals and effects for resident populations of small cetaceans in inshore waters.

Sea surface temperature increase is likely to be one of the first manifestations of climate change for small cetaceans in shallow, coastal, non-polar waters. Resident dolphins in Sarasota Bay have remained in the area for decades, at least, persisting through large scale environmental perturbations such as red tides. Existing data suggest that these animals may face increasing health problems if they remain in warming waters due to increases in harmful algal bloom exposure or thermoregulatory issues. High summer metabolic rates and mortality rates suggest challenges to thermoregulation due to water temperature approaching body temperature; this situation may be exacerbated by climate change. Thermal stresses may combine with toxicological stresses to increase mortality under warm water conditions. Lipids released from thinning blubber as waters warm can transport associated toxic environmental contaminants (e.g. PCBs, DDT and metabolites) to target organs or to organs where biotransformation can modify toxicity, leading to compromised immune function. Warmer waters are likely to support a variety of pathogens, reduce host resistance, and/or increase the associated pathways of exposure. Transfer of contaminants via lactation has been suggested as one cause of the increased mortality documented for first-born calves in the area. Taken together, these factors suggest that seasonal warming appears to lead to health challenges for Sarasota Bay bottlenose dolphins. It is difficult to predict how this scenario might change under an incremental warming situation as might occur with climate change, but a suite of health, body condition, life history, and population dynamics parameters should be monitored

and analysed to investigate signals or effects of climate change.

During discussion, the success of the Sarasota Bay study was commended. It was noted that it is possible to implement similar studies in other areas. The long-term success of such a programme is due to several factors, including:

(1) the shallow water environment that facilitates animal handling;
(2) protection from rough seas and currents, and minimal tide change;
(3) financial resources for start-up and maintenance of facilities and salaries; and
(4) on-site researchers to ease logistical difficulties associated with field work.

Shark Bay in western Australia is an example of another long-term population monitoring study with a behavioural emphasis. It is noteworthy that Shark Bay dolphins presumably have lower toxic loads, but first-time mothers lose more calves than experienced mothers, as documented in the Sarasota Bay system. Consequently, disentangling the influence of toxins and experience levels of mothers represents an important challenge.

Contaminants were also discussed. The sources of contaminants in the Sarasota Bay area are unknown, but are thought to be transported through the air from distant sources because no known point sources exist nearby. There may be a decline in 'legacy contaminants' in the area, and emergent contaminants are being measured. Although emergent contaminants are detectable, it is unknown whether the contaminant load is increasing in the area because the time series is relatively short.

With respect to red tides, the possibility was raised of correlating the frequency of red tides with mortality events in Sarasota Bay and using this to predict whether increasing frequencies of red tides would have a substantial effect on the dolphin population. However, red tides are complex phenomena and this was not deemed likely to succeed. For example, they contain more than ten different neurotoxins exist in varying strengths, they are patchy events that are difficult to measure, and high cell counts are not directly correlated with toxicity (the toxins may remain enclosed in the cells and, therefore, sequestered from the outside environment). For example, during a 2005 harmful algal bloom in the Sarasota Bay area, resident dolphins did not die immediately from biotoxins, but dolphin mortality was associated with a temporal lag due to changes in the environment. The biotoxins can remain in the environment for a period of time following a red tide event, and they may accumulate over time. It was noted that the Sarasota Bay researchers conduct necropsies on all fresh carcasses that they can obtain.

3.2.4 Oceanography and cetaceans in the Eastern Tropical Pacific

SC/F09/CC10 combined oceanographic and cetacean sightings data in the Eastern Tropical Pacific (ETP) from surveys conducted by NOAA's Southwest Fisheries Science Center. There are two predominant modes of inter-annual variability in the Pacific: the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The ENSO has its greatest amplitude in the central and eastern tropical Pacific and varies on scales of 3-7 years. The PDO has its greatest amplitude in the North Pacific and tends to vary most strongly on scales of 20-30 years. The projections from the 4th IPCC report (IPCC, 2007) predict the following changes that are relevant to the ETP:

(1) the ocean is warming, although not uniformly;
(2) net freshwater flux into the ocean is increasing at higher latitudes and decreasing at lower latitudes, with concomitant changes in salinity of surface waters;
(3) vertical structure of the water column is changing, affecting stratification and nutrient input to surface waters; and
(4) CO_2 is entering the oceans in increasing concentrations, resulting in acidification and a subsequent shoaling of the calcium compensation depth.

A weak shift towards 'El Niño-like' conditions is predicted to occur in the ETP. In addition, weakening trade winds could result in reduced equatorial upwelling and primary production (Vecchi and Soden, 2007; Vecchi *et al.*, 2006). Finally, evidence from remotely sensed chlorophyll data suggests that productivity in the ETP has already declined (Gregg *et al.*, 2003; Polovina *et al.*, 2008).

Cetacean distribution in the ETP exhibits spatiotemporal variability due to a number of factors, including the distribution or abundance of prey, and inter- or intra-specific interactions among cetaceans. Cetacean habitat models built within a generalised additive modelling framework identified species-specific relationships to a suite of oceanographic variables in the ETP. Eastern spinner dolphins tended to be more abundant in warmer Tropical Surface Water where the thermocline is fairly shallow. Common dolphins were more abundant in cooler waters affected by coastal and oceanic upwelling. The model results were less satisfactory for the Bryde's whale. Bryde's whales have a widespread distribution in tropical and warm temperate waters, and it is likely that all of the ETP could be considered Bryde's whale habitat. These cetacean-habitat models can be used to create hypotheses regarding expected changes in cetacean distribution and relative density due to climate change, but they cannot predict population size at a future environmental state.

The cumulative effects on cetaceans of these physical changes in the ETP ecosystem are unknown. It was noted that cetacean populations in the ETP have experienced and survived climate change in the past, along with severe fishery and whaling mortality, although the rate of change to the physical environment due to climate change is a novel challenge. To address a climate change scenario specific to the ETP, an Ecopath with Ecosim model of the pelagic ecosystem was presented (Watters *et al.*, 2003). The model was forced with a global-warming projection of SST, with bottom-up effects on phytoplankton biomass and top-down effects on predator recruitment. Although the model predicted that phytoplankton would decline by 50%, animals at higher trophic levels could decline by only 10-20% (spotted dolphins) or even increase (yellowfin tuna).

In discussion, the Workshop recalled the difficulties in ecosystem modelling highlighted at a number of previous IWC and other meetings (e.g. SC/61/Rep2; IWC, 2004; FAO, 2003; Plaganyi, 2007; and see Items 3.3 and 6), both from the perspective of the models themselves and the input data. Accounting for uncertainty in models is a daunting challenge, yet essential. A model must adequately incorporate the variance associated with input parameters to

be useful. In many cases this is simply not possible and it is important to clearly state the limits to model output and identify where they can provide useful direction and where they cannot. As an example, a key outcome of the ecosystem modelling workshop in San Diego was that at this time models cannot predict effects of fisheries on whales or whales on fisheries (IWC, 2004).

A question arose as to the confidence placed in proxy reconstructions of sea surface temperature (SST) back to 1860, which are often based upon tree rings, pollen records and fish scale deposition. In general, there is good confidence in these reconstructions as they are calibrated on a regional basis and so thought to reflect local conditions. Further discussion focused on the question of whether or not environmental signals related to climate change might be 'masked' by natural variability associated with seasonal, inter-annual, ENSO or PDO-type cycles. Specifically, it has been suggested that cetaceans have lived through eras of a very 'warm climate' in the past, but we do not know how populations of cetaceans fared in these conditions. It was noted that cycles of variability require sampling at appropriate temporal and spatial resolution in order to be able to at least try to distinguish climate change signals from 'natural' cycles of variability.

3.3 Modelling the impacts of climate change on management strategies: examples from fisheries

Punt provided an introduction to the role of modelling in examining the impacts of climate change on management strategies. The principle behind the development of the IWC's Revised Management Procedure (RMP) and the *Strike Limit Algorithms* (*SLAs*) developed under the Aboriginal Subsistence Whaling Management Procedure (AWMP) is one of simulation testing under a plausible set of scenarios that take into account biological and environmental uncertainty. Inter alia, the scenarios considered time varying trends in carrying capacity, natural mortality and productivity, and the occurrence of 'catastrophes' which were intended to reflect in an integrative manner environmental impacts including climate change. Similar approaches are/have been used to evaluate the management strategies used as the basis for providing scientific management advice in fisheries. In addition, both the RMP and AWMP incorporate regular (5-year) *Implementation Reviews* during which new information on cetaceans and their environment is evaluated to ensure that the parameter space tested by the simulation trials is adequate; if it not new trials are determined.

There are several modelling approaches that have the potential to assist in the evaluation of the impact of climate change on our ability to meet management objectives. One approach is to use full ecosystem models (those which include links between climate, oceanography, lower trophic level organisms, forage fish and upper trophic level species) as the basis for operating models[1]. Such operating models are more likely to explicitly represent the processes driving the population dynamics. An alternative approach is to base operating models on minimal realistic models. Such models, which represent only a few species, are more tied to actual data. However, they do not explicitly consider biological processes and thus can only link climate and population dynamics empirically. The full ecosystem modelling approach has been adopted for the Bering Sea Integrated Ecosystem Research Program (BSIERP) and Bering Ecosystem Study (BEST), while minimal realistic models have been used to evaluate the impact of climate change on rock lobsters off Tasmania and walleye pollock in the Gulf of Alaska.

Development of full ecosystem models is computationally very challenging because it is necessary to link several different components (e.g. climate change models, NPZ models, forage fish models) which may operate on different temporal and spatial scales. Parameterising these models is also extremely difficult because full ecosystem models involve a large number (>1,000 in same cases) of rate parameters, for which field data rarely exist (or can even be obtained).

It is important to fully consider uncertainty in all of the various components of the operating model when evaluating management strategies. Previous operating models for whale populations have often focused on observation and model structure error. The evaluation of the impact of climate change also requires consideration of the relative reliability of the various IPCC climate models since these models will probably form the basis for the climate forecasts which drive the dynamics for the populations of primary interest. The various IPCC models perform differently in many ways including in terms of their ability to reproduce actual historical observations ('hindcast skill'). Furthermore the performance of various IPCC models may vary by region. While good hindcast skill does not guarantee good forecast skill, poor hindcast skill suggests that forecast skill will also be poor.

In discussion, it was noted that at least for the Gulf of Alaska pollock, management strategies that use climate data did not outperform the current management strategy that does not. In principle, a management strategy that is more adaptive to the data than that in current use might perform better at reacting to climate change. However, adaptive management strategies have the danger that they can react to noise rather than signal.

4. EMPIRICAL TECHNIQUES TO INVESTIGATE LINKAGES BETWEEN WHALES AND THEIR ENVIRONMENT: SOME EXAMPLES

4.1 Biochemical tools and physiological indicators and their use in retrospective studies of archived material

SC/F09/CC4 addressed the various biochemical tools that can be applied to assess potential effects of climate change on cetaceans and that offer an independent means of examining hypothesis about effects of climate change put forward from data on oceanographic parameters or distribution of cetaceans. Biochemical indicators can be applied to samples collected from both live and dead specimens. Very importantly, some of them can also be applied to samples than are deposited in museums or scientific collections, and therefore allow retrospective monitoring extending over historical or, even, pre-historical

[1]The operating model is the simulation model used to represent the 'real world' when testing a management procedure to enable the consequences of management actions specified by the management strategy to be determined, it also simulates the data used in the stock assessment part of the management strategy. Operating models are usually much more complex than a stock assessment model, as it is designed to mimic the real world as far as possible and to allow examination of the consequences of failures of the assumptions in the stock assessment model.

time series, thus extending capacity to understand long-term change. The set of biochemical indicators presented include stable isotopes, blubber lipid content, fatty acid signatures and trace element profiles. In combination or investigated alone, these tracers have a high potential for assessing changes in habitat and residence area, nutritive condition, food availability and diet. For each of them, Cardona presented their potentials and limitations, the available sources for material, the ability of the tools for conducting retrospective studies, and briefly reviewed some case-studies that have successfully used these tracers to assess long-term environmental change in marine mammals.

There was some discussion about the ability of these techniques to characterise a given specific change; it was **agreed** that they can represent a useful valuable alternative to observational data and may provide valuable insights into cause-effect relationships in changes observed in populations. For example, biochemical techniques can explain whether an observed change in distribution is caused by variation in water temperature or in food availability.

Rowntree presented Rowntree *et al.* (2008) which applied tracer analyses of right whale skin and baleen to infer foraging behaviour. The right whale population that uses Peninsula Valdes, Argentina as a calving ground has fewer calves that expected in years when sea surface temperatures are higher than usual off South Georgia which in turn is correlated with reduced krill abundance in the region (Leaper *et al.*, 2006; Priddle *et al.*, 1988). Stable carbon isotope and genetic analyses of 131 skin biopsy samples collected from Patagonian right whales over a four-year period showed that individual whales fed in different locations that spanned a broad latitudinal range. Thirty-one mitochondrial haplotypes represented in the biopsy samples were not randomly distributed across the isotopic range but correlated significantly with specific isotopic signatures. These results indicate that right whale calves learn their foraging locations from their mothers and may have difficulty finding new foraging locations. Skin samples represent feeding over a short period of time (a week) while baleen plates contain a continuous 5-6 year record of the stable isotopes and trace metals in the whale's diet.

Analyses of the stable carbon isotopes along the length of five baleen plates showed that the baleen grew an average of 31cm/year with significant inter-annual variation in baleen growth (SD=5.8cm) within individuals but no significant growth differences between whales. The baleen plates showed distinct individual foraging strategies. Two whales had small N-S ranges, one whale fed only in warmer waters (probably on the Patagonian shelf). Three whales followed similar foraging paths covering broad N-S ranges. Baleen grew more in years when the whales fed in the coldest waters of their range, indicating that prey in southern regions may be more nutritious or in greater abundance. The results of these analyses indicate that tracers can be useful in documenting a whale's foraging response to changes in prey distribution and abundance than could arise with climate change.

4.2 Ancient DNA and climate change: examples from bowhead and gray whales

Alter presented a report on the utility of historic samples in investigating the impacts of climate change on the demography of bowhead and gray whales. Ancient DNA was used to examine pre-whaling demography in order to better understand how climate and whaling may have affected population dynamics and stock structure. Results indicated that both overall abundance (gray whales) and population structure (bowhead whales) were affected by past climatic conditions. These results suggested that overall genetic diversity in bowhead and gray whales was higher in the Holocene than at present. In gray whales, genetic data showed that the primary decline is coincident with commercial whaling, but heavier ice cover during the Little Ice Age may have contributed to a more gradual decline beginning ~700 ybp. In bowhead whales, the comparison of ancient mitochondrial sequences with modern data from this region indicated that population structure may have existed in the past between Baffin Bay/Davis Strait and Hudson Bay/Foxe Basin. This difference may be attributable to changing ice cover in the Canadian Arctic over the late Holocene (including the closure of Fury and Hecla Strait). Another possible cause is commercial whaling on bowhead whale populations in eastern Canada and Greenland. Future work will focus on using ancient and modern genetic data to estimate the envelope of possible demographic trajectories and to test the statistical rigor of diversity and differentiation measures.

Alter also commented that whether microsatellite analysis would be able to detect the effects of recent whaling would dependent on the magnitude of the depletion; a severe reduction in size should be able to be detected in just two or three generations.

5. CETACEANS AND CLIMATE CHANGE: CASE STUDIES

5.1 Large cetaceans

5.1.1 Long-term cetacean datasets in the Southern Hemisphere

SC/F09/CC2 reviewed available cetacean datasets in the Southern Hemisphere with potential utility for climate change research. It was proposed that three critical characteristics make datasets relevant to addressing questions regarding climate change, namely:

(a) Duration: The overall time span of the dataset should be at least twenty to thirty years long (exceptions to this rule exist for highly sensitive ecosystems that undergo rapid changes due to the warming climate).
(b) Temporal Resolution: The dataset must capture variability ranging from interannual to multi-decadal time scales. This criterion is met with annual surveys. Alternatively, this criterion could be met if the overall dataset comprises multiple blocks of time, spanning several years each, in which annual surveys were conducted.
(c) Spatial Scale: The relevant spatial scales for studying climate change range from the mesoscale (eddies, fronts, and upwelling zones) to the full extent of a population's distribution (circumpolar, for some Southern Hemisphere baleen whales).

The financial and logistical constraints of satisfying the three data criteria could be overcome through collaboration among researchers, institution, and nations, using

strategically designed hierarchical or nested sampling protocols.

SC/F09/CC2 highlighted four datasets on baleen whales in the Southern Hemisphere that meet these criteria. First, the shore-based counts of humpback whales off East Australia (e.g. Noad *et al.*, 2008) could be used to investigate population abundance and trends with respect to climate change. Two long-term studies of southern right whales meet all three criteria: (1) studies off Peninsula Valdez, Argentina (covered by Rowntree *et al.* under Key Study 2 of this workshop); and (2) studies off South Africa (Best *et al.*, 2005; Best *et al.*, 2001). Finally, international collaborative research programs (e.g. SO-GLOBEC, CCAMLR 2000) as well as the Argentinean, Brazilian, British, Chilean, German and U.S. Antarctic survey programs have been working largely independently in the waters off the Western Antarctic Peninsula, between Elephant Island and Margueritte Bay. These programs encompass a variety of studies, including physical and biological oceanography, but many have a dedicated whale component. Therefore cetacean sighting data and biopsy samples have been collected during some of the research cruises. SC/F09/CC2 noted that it was unknown whether the collective cetacean data from these nations would satisfy these criteria for relevance to climate change research, but encouraged that this be investigated further.

In discussion, two additional datasets were noted which could be added to this list: (i) age-data from Antarctic minke whale catches may provide some indication of factors which may be related to environmental conditions, e.g. year-class strength (Punt and Polacheck, 2008) - issues associated with these age data have been discussed by the IWC Scientific Committee but have not yet been fully resolved; and (ii) photo-identification catalogues of humpback whales (possibly combined across stocks).

Additionally, a similar review of suitable datasets was suggested for future work, but with a focus on available biological data (e.g. tissue samples). Gales noted that a meeting in late March 2009 in Hobart on the Southern Ocean Research Partnership will review research needs, existing data and will engender a collaborative research focus on whales in the Southern Ocean.

The Workshop noted the utility of reviews of this nature and **recommends** that a similar exercise be conducted for cetacean data series in the Northern Hemisphere.

5.1.2 Southern right whales and climate change: example from the western South Atlantic and Southern Ocean

SC/F09/CC12 described analyses of the link between environmental changes and the reproductive success of Southern right whales (*Eubalaena australis*) wintering off Peninsula Valdes, Argentina. This population has been studied every year using photo-ID since 1971, mainly in September. The birth-interval model of Payne *et al.* (1990) had been reformulated as a Markovian transition probability model, to allow for inter-annual variation in calving probabilities through addition of a year-specific random effect (Cooke *et al.*, 2003). The model assigned reproductive females to three stages: nursing, resting and pregnant. Significant inter-annual variation was found in the probability of a reversion from pregnant to resting (which results in a calving interval of 5 years or more). The year-specific anomalies in the reversion probability provide a measure of reproductive success that can be correlated with environmental factors. Some matches with animals seen off South Georgia indicate that at least some of the population feeds there. Breeding success of land-based krill predators (gentoo penguins and fur seals) have shown a strong correlation with annual anomalies in sea surface temperature off South Georgia, which have been recorded since 1982 (Trathan *et al.*, 2003). The right whale breeding success anomalies also exhibited a significant correlation with the SST anomalies with a time lag of one year (Leaper *et al.*, 2006). The effect is small enough that over the range of SST anomalies observed to date, a positive net reproductive rate is expected, implying persistence of the population. Extrapolation to the range predicted under a particular set of IPCC 4 climate change scenarios towards the higher end of the range of warming scenarios (see the paper for details) shows that under these scenarios, the population would not necessarily be able to persist.

In discussion it was noted that the mechanisms behind the observed correlation between SST and calf production were not fully understood. For example, at South Georgia intrusions of warm water from the north have been observed to displace krill to the south, which has a negative effect on central place foragers (e.g. fur seals), but does not directly affect the abundance of their prey item. The authors of SC/F09/CC9 agreed that such considerations were certainly important when extrapolating future effects of sea surface temperature change on population dynamics.

Recent mortality events in the Patagonian right whale population. The Southern Right Whale Health Monitoring Program recorded high mortalities of right whales on their nursery ground at Peninsula Valdés in 2005 (47), 2007 (83) and 2008 (100). These cannot be directly attributed to climate change, but are of interest because of potential links between warmer temperatures and increases in harmful algal blooms. Some 86% of the strandings during these years were 0-3 month old calves. Most of the whales died in deep water and by the time the carcases reached the shore they were in a decomposed condition. Therefore, tissue samples collected during necropsies were too decomposed to determine cause of death. Satellite maps showed unusually high levels of Chl-a in the weeks surrounding the peaks of strandings in October-November. The whales begin to feed sporadically on the nursery ground in late September. 2008 was unusual with a first peak of strandings (25 whales) in mid-August and a second but lower peak in mid- October. Analyses of water samples in 2007 showed high concentrations of the toxic dinoflagellate *Alexandrium tamarense* (18,125 *cells*/l), the non-toxic green algae *Lepidodinium chlorophorum* (16,488 cells/l), and the diatom *Pseudo-nitzschia* spp. (1-2 million cells/l) which can produce domoic acid. The concentrations of *Pseudo-nitzschia* spp. in 2007 were the highest recorded since the year 2000. There was no evidence relating these blooms to the strandings other than they occurred at the same time. However, the results of the analyses of tissue samples collected from stranded whales in 2008 may shed light on the cause(s) of death.

5.1.3 Assessment of the eastern stock of North Pacific gray whales; incorporating calf production, sea-ice, and stranding data

SC/F09/CC5 introduced a stochastic population dynamics modelling framework that incorporated a hypothesised relationship between an environmental variable and process

error in life history parameters for a cetacean population. An index of sea-ice in the Bering Sea, which has been hypothesised to pertain to eastern North Pacific gray whale calf production, was integrated into a stock assessment. In addition to stochastic birth rates, the framework also allowed for stochasticity in survival rates, and was fit to an index of strandings in order to capture the resulting dynamics during the mortality event experienced by this population in 1999 and 2000. The results of this framework were compared to those based on a deterministic model that was only fit to the abundance data. These alternatives were each able to fit the abundance data well, but led to different interpretations with regards to current depletion and other quantities of interest. The framework developed in SC/F09/CC5 could be used as an operating model with which to test the robustness of the *Gray Whale SLA*, given climate forecasts and hypotheses regarding environmental impacts on population dynamics.

In discussion, it was noted that future projections should investigate an index of sea-ice that included both the Bering and the Chukchi Seas (perhaps considering them separately to address recent evidence for a de-coupling in the system), in order to take into account the full Arctic feeding range of this population.

5.1.4 B-C-B bowhead whale body condition and sea-ice in the western Arctic

SC/F09/CC1 described investigations into bowhead whale body condition and sea ice density. A body condition index (BCI) was computed for bowhead whales as the mean of the annual residuals from a model fitted to axillary girth as a function of body length for a specific year. Data were sufficient to estimate BCI for 11 years between 1982 and 2000. Sea ice densities were computed for the entire period (1982-2000). Preliminary analyses indicated a correlation between bowhead whale body condition in a given year and the amount of open water (i.e., lack of sea ice) in the known feeding areas of the Eastern Beaufort Sea. BCI was significantly different between years with heavy and light sea ice cover. The areas with the highest correlations (BCI and percent sea ice) were those independently believed to be important feeding areas for bowhead whales based on direct observations.

Current and past post-mortem examinations, data and sample collection on landed bowhead whales were described in SC/F09/CC1. A series of morphometric measurements dating to 1974 and suite of samples have been collected primarily for many animals landed at Barrow and Kaktovik. The NOAA and North Slope Borough (NSB) databases on landed bowheads have been combined into a single database which is maintained by the NSB. Indices of calf production have been collected since 1978 during ice-based and aerial surveys. Evidence of synchronous calving was apparent in the time series of calf production data and calf production appeared to be higher in the last decade.

The hypodermal layer of blubber underlies the typical 'structural' layer of blubber seen in most whales. It has little collagenous framework and has been described most often in polar mysticetes that are seasonal feeders. The hypodermis is thought to be the most metabolically active layer of fat, being the most recently laid down and the first to be catabolised in a time of energy expenditure. It is seen to varying extents in bowhead whales, but is most commonly noted in yearlings ('ingutuks'), which have girths approaching their lengths, in states of extreme fattening post-weaning. In the context of the previously discussed body condition work (i.e. length:girth ratio) and demographic measurements (i.e. calf counts), monitoring the body condition of yearlings may provide a useful means for assessing the effects of climate change on this species. Changes in, or disappearance of, this hypodermal layer of fat may relate to environmental conditions.

Some preliminary conclusions included:

(1) that most typical demographic indicators suggest B-C-B bowheads are not showing obvious negative effects from ice reduction;
(2) that various datasets were available to investigate climate change effects on B-C-B bowheads;
(3) the length/girth body condition indices appear to provide meaningful data; and
(4) that the most variation in the BCI signal occurs in sub-adults.

SC/F09/CC1 concluded with some suggestions for continuing studies which were mainly to maintain the current time series of post-mortem examinations, population and life history studies. SC/F09/CC1 considered several potential problems associated with continued climate retreat: expansion of commercial fishing into the range of B-C-B bowheads, expansion of commercial shipping in the Arctic, increase in offshore oil and gas activity, invasive species/diseases (including the range extension of new species into native/naïve species ranges), competition from other vertebrates including whales (i.e., gray and humpback whales in Chukchi and Beaufort Sea), changes in prey composition and diet, killer whale predation, ocean acidification and thermoregulatory stress.

In discussion, it was noted that blubber thickness is not a good indicator of body condition in itself (e.g. Aguilar *et al.*, 2007). However, the lipid composition of blubber is meaningful, and the hypodermal thickness may be a useful indicator of body condition. The Workshop **agrees** that girth measurements have potential to be a good indicator of body condition, because they integrate many physiological components including the hypodermis, visceral fat and muscle mass.

5.1.5 Climate change in West Greenland and its consequences for cetaceans

The marine ecosystem along the West Greenland coast is a latitudinal gradient that spans 60°N to 80°N with the southern latitudes located in the dynamic North Atlantic ecosystem and the northern latitudes located in the stable high Arctic. Large changes in physical and biological parameters have been observed over the past 50 years, including: declines in sea ice coverage in Baffin Bay and Davis Strait since 2000, warming in surface waters on the banks of West Greenland (0-50m), warming bottom temperatures in Baffin Bay (<900m), increased outflow of freshwater, and interactions between these parameters. These changes have had observable impacts on the distribution, catches, abundance, movements, densities, and demography of both Arctic and sub-Arctic cetaceans in the ecosystem. Four examples were discussed: (1) longitudinal displacement of white whales (*Delphinapterus leucas*) as a response to changes in winter sea ice conditions; (2) effect of contrasting sea ice regimes on the movements of narwhals (*Monodon monoceros*) in the offshore pack ice

wintering grounds; (3) increasing abundance and influx of bowhead (*Balaena mysticetus*) whales to Disko Bay; and (4) changes in the sex ratio of common minke whale (*Balaenoptera acutorostrata*) catches in southwest Greenland in relation to warming sea temperatures on the banks.

The Workshop noted a significant body of published work on the Greenland situation (see reference list).

5.2 Small cetaceans

5.2.1 Cetacean assemblages in the riverine and shallow waters of Bangladesh

Waterways of the Sundarbans mangrove forest are inhabited by two freshwater-dependent cetaceans: the Ganges river dolphin (*Platanista gangetica gangetica*) and the Irrawaddy dolphin (*Orcaella brevirostris*). Generalised Additive and Chi-squared Models of sighting data collected during two surveys of waterways in the Sundarbans mangrove forest of Bangladesh indicated that the distribution of both species is sharply determined by different requirements of salinity, depth and turbidity, but similar requirements related to geomorphology (Smith *et al.*, 2008). Due to their obligate dependency on freshwater, the downstream range of Ganges River dolphins would be expected to contract with declining freshwater flows and sea-level rise. The limits to the upstream range of Irrawaddy dolphins may be more constrained by inter-specific competition with Ganges river dolphins rather than by dependence on salinity. It could therefore be hypothesised that the response of Irrawaddy dolphins to a decline in the range of Ganges River dolphins would be to extend their range upstream in the mangrove forest.

However, upstream habitat may disappear with increasing sedimentation at confluences (Smith *et al.*, In press). Generalised Additive Models using oceanographic data (depth, salinity, sea surface temperature and turbidity) indicated that the presence of Irrawaddy dolphins in open estuarine waters was conditionally dependent on low salinity and shallow depth, which explained 36% of the variance (Smith *et al.*, 2008). This implies that the availability of coastal habitat for the Irrawaddy dolphins offshore the Sundarbans mangrove forest will probably contract due to declining freshwater flows and sea-level rise.

Given the sensitivity of both species to salinity changes, these animals may be an efficient model for gauging the effects of declining freshwater supplies and sea-level rise on the same species elsewhere in their range, and possibly other cetaceans subject to similar environmental pressures. In addition, studies of this cetacean community may provide fundamental insights on the nature and magnitude of more general ecological effects (e.g. changes in the abundance and species composition of lower-level trophic communities) and a basis for developing appropriate management responses. Baseline information and trained local expertise is available, thus offering a solid ground for long-term studies and monitoring.

The Workshop **commended** the work being done and strongly **encouraged** future conservation efforts with respect to anticipated effects of altered hydrologic regimes, sea level rise and other climate-related impacts in combination with other anthropogenic factors in this area and with respect to the development of MPAs.

6. EVALUATION OF ANALYTICAL AND MODELLING APPROACHES TO INVESTIGATE LINKAGES BETWEEN WHALES AND THEIR ENVIRONMENT, WITH AN EMPHASIS ON CLIMATE CHANGE

6.1 Uses and types of models

Models can be used for a variety of purposes, including

(a) understanding of population dynamics (e.g. why has the rate of increase of a recovering cetacean population slowed down when it is still below its historical carrying capacity);
(b) making forecasts of the implications of management actions (e.g. catch limits, and spatial and temporal closures) and anthropogenic impacts (e.g. how the spatial distribution of a population will change under a set of climate scenarios); and
(c) forming the basis for evaluating feedback-control management strategies (e.g. the RMP and the gray and bowhead whale *SLAs*) by considering whether candidate management strategies are robust to climate change.

The Workshop noted that there are many cases in which data will be insufficient to parameterise models, and **agreed** that in these cases it may still be possible to provide useful management advice based on expert judgement, comparisons with other situations and, with respect to (c), incorporation of a sufficiently broad but plausible range of scenarios for simulation testing.

The models presented to the meeting considered:

(a) the relationship between the presence/absence or density of cetaceans and environmental, physical or habitat covariates (and how this might change with a changing environment),
(b) the population dynamics of cetacean species which are impacted by environmental variation and climate change.

The two examples of the second type of model presented to the meeting (see Items 5.1.2 and 5.1.3) treated the environmental data differently. The model for southwest Atlantic right whales fitted a stochastic population dynamics to mark-recapture and calving data and explored relationships between the inter-annual variation in the probability of calving for 'receptive' females and environmental variables considered *a priori* to impact these probabilities. In contrast, the model of Eastern North Pacific gray whales integrated the environmental data (a time-series of sea-ice coverage) directly into the parameter estimation, in part because it allowed the sea-ice data to inform birth and survival rates for the years before data on strandings and calf numbers are available.

The Workshop noted that models existed which could capture the impact of climate on full ecosystem dynamics by linking climate models, regional oceanographic models and ecosystem models. Examples of these models include the Atlantis model *http://atlantis.cmar.csiro.au* and that on which the BSIERP and BEST will be based. It was noted that although these models include several trophic levels, they do not focus on the dynamics of cetaceans. The need to properly incorporate uncertainty in such models was emphasised (and see Item 3).

6.2 Strengths and weaknesses of existing approaches

The Workshop recognised that while models are capable of providing predictions of the consequences of management actions and of the performance of management strategies under climate change, such predictions are currently highly uncertain (owing to lack of data, a poor understanding of mechanisms, and an inability to adequately model mechanisms). It therefore highlighted the value of using models to represent a variety of alternative (yet plausible) scenarios and hence identify the data, which, if collected, could discriminate among the scenarios.

The Workshop noted that the hypotheses underlying most of the models were based on correlations between parameters determining distribution and population dynamics of cetaceans and environmental variables. The predictions using models will often involve extrapolation beyond the available environmental conditions and care should therefore be taken to ensure that the range of outcomes (rather than just the point estimates) is provided along with appropriate caveats. Moreover, the value of a mechanistic understanding of the factors driving how the environment (and hence climate) impacts population dynamics will help to ensure that the results of models are properly understood and used. The mechanisms underlying population dynamics models will generally be related to impacts on the health of individuals through survival and reproduction.

There are a variety of functional forms for the relationships between climate variables and population dynamics processes. For example, demographic parameters (such as reproductive rate and/or survival) could change smoothly with climate variables such as sea surface temperature, or they could change in a knife-edge fashion if there are threshold levels of these variables. It was noted that while existing data may inform models based on the first case, there were few data to examine how often regime-shift- like changes in population dynamic processes occur for cetaceans.

It was noted that many ecosystem models (e.g. NPZ models) operate at spatial and temporal scales that are inappropriate for evaluating impacts on cetaceans; care therefore needs to be taken when designing models to examine the impact of climate change on cetaceans to ensure that the spatial and temporal scale of the models are appropriate given the questions they are designed to address.

With respect to testing whale management approaches, the environmental change scenarios considered in the development of the RMP had mainly involved changes in carrying capacity (K), either as one-time changes, or trends or fluctuations. Subsequent work including that presented to this workshop (e.g. southern right whales; SC/F09/CC12) has shown that climate-related changes in recruitment rate can occur even at low population sizes relative to K, with the implications that environmental change may affect both the resilience (r_0) and carrying capacity of populations. The Workshop agreed that the *Robustness* and *Evaluation Trials* for the RMP and AWMP be re-examined to ensure that the trials adequately capture scenarios that involve the kinds of demographic changes that might be expected in climate change scenarios. The modelling framework described in SC/F09/CC5 may be useful for constructing suitable scenarios, as also may be the environmental-variation scenarios considered by the recent workshops on MSY rates (IWC, 2009).

6.3 Analysis needs

Based on the above discussions, the Workshop **recommends** that:

(a) some priority be accorded to developing models that can integrate the demographic and spatial consequences of climate change;
(b) effort be allocated to exploring the value of developing ecosystem models that begin with baleen whale dynamics rather than building bottom-up ecosystem models;
(c) the scenarios used in the *Implementation Simulation Trials* for the RMP and the *Evaluation Trials* for the AWMP should be re-evaluated in the light of discussions at this workshop and additional trials which consider climate impacts added if necessary (see item 6.2 above);
(d) where possible, further correlative studies should be undertaken in order to improve the conceptual understanding of population processes, and hence enable the development of a set of testable hypotheses; and
(e) telemetry studies should be increased and the data should be explored for correlation between movement patterns and environmental variables, and the results of these analyses used as basis for developing hypotheses regarding the mechanisms which determine movement.

7. REGIONAL WORKING GROUPS

These are small groups tasked with deriving regional-scaled conclusions on key vulnerabilities, knowledge gaps, recommendations for future research and interactions of climate change effects with other anthropogenic impacts.

A great deal of uncertainty exists in forecasting the physical and biotic consequences of climate change and the potential consequences for cetacean populations. Disentangling climate-related behavioural and life history consequences for cetaceans from other concomitant or additive anthropogenic effects remains a major challenge.

What is clear is that our capacity to make defendable scientific judgments and to provide robust management advice will depend upon the nature and extent of our knowledge of how cetaceans use their environment and on what factors drive their behaviour and life history.

Presentations and discussions during this workshop have highlighted that climate mediated changes in the environment (be they changes is temperature, salinity, sea water pH, ice extent, contaminant pathways or frequency and type of algal blooms) that impact cetacean populations might be most manifest in movement patterns (use of habitat and adjustments to distribution) and in variations in populations trajectories (through a composite of potential effects to carrying capacity, reproductive output or survival).

However, obtaining long term monitoring data relevant to cetacean habitat use, distribution and abundance at a level that will allow trends/changes to be detected is expensive and indeed may be at such coarse resolutions that it is

effectively uninformative. Data and sample series that aim to monitor climate signals must be long (i.e. multi-generational to decadal or greater scales) and be measured across appropriate temporal and spatial resolutions. Determining these scales will depend on the question being asked and thus, which variable(s) are being examined).

Three working groups were established 'Arctic' (chaired by Moore with Laidre and Ferguson as rapporteurs); 'Southern Ocean' (chaired by Nicol, rapporteur Leaper) and 'Small Cetaceans' (chaired by Wells, rapporteur Bjørge) whose terms of reference were to consider and report back on:

(A) Their ability to measure:
(1) population trajectories;
(2) habitat use; and
(3) distribution of the cetaceans in their region, including a consideration of:
   (a) The practicality of conducting appropriate sampling;
   (b) the status of current knowledge;
   (c) the scales at which these data can be (or have been) collected;
   (d) what spatial and temporal scales of climate related effects are changes in the cetacean time series data likely to reflect? and
   (e) the ability to detect changes of various magnitudes should they occur.

(B) In the light of (A), consideration should be given appropriate 'indicator' species and parameters that might be selected that are representative of:
   (a) ecological niche(s) or function;
   (b) region(s);
   (c) hypothesised vulnerabilities and/or adaptabilities of the cetaceans in the region (and empirical bases to assess and rank these); and
   (d) potential explanatory variables that might be related to observed changes in habitat use, distribution and/or abundance should they occur.

(C) Taking into account (A) and (B), a recommendation for one or more long-term research projects that are most likely to lead to an improved understanding of how cetaceans might respond to, or be affected by, a range of plausible climate change scenarios in their region. Include:
   (a) species/population; and
   (b) field and analytical methods (including temporal and spatial scales).

The reports of the working groups have been incorporated directly into the relevant sections below.

7.1 Large whales

7.1.1 Southern Ocean (with linkages to lower latitudes)

POPULATION TRAJECTORIES

Species of cetaceans in the Southern Ocean vary tremendously with respect to the availability of data and the potential to collect data on population trajectories. To assess potential effects of climate change on population dynamics, sufficient data are required in order to detect a correlation with climate associated with some assessment of precision. In order to investigate correlations, some inter-annual variability in a measurable parameter is required.

Several cetacean species that occur in the Southern Ocean were considered to have insufficient data, with little prospect of increased data in the near future, to make recommendations relating to investigations of the effects of climate change. These include all the toothed whales with the exception of killer whales, and the sei whale. Sei whales are poorly understood due to their northerly distribution which has largely been outside the areas with most effort from surveys such as IDCR/SOWER (generally south of 60ºS).

Although survey data exist for male sperm whales at high latitudes and passive acoustic surveys are potentially an effective method for obtaining abundance estimates, there is very little known about the squid species that are sperm whale prey in the Southern Ocean. There is also a poor understanding about the relationships between the male component of the population at high latitudes and females at lower latitudes in terms of overall population dynamics. While there are considerable data on beaked whales from the SOWER surveys it is only in recent years that these have been identified to species level. At the species level, beaked whales and other small cetacean species in the Southern Ocean are relatively poorly understood.

Although data on killer whales are limited, their unique role as a predator of other whale species potentially makes their response to climate effects of particular significance. Killer whales are closely associated with sea ice habitat and three ecotypes with different prey species and habitat have been described. IDCR/SOWER surveys have suggested potentially large changes in killer whale numbers but these may be confounded by changes in survey design (particularly with respect to the ice edge) between surveys. The Workshop **recommends** further investigation of the IDCR/SOWER and other available datasets to investigate these changes.

The IDCR/SOWER surveys overlap with fin whale habitat but do not include the full extent of the summer range of the species. Thus there are no estimates of total abundance for fin whale populations in the Southern Ocean. There are estimates of abundance and trend for blue whales although the low sighting rates have complicated analyses. There is good potential for measuring call rates for both fin and blue whales using autonomous bottom mounted acoustic recorders (Sirovic *et al.*, 2009). Call rates provide a measure of occurrence and potentially an index of abundance for a particular location to be collected over periods of several years. The Workshop **agrees** that such long-term time series from specific locations may be of value in investigating effects of climate change on these species. The small size of true blue whale (and possibly pygmy blue whale) populations may also facilitate mark-recapture studies. A photo-identification catalogue for Antarctc blue whales based on photographs taken on the IDCR/SOWER cruises is under development (Olson, 2008). Genetic mark recapture may be appropriate for these species which are not as amenable to photo-identification as humpback or right whales.

There has been considerable survey and analysis effort to generate abundance and trend estimates for Antarctic minke whales which have been complicated by a number of factors, some of which are related to environment. These factors include the relative proportion of the population within the sea ice and polynyas compared to open sea.

Table 2
Summary of data available on southern right and humpback whale populations.

Population	Information from breeding grounds	Information on Southern Ocean feeding grounds	Information on migration patterns
Southern right whales breeding W of S America	Limited data	Limited data	Limited data
Southern right whales breeding at Peninsula Valdes	Estimate of abundance, trend, demographics	Some data from isotope and fatty acid analyses	Limited data
Southern right whales breeding in South Africa	Estimate of abundance, trend, demographics	Some data from isotope analyses	Limited data
Southern right whales breeding of Australia	Estimate of abundance, trend, demographics	Limited data	Limited data
Southern right whales breeding off New Zealand	Estimate of abundance	Limited data	Limited data
Humpback breeding stock A	Estimate of abundance and trend	Some data	Telemetry studies
Humpback breeding stock D	Estimate of abundance and trend	Survey and photo-id data	Telemetry studies
Humpback breeding stock E (E Australia)	Estimate of abundance and trend	Survey and photo-id data	Telemetry studies

The Workshop identified the populations of humpback and right whales in Table 2 as having the greatest potential for investigating the effects of climate change due to the combination of data collected on feeding grounds and well-studied coastal breeding grounds. These data include abundance, population trends and inter-annual variation in demographic parameters. Both species have distinctive markings which facilitate individual photo-identification studies.

The Workshop **emphasises** the fact that the value of photo-identification studies is greatly enhanced by collaboration amongst all groups; as the Committee has done in the past, the Workshop **recommends** that every effort be made by researchers to participate in co-operative studies that can address matters of important conservation concerns, including the potential effect of climate change. In particular, it **recommends** that the established photo-identification catalogues of humpback whales be investigated with respect to the estimation of demographic parameters.

The Workshop noted the value of the several long-term photo-identification studies of southern right whales and humpback whales as well as the long time series of shore based surveys off Australia. Shore based surveys off eastern Australia have shown a consistent annual increase of 10.9% per annum (95% CI 10.5 – 11.4%) which is close to the maximum of the biologically plausible range for a humpback whale population (Noad *et al.*, 2008). Although the lack of variability in estimate of population growth rates precludes attempts to correlate with environmental variables, it is inevitable that this will change at some point in the future. The Workshop **recommends** the continued collection of these data and notes the need to collect further data to allow different hypotheses regarding the causes of changes in population growth rate, including environmental change, to be investigated in this population when such changes occur. In conclusion, the Workshop again **emphasises** the great value of long-term datasets and **recommends** that funding be provided to ensure their continuation.

HABITAT USE AND DISTRIBUTION

Habitat characteristics and usage by whales, together with spatial distribution patterns in the Southern Ocean, may be influenced by climate change. Time series of large-scale, synoptic, physical and biological co-variates to describe habitat that can be obtained from remote sensing include; sea ice concentration and drift patterns, primary productivity (available from around 1997 from SeaWifs), sea surface temperature (available from around 1981), and sea surface height used to locate major frontal systems. There is a general lack of data on key ecosystem variables prior to the 1970s and a lack of consistent historical data that could be used to determine climate related effects on krill, although attempts have been made using available data and several hypotheses have been generated, particularly linking krill distribution and abundance to sea ice extent and duration (Atkinson *et al.*, 2008).

The Workshop noted the significance of past and future changes in sea ice in particular, with significant recent decreases in annual sea ice extent being detected off the Western Antarctic Peninsula region – an area critical to krill. De la Mare (2009) provided a re-analysis of previous data from locations of whale catches, suggesting a large reduction of overall ice extent (~20%) in the average extent of sea ice in the 1950s and 1960s. These results remain controversial among sea-ice specialists. The Workshop **agrees** that resolving the disagreement over whether the reduction suggested by de la Mare had actually occurred is important for interpreting more recently observed changes in sea-ice.

Around Antarctica there are several contrasting regions that may provide opportunities to compare the effects of observed environmental changes. Three such regions where considerable physical and biological data have been collected include South Georgia, the Antarctic Peninsula and Eastern Antarctica. Historically, South Georgia has high krill densities but no sea ice, the Peninsula region has shown rapid changes, particularly in sea ice extent, whereas Eastern Antarctica has shown no discernable temporal trend in sea ice, although there are considerable geographic differences across this area. These areas have been the subject of intensive ecosystem studies and there are time series of data from a number of land-based krill consumers, as well as data on krill distribution and abundance which could be of use in interpreting any changes in whale populations.

Whale populations which feed in regions showing differing patterns of environmental change that might allow pair-wise comparisons include humpback whales off South America (Breeding Stock A) compared with Australia (Breeding Stock D/E) and southern right whales from Argentina compared with Australia. The Workshop **recommends** emphasis on cetacean studies which allow comparisons between contrasting regions where data on a wide range of ecosystem components are available from ongoing multi-disciplinary projects.

For some humpback and southern right whale populations, there are long-term series of data on timing of

arrival on the breeding grounds. Although timing of events in other taxa such as pinnipeds has not shown clear relationships with climate, the Workshop **recommends** that where data exist, these should be examined with respect to timing of arrival on and departure from the breeding grounds particularly with respect to different components of the population.

Comparisons of Antarctic minke whale use of sea ice habitat between areas showing differing rates of change may also be informative. The Workshop noted aerial surveys for minke whales by Australia around Casey station and by Germany in the Weddell Sea. Co-ordinating methodology and seasonal timing of such surveys needs consideration if comparisons between regions are to be possible.

A number of characteristics were identified which may make populations especially vulnerable to climate change effects. Populations that use coastal breeding areas that are subject to large temperature changes may be more vulnerable to environmental changes such as conditions that cause harmful algal blooms. Species that show a lack of flexibility in feeding patterns, such as evidence for maternally inherited feeding grounds in southern right whales (Valenzuela *et al.*, 2009), may be vulnerable if distribution patterns of prey species change. Antarctic minke whales which have lower seasonal energy reserves compared to other larger baleen whale species may be less able to withstand changes in prey availability (Leaper and Lavigne, 2007). The distribution patterns of Antarctic minke whales in the austral winter are not well known, but this species is likely to rely on feeding during winter. Antarctic minke whales may therefore be particularly vulnerable to changes in the winter environment and the Workshop **recommends** studies (e.g. telemetry studies) to investigate movements and feeding ecology of Antarctic minke whales in winter.

Smetacek (2008) presented a hypothesis regarding the role of large whales in the cycling of iron within the Southern Ocean ecosystem. The suggestion is that the presence of whales enhances primary productivity through making iron available in surface layers from whale faeces, and that a decline in whale numbers might have resulted in a decline in krill abundance rather than a krill surplus. Enhanced primary productivity in the Southern Ocean could play a role in the global carbon cycle and thus whales may affect climate in addition to climate change affecting whales. The Workshop **encourages** further studies into the interactions between large whales and the overall productivity of the marine ecosystem.

RESEARCH PROJECTS

In addition to the specific recommendations in the previous section, there have been several multi-disciplinary cruises where cetacean data have been collected and the Workshop **recommends** further investigation of data from these (including CCAMLR 2000, SO-GLOBEC and BROKE surveys). Changes in environment may also result in changes in human activities in the Southern Ocean (such as increased tourism in some sectors). These need to be taken into account when relating changes observed in whale populations to possible factors. Tourist and fishing vessels may also provide opportunities for data collection. New research methods including sea gliders with acoustic capability, unmanned aerial vehicles, also have potential. Telemetry studies were identified as of key importance for understanding linkages between feeding and breeding grounds and will be facilitated by further developments in tag design and deployment.

There is also a need for further interpretation of predictions from climate models to understand how these relate to changes most likely to impact on whales. For example, mean changes in sea surface temperature through overall warming need to be separated from changes in locations of fronts and water masses.

There was insufficient time to develop full research proposals during the Workshop; this would need to be guided by the Scientific Committee. Gales also indicated that further progress may be made during the Southern Ocean Partnership Workshop.

7.1.2 Arctic

Moore provided a brief overview of sea ice loss in the Arctic over the past 30 years, emphasising the extreme seasonal retreats observed in 2007 and 2008 (Overland *Powerpoint*). Given the dramatic loss of multi year ice in 2007, it is unlikely that late summer sea ice cover will return to conditions seen in 1980s in the near term. Specifically, recent projections suggest that the Arctic maybe ice free in summer by 2030. The Workshop did not discuss other aspects of potential climate related changes to the Arctic physical environment due to lack to time, noting that such factors (e.g. wind, hydrography, fresh water) could have important effects on cetacean habitats.

The information in Simpkins *et al.* (2009) was used as a starting point for the development of a summary table related to existence of (and/or the possibility of) obtaining information on population abundance and trend for populations of Arctic and sub-Arctic cetaceans (Table 3)[2]. Rankings of high, medium, and low were assigned to columns labelled 'Population Trajectories,' 'Summer Distribution,' and 'Habitat Use', based upon the ability to measure these parameters as demonstrated by available field and analytical methods. The Workshop focused almost exclusively on summer distribution and habitat use, as winter distribution is unknown for most populations. Distribution was defined as the general location of the stock, whereas 'habitat use' included cases where location could be better defined via kernel analysis from tagged animals, or indices of relative abundance from sighting data. Further, habitat use often includes information about the biological and physical environment that influence why an animal would be located in a specific area (explanatory variables for spatial modelling approaches). Populations were then flagged as 'feasible', at least in principle, for conducting research into the effects of climate change based on their rankings in the three columns. Eleven populations were thus flagged and moved forward for further evaluation.

The eleven populations flagged were subsequently ranked with regard to eight biological parameters believed to be useful for creating models that will be informative in studying the effects of climate change on arctic and sub-arctic cetaceans (Table 4). The Workshop defined 'monitor' as the ability to detect trends over time should they occur. As before, the spatial and temporal distribution column refers to summer, with the exception of West Greenland

[2] There had been insufficient time to consider killer whales adequately.

Table 3

Arctic and sub-arctic cetacean populations ranked with regard to ability to measure population trajectories, summer distribution and habitat use*.

Population	Trend (current knowledge – values to be added with CVs)	Ability to measure			Flag for feasibility
		Population trajectories	Summer distribution	Habitat use	
Bowhead whale					
Bering-Chukchi-Beaufort Seas	Increasing	High	High	Medium	X
E Canada-W Greenland	Increasing	High	High	Medium	X
Svalbard	Unknown	Low	Low	Low	
Okhotsk Sea	Unknown	Low	Low	Low	
Gray whale					
Eastern	Stable	High	High	Medium	X
Western	Increasing	High	Medium	Medium	
Beluga/white whale					
Cook Inlet	Declining	High	High	High	
Eastern Bering Sea	Unknown	Low	Low	Low	
Bristol Bay	Increasing	High	High	High	X
Eastern Chukchi Sea	Stable	Medium	Medium	Medium	X
Eastern Beaufort Sea	Stable	Low	High	Medium	
Foxe Basin	Unknown	Low	High	Medium	
Western Hudson Bay	Unknown	Low	High	Medium	
Southern Hudson Bay	Unknown	Low	High	Medium	
James Bay	Unknown	Low	High	Medium	
St. Lawrence River	Stable	Low	High	Medium	
Eastern Hudson Bay	Declining	Medium	High	Medium	
Ungava Bay	Unknown	Low	High	Medium	
Cumberland Sound	Increasing	Medium	High	Medium	
Eastern High Arctic-Baffin Bay	Stable	Medium	High	Medium	
West Greenland	Increasing	High	High	Medium	X
3 stocks in Okhotsk Sea	Unknown	Low	High	Medium	
11 additional stocks	Unknown				
Narwhal					
Canadian High Arctic	Unknown	Medium	High	Medium	
Northern Hudson Bay	Unknown	Medium	High	Medium	
Eastern Baffin Island	Unknown	Low	High	Medium	
Inglefield Bredning	Unknown	Medium	High	Medium	
Melville Bay	Unknown	Medium	High	Medium	
West Greenland Winter	Unknown	High		Medium	X
East Greenland	Unknown	Low	High	Medium	
Fin whale					
North Pacific	-	Low	Low	Low	
West Atlantic	-	High	High	Medium	
Central Atlantic	-	High	High	Medium	X
Eastern Atlantic	-	High	High	Medium	
Common minke whale					
West North Pacific	-	High	High	Medium	
J stock	-	High	High	Medium	
East North Pacific	-	High	High	Medium	
West Atlantic	-	High	High	Medium	
Central Atlantic	-	High	High	Medium	X
East Atlantic	-	High	High	Medium	
Humpback whale					
Southeast AK	-	High	High	High	X
California-Oregon	-	High	High	High	
Northern WA-Southern BC	-	High	High	High	
Northern BC	-	High	High	High	
Northern Gulf of AK	-	High	High	High	
Western Gulf of AK	-	High	High	High	
West Greenland	-	High	High	High	
Bering Sea	-	High	High	High	X
Russia (3 areas)	-	High	High	High	
Aleutians	-	High	High	High	
Iceland	-	High	High	High	
Norway	-	High	High	High	
Gulf of Maine	-	High	High	High	
Newfoundland	-	High	High	High	
Blue whale					
Gulf of Lawrence	-	High	High	High	
Central Atlantic	-	Low	Low	Low	
East Atlantic	-	Low	Low	Low	
East Pacific	-	Low	Low	Low	
West Pacific	-	Low	Low	Low	

Cont.

Population	Trend (current knowledge – values to be added with CVs)	Ability to measure: Population trajectories	Ability to measure: Summer distribution	Ability to measure: Habitat use	Flag for feasibility
Table 3 cont.					
Killer whale					
Norwegian Sea	-	-	-	-	-
N Norway - coastal	-	-	-	-	-
Iceland and Faroe Islands	-	-	-	-	-
NW Scotland	-	-	-	-	-
North Sea/W of Great Britain	-	-	-	-	-
NE Atlantic	-	-	-	-	-
NE Atlantic	-	-	-	-	-
NE Atlantic	-	-	-	-	-
NE Atlantic	-	-	-	-	-
Newfoundland/Labrador	-	-	-	-	-
W North Atlantic	-	-	-	-	-
Central Bering Sea	-	-	-	-	-
SE Bering Sea	-	-	-	-	-
Aleutian Islands	-	-	-	-	-
Gulf of Alaska, E of Unimak	-	-	-	-	-
Aleutian Islands, W of Unimak	-	-	-	-	-
Gulf of AK *transients*	-	-	-	-	-
W AK (excluding Kodiak)	-	-	-	-	-
BC/Washington *residents*, summer	-	-	-	-	-
Alaska SE to Kodiak *residents*	-	-	-	-	-
Sea of Okhotsk	-	-	-	-	-
Kamchatka and Commander Islands	-	-	-	-	-
Russian Far East	-	-	-	-	-
Sakhalin Island area, Russian Far East	-	-	-	-	-
Chukotka	-	-	-	-	-
Sea of Okhotsk	-	-	-	-	-
Primorsky Krai	-	-	-	-	-
Japan (aerial surveys)	-	-	-	-	-
WN Pacific	-	-	-	-	-

*Note: the group reviewed population abundances and trend data available from Simpkins (2009). This was the best information available to the Workshop. The group has commenced to flag populations for focused research; this is an ongoing process.

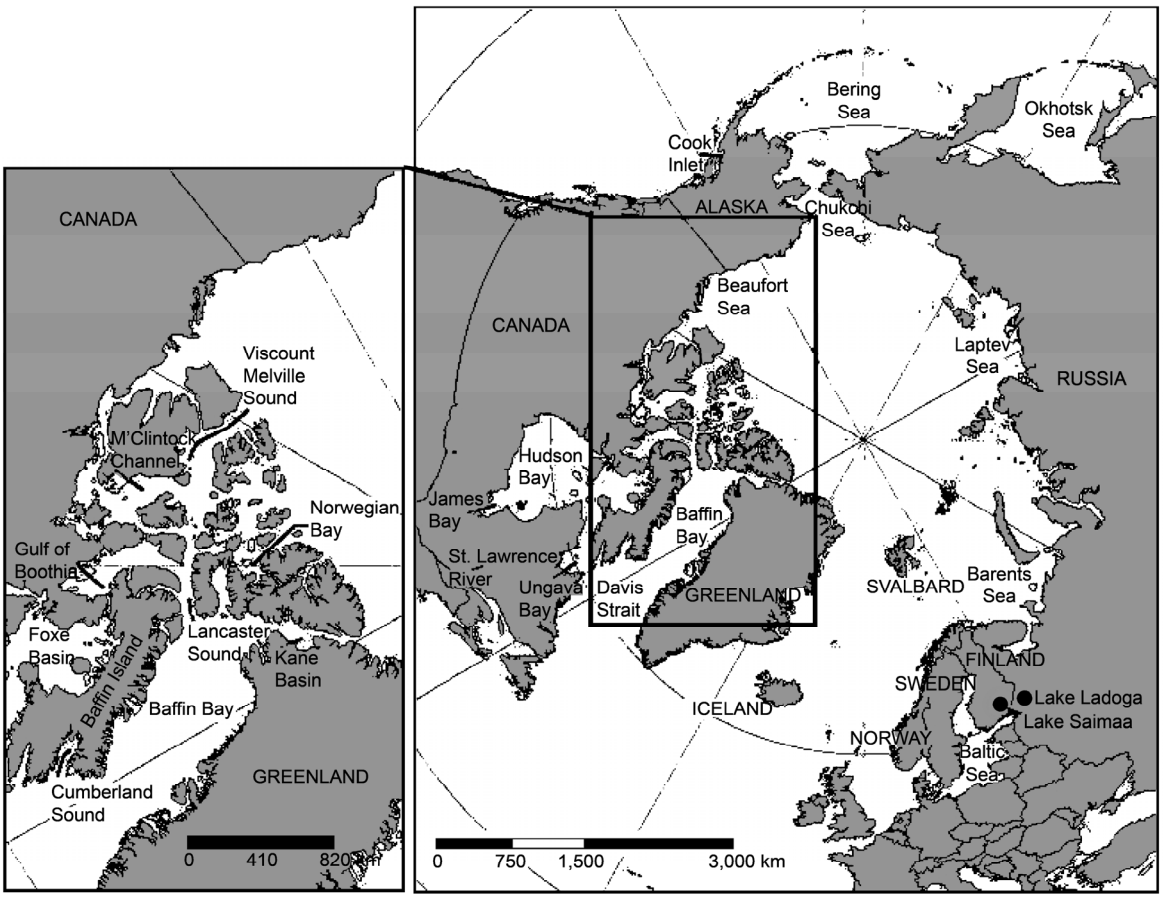

Fig. 2. Map of the Arctic with place names referred to in the text or in Tables 3 and 4.

Table 4

Ranking of selected cetacean populations with regard to the ability to monitor (H=high, M=medium, L=low) eight biological parameters: prey distribution and abundance (prey); diet/feeding habits (diet); survival rates (surv); reproductive rates (repro); body condition/health (BCH); pollutants by chemical analysis (poll); individual movement (move); spatial and temporal distribution (dist). Resultant 'recommended' studies* include: A =comparison between bowhead whale populations in two arctic regions where climate change effects are predicted to differ; B=comparison among three cetacean species (bowhead, gray and beluga whales) that occupy different trophic niches within one arctic region; C=investigation of distribution shift for minke whales in the North Atlantic where a 20+ year data record is available via NASS.

Study*	Species	Stock	Prey	Diet	Surv	Repro	BCH	Poll	Move	Dist
AB	Bowhead whale	Bering-Chukchi-Beaufort Seas	M	M	L	H	M	H	H	H
A	Bowhead whale	E Canada-W Greenland	M	M	L	H	M	H	H	H
B	Gray whale	Eastern	M	M	L+	H	M	H	H	M
	Beluga whale	Bristol Bay	M	M	L	M	M	H	H	M
B	Beluga whale	Eastern Chukchi Sea	L	M	L	M	M	H	H	H
	Beluga whale	West Greenland	M	M	L	M	M	H	H	H
	Narwhal	West Greenland Winter	M	M	L	M	M	H	H	M
C	Common minke whale	Central Atlantic	H	M	L	L	L	H	L	M
	Fin whale	Central Atlantic	M	M	L	L	L	H	M	M
	Humpback whales	Southeast AK	M	L	M	M	M	H	H	M
	Humpback whales	Bering Sea	M	L	M	M	M	H	H	M

L+: data from stranding events. Suggested studies (A-C): A= Regional comparison between bowhead whales; B=comparison across trophic levels in a single region; C=distribution change based on surveys (NASS) of a sub-arctic cetacean (using prey data).

Table 5

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.

Habitat	Area	Type of data	Scale, spatial and temporal	Examples
Freshwater and 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	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	Alborán 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); Alborán Sea (Alnitak);
	British Isles	Stranding	British Isles, decades	TBC

white whales and narwhals for which information is available only in winter. With the exception of 'pollution,' the rankings of high, medium, and low were based solely upon the ability to estimate the parameter at a level of uncertainty that could support useful modelling. This consideration takes into account the availability of appropriate field and analytical methods, ability to collect large enough sample sizes to identify changes in the parameter over time, and general knowledge of the species'/stock's distribution and diet. In contrast, classification in the 'pollution' column required the additional constraint that a baseline must exist in order to be ranked 'high.' This is because it is essential to understand what levels of a chemical can be considered 'normal,' and this is a factor that is likely to have less plasticity than any of the other parameters listed in the table. Specific considerations with regard to the definition and rationale for each parameter included the following.

(1) Prey distribution and abundance: understanding the spatial and temporal distribution and the population dynamics of the prey are critical to understanding the analogous parameters for each cetacean stock.
(2) Diet and feeding habits: obtained through stomach samples and/or tissue analysis (e.g. isotopes, fatty acids). Location and timing of feeding (behavioural data) also important.
(3) Survival rates: obtained by following individuals through time.
(4) Reproductive rates: obtained through calf counts or following individuals through time.
(5) Body condition/health: this parameter combines attributes from measures of fat/blubber, lean body mass, disease exposure, stress status and contaminant loads. Where body condition data (including morphometric/ anatomical measurements) comes from the catch, an evaluation needs to be made as to whether the sample can be considered representative sample given hunter selectivity for certain size/age cohorts. Whatever method is used, there is value in trying to obtain a representative sample from the population.

(6) Pollutants and other chemical parameters: analyse samples for lipids, fatty acids, stable isotopes, POPs.
(7) Individual movement: obtained primarily through tagging, mark-recapture studies and tracer studies to investigate fine scale behaviour of individual animals.
(8) Spatial and temporal distribution: this includes consideration of habitat, as defined for Table 3.

Three **recommended outline studies** (A, B, C) were identified from the ranking of the eight biological parameters for the eleven selected populations. The Workshop noted that it was not possible in the time available to examine fully feasibility in terms of our ability to detect changes in parameters should they occur. This work **must** be undertaken before final recommendations are made. The outline studies recommended for further consideration are summarised briefly below.

A. Single Species – Regional Contrast: investigate and model biological parameters for bowhead whales in two regions of the Arctic where climate change scenarios predict contrasting physical conditions (i.e. Pacific Arctic vs. W. Greenland regions)

B. Trophic Comparison: investigate and model biological parameters for three species of cetaceans that occupy different trophic levels (plankton, benthos, nekton) within a single Arctic region. Specifically, B-C-B bowheads, Eastern North Pacific gray whales and Eastern Chukchi white whales within the Pacific Arctic region.

C. Distribution Shift: examine the available data for the Central Atlantic common minke population, particularly in Icelandic coastal waters where a major change in distribution was seen recently, from the 20-year sighting record from the North Atlantic Sighting Surveys (NASS) and from the more frequent national surveys. Specifically examine these data to see if they are sufficient to detect any change or shift in distribution and relative abundance with regard to changes in ecosystem parameters (several of which are available with respect to fisheries studies), particularly those which may be attributable to climate change.

As noted above the Workshop was not in a position to develop specific recommendations regarding analytical methods. However, it was generally agreed that research programmes ranging over a 10-year period would be desired. The cetacean populations listed under each recommended study generally have extant databases of 10 to 40 years duration which then provides a 20-50 year timeline for investigation and modelling of climate-related events. The Workshop **encourages** continued development of detailed analytical and modelling plans, under the general guidelines set forth for each of the three recommended studies. Development of such plans will be incorporated into discussions at the 2009 Annual Meeting.

7.2 Small cetaceans

Ability to measure population trajectories, habitat use and distribution of small cetaceans

Changes in: (1) temperature; (2) freshwater input; and (3) sea level rise and other geomorphological alterations are the climate-related stressors most likely to have direct impact on small cetaceans. A set of hypotheses was developed for how these stressors can impact small cetaceans, described below. In all cases it is assumed that relevant environmental parameters will be measured in addition to those explicitly identified, including anthropogenic factors. It is recognised that broad, multi-disciplinary approaches, such as the inclusion of hydrologists, will be required to address these hypotheses.

HYPOTHESES RELATED TO TEMPERATURE

T_1: Small cetacean species will redistribute to avoid thermal stress where possible;

T_2: Modification of ecosystem structure and productivity will lead to changes in cetacean distribution to meet trophic demands;

T_3: Species in restricted habitat with little or no capacity to redistribute will be exposed to thermal, nutritional and health related stress.

HYPOTHESES RELATED TO HYDROLOGY

FW_1: Changes in hydrological regime will entail changes in habitat use for obligate freshwater and estuarine species and populations.

HYPOTHESES RELATED TO SEA LEVEL RISE AND GEOMORPHOLOGIC ALTERATIONS

SL_1: Changes in salinity and sedimentation rates will entail habitat alterations for riverine and estuarine species;

SL_2: Sea level rise will physically reduce habitat for obligate freshwater species;

SL_3: Loss of supporting habitat for coastal/estuarine species, including small cetaceans and their prey (sheltering areas, nurseries for prey species, etc.)

Consideration of appropriate 'indicator' species and research situations

The extreme diversity in population size, range and preferred habitat of small cetaceans, make it difficult to apply one standardised methodological approach across this taxonomic group. The geographic scale of the monitoring programme is also dependent on the population subject to monitoring. In general, pelagic monitoring programmes are conducted on a large spatial scale (e.g. in Eastern Tropical Pacific (ETP) and in the northeast Atlantic). Neritic programmes typically have an 'ecosystem' or habitat-wide coverage (e.g. the SCANS surveys covered the entire North Sea, the Irish Sea, and the Norwegian NASS covers the entire Barents Sea). Studies at the population level, e.g. Sarasota Bay and Moray Firth bottlenose dolphins, are typically conducted through high effort projects at a small geographic scale. It may be possible in some cases to obtain the necessary data from ongoing, long-term research programs. It may also be advantageous to support the development of more recent research programs that are addressing relevant environmental questions in order to expand the availability of relevant datasets for examining climate-related change.

Below are general suggestions for appropriate indicator species and areas. The paragraphs refer to the hypotheses described above.

T_1: For populations occurring in an oceanic 'open' habitat, redistribution along a temperature gradient is the most likely response to sea temperature change. Changes in northern and southern edges of ranges are possibly the most easily detectable changes. Large scale oceanic surveys (e.g. SWFSC/IATTC/ETP and Northeast Atlantic SCANS and NASS surveys, only when combined with other datasets)

are appropriate candidates for detecting shifts in distribution of small cetaceans and examining how this may affect total abundance. Long-term stranding data may also yield useful data to further illuminate shifts.

T_2: Temperature-driven modification of ecosystem structure and productivity entailing shifts in distribution of pelagic small cetacean populations can best be studied by simultaneous studies of oceanography, prey availability and cetacean distribution. The long-term SWFSC/IATTC/ETP programmes and the Norwegian Barents Sea Ecosystem surveys are possible candidates for such studies.

T_3: For populations with small ranges in restricted habitats that cannot relocate due to lack of suitable habitat (oceanographic or land barriers creating 'cul-de-sacs') or other constraints (long-term residency to specific geographical sites) (e.g. riverine sites, Black Sea, Adriatic Sea, Bay of Bengal, Gulf of California) 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. The workshop agreed that these populations deserve particular attention.

FW_1: 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. Possible candidate species include the riverine *Inia geoffrensis*, *Platanista gangetica*, *Sotalia fluviatilis*, and the estuarine *Orcaella brevirostris*, for which existing datasets could be built upon.

SL_1: Sea level rise is a stressor that has little or no direct impact on pelagic species. The impact will primarily be experienced by coastal and estuarine populations and riverine populations in the lower parts of rivers. In estuaries and lower parts of rivers, sea level rise is potentially very interactive with changes in fresh waters regimes. Possible responses are aggregation of animals in core preferred habitats (shrinkage of distribution leading to increased density). Candidate species include riverine and estuarine species (*cf.* FW_1) and marine species occurring in shallow, nearshore or semi-enclosed coastal waters (e.g. *Neophocaena phocaenoides*, *Phocoena sinus*, *Phocoena phocoena*, *Tursiops truncatus*, *Tursiops aduncus*, *Cephalorhynchus* spp., *Sousa chinensis*).

SL_2: Sea level rise will physically eliminate portions of the habitat of riverine (and possibly estuarine) species or populations. Possible responses are aggregation of cetaceans in remaining habitats entailing density dependent population level effects. Possible study species *cf.* riverine species in FW_1.

SL_3: Sea level rise in itself and in particular in combination with extreme events can change fluvial through-flow or otherwise reduce, modify, or remove supporting habitat (e.g. mangrove forests, seagrass meadows) for riverine or estuarine species or populations. Supporting habitats include sheltering areas, nursery grounds and prey species habitats, among others.

The Workshop also noted the vulnerability and importance to some cetacean populations of coral reefs and the potential impacts from changes in pH and other factors on these habitat features.

A variety of small cetacean research projects underway around the world may have bearing on identifying climate-related change, especially when considered in conjunction with other datasets. However, it was not possible to consider an exhaustive list of such projects. A few potential examples known to the Workshop participants are presented in Table 1. A more formal examination of available datasets and their applicability for such studies is required.

8. CONCLUSIONS AND RECOMMENDATIONS TO SCIENTIFIC COMMITTEE

8.1 Current state of knowledge on the effects of climate change on cetaceans

It was noted that there had been a change in focus between CC1 and CC2 in that CC2 had less emphasis on the consequences of ozone depletion and substantially more emphasis on the emission of greenhouse gasses and the effects of temperature increase.

The Workshop noted that knowledge about climate change had advanced substantially since the first IWC Workshop on climate change in 1996. Specifically, the 4th report from the IPCC showed that unequivocal greenhouse-gas mediated global warming was occurring. Subsequent studies have shown this is often at rates that exceeded some worst-case modelling scenarios. In addition, improvements in climate models, as well as models that relate environmental indices to whale demographics and distribution had occurred. However, all models remain subject to considerable uncertainty. Given these developments, the present Workshop was in a much better position to identify studies that would lead to an improved understanding of the consequences of climate change for cetaceans. For example, cetacean populations might be expected to alter habitat use or range in response to a changed environment, or potentially experience altered population trajectory through changes in environmental carrying capacity or altered population-scale resilience. The Workshop also recognised the need to better understand the manner in which climate effects will interact with other anthropogenic impacts on cetacean populations.

Notwithstanding the uncertainties inherent in models and in the data that drive them, it is clear that climate-related changes will impact negatively on at least some species and populations, especially those with small and/or restricted ranges, those already impacted by other human activities and those in environments subject to the most rapid change (e.g. Arctic sea-ice). For these species there is a real potential for elevated risks of extinction. The Workshop therefore **recommends** that IWC member countries (and indeed all countries) and relevant organisations:

(1) take the potential effects of climate change on cetaceans seriously and include these considerations in relevant climate-related and conservation management initiatives, including implementation of emission controls; and
(2) support the research recommendations given here, which will be further elaborated at subsequent meetings of the Scientific Committee.

8.2 Recommendations for future research

There are a number of recommendations found throughout this report – all are important. This section however focuses on the key recommendations found under Items 6 and 7.

8.2.1 Modelling (see Items 3 and 6)

In order to provide quantitative advice on possible effects of climate change on cetaceans and how this interacts with potential management advice, ecosystem modelling, simulation modelling and spatial modelling are essential. It is of course, also **essential** that the inevitable scientific uncertainty is fully taken into account. The great difficulties and challenges with respect to ecosystem modelling have been explored fully by the IWC in recent years (e.g. cetacean fishery modelling workshop, the CCAMLR-IWC workshop, the working group on ecosystem modelling) and these are endorsed but not repeated here. In addition to those earlier recommendations, based on the discussions under Items 3.3 and 6, the Workshop **recommends** that:

(a) some priority be accorded to developing models that can integrate the demographic and spatial consequences of climate change;
(b) (effort be allocated to exploring the value of developing ecosystem models that begin with baleen whale dynamics rather than building bottom-up ecosystem models;
(c) the scenarios used in the *Implementation Simulation Trials* for the RMP and the Evaluation Trials for the AWMP are re-evaluated in the light of discussions at this workshop and additional trials which consider climate impacts added if necessary;
(d) where possible, further correlative studies should be undertaken in order to improve the conceptual understanding of population processes, and hence enable the development of a set of testable hypotheses;
(e) the predictions and levels of uncertainty with respect to the many IPCC modelling exercises need to be carefully reviewed with respect to choosing those most appropriate (including taking into account temporal and spatial scales and separating out factors such as mean overall SST warming from the changes in the positions of fronts and water masses) for incorporation into modelling exercises with respect to cetaceans; and
(f) telemetry studies should be increased and the data should be explored for correlation between movement patterns and environmental variables, and the results of these analyses used as basis for developing hypotheses regarding the mechanisms which determine movement.

The Workshop recognised the need to take into account cumulative effects in any modelling work done on individual factors. Whilst there is as yet no well-defined analytical approach to address this, such work is important and valid. It was noted that where the parameter of interest is population abundance and trends, this in effect represents the integration of all effects both individually and cumulatively.

8.2.2 Southern Ocean with linkages to lower latitudes (see Item 7.1.1)

The Workshop focussed attention on examining the information available on population trajectories, habitat use and distribution and potential research projects. The Workshop made a number of specific recommendations for future work that are briefly summarised here:

(1) further investigation of the IDCR/SOWER datasets (and others) to investigate possible changes in killer whale abundance, given their unique role as predators of other whale species;
(2) further investigation of the use of autonomous bottom mounted acoustic recorders to obtain long-term datasets for fin and blue whales;
(3) continued investigation and analysis of individual identification data for blue whales (genetic and photographic) for potential mark-recapture studies;
(4) resolution of the controversy over the interpretation of whaling data to infer long-term changes in sea-ice (De la Mare, 2008);
(5) further efforts (e.g. telemetric) to examine the movements and feeding ecology of Antarctic minke whales in winter;
(6) further studies into the interactions between large whales and the overall productivity of the marine ecosystem.

However, in terms of the potential to investigate the effects of climate change, the Workshop identified the populations of humpback and right whales in Table 2 due to the combination of data collected on feeding grounds and well-studied coastal breeding grounds. These data include abundance, population trends and inter-annual variation in demographic parameters. Both species have distinctive markings which facilitate individual photo-identification studies.

The Workshop **emphasises** the fact that the value of photo-identification studies is greatly enhanced by collaboration amongst all groups; as the Committee has done in the past, the Workshop **recommends** that every effort be made by researchers to participate in co-operative studies that can address matters of important conservation concerns, including the potential effect of climate change. In particular, it **recommends** that the established photo-identification catalogues of humpback whales be investigated with respect to the estimation of demographic parameters.

Although the lack of variability in estimate of population growth rates (e.g. for eastern Australian humpbacks which have been increasing at close to the maximum rates possible) precludes attempts to correlate with environmental variables, it is inevitable that this will change at some point in the future. The Workshop **recommends** the continued collection of these photo-identification data to allow different hypotheses regarding the causes of changes in population growth rate, including environmental change, to be investigated when such changes occur. In conclusion, the Workshop again **emphasises** the great value of long-term datasets and **recommends** that funding be provided to ensure their continuation.

In general terms, the Workshop **recommends** emphasis on cetacean studies which allow comparisons between contrasting regions where data on a wide range of ecosystem components are available from ongoing multi-disciplinary projects. It notes that for some humpback and southern right whale populations, there are long-term series of data on timing of arrival on the breeding grounds. Although timing of events in other taxa such as pinnipeds has not shown clear relationships with climate, the Workshop **recommends** that where data exist, these should be examined with respect to timing of arrival on and

departure from the breeding grounds particularly with respect to different components of the population.

The Workshop also **recommends** further investigation of data from the several multi-disciplinary cruises where cetacean data have been collected (including CCAMLR 2000, SO-GLOBEC and BROKE surveys).

The Workshop notes the ongoing work within the Scientific Committee with respect to trends in abundance of Antarctic minke whales and possible links to environmental factors such as sea ice and it **recommends** that this work continues. Comparisons of Antarctic minke whale use of sea ice habitat between areas showing differing rates of change may also be informative. Aerial surveys have occurred/will occur for minke whales by Australia around Casey station and by Germany in the Weddell Sea. The Workshop **recommends** the co-ordination of methods and seasonal timing of such surveys if comparisons between regions are to be possible.

Whilst the Workshop was unable to develop specific research recommendations in the time available it **recommends** that the development of detailed recommendations (including analytical and practical recommendation) should be incorporated into discussions at the 2009 Annual Meeting.

8.2.3 Arctic (see Item 7.1.2)

The process followed to identify outline recommendations for research programmes for Arctic whales is given in detail under Item 7.1.2. As a result, the Workshop agreed to three **recommended outline studies** (A, B, C). The Workshop noted that it was not possible in the time available to examine fully feasibility in terms of our ability to detect changes in parameters should they occur. This work **must** be undertaken before final recommendations are made. The outline studies recommended for further consideration are summarised briefly below.

A. Single Species – Regional Contrast: investigate and model biological parameters for bowhead whales in two regions of the Arctic where climate change scenarios predict contrasting physical conditions (i.e. Pacific Arctic vs. W. Greenland regions).

B. Trophic Comparison: investigate and model biological parameters for three species of cetaceans that occupy different trophic levels (plankton, benthos, nekton) within a single Arctic region. Specifically, B-C-B bowheads, Eastern North Pacific gray whales and Eastern Chukchi white whales within the Pacific Arctic region.

C. Distribution Shift: examine the available data for the Central Atlantic common minke population, particularly in Icelandic coastal waters where a major change in distribution was seen recently, from the 20-year sighting record from the North Atlantic Sighting Surveys (NASS) and from the more frequent national surveys. Specifically examine these data to see if they are sufficient to detect any change or shift in distribution and relative abundance with regard to changes in ecosystem parameters (several of which are available with respect to fisheries studies), particularly those which may be attributable to climate change.

As noted above the Workshop was not in a position to develop specific recommendations regarding analytical methods. However, it was generally agreed that research programmes ranging over a 10-year period would be desired. The cetacean populations listed under each recommended study generally have extant databases of 10 to 40 years duration which then provides a 20-50 year timeline for investigation and modelling of climate-related events. The Workshop **encourages** continued development of detailed analytical and modelling plans, under the general guidelines set forth for each of the three outline studies. The Workshop **recommends** that the development of such plans is incorporated into discussions at the 2009 Annual Meeting.

8.2.4 Small cetaceans (see Item 7.2)

Not surprisingly, given the large number of species/ populations and the wide variety of habitats they occupy, work on developing recommendations for small cetaceans was in some ways the most challenging. The Workshop focussed on changes in: (1) temperature; (2) freshwater input; and (3) sea level rise and other geomorphological alterations that it believed are the climate-related stressors most likely to have direct impact on small cetaceans. For each it developed a set of hypotheses for how these stressors can impact small cetaceans as detailed in Item 7.2. It is recognised that broad, multi-disciplinary approaches, such as the inclusion of hydrology, will be required to address these hypotheses. The Workshop then went on to consider some candidate indicator species and geographical areas (and datasets) that might be appropriate for investigating these hypotheses (see Item 7.2 and Table 5) but **recognises** that in providing the listing in Table 5 that this is not an exhaustive list and that a more formal examination of available datasets and their applicability for such studies is required.

The Workshop **recommends** that the sub-committee on small cetaceans considers the hypotheses that link climate to small cetacean population trajectories and the suggested indicator species and research situations, with the aim of indentifying specific research projects.

8.3 Implications for the work of the IWC

The implications for the work of the Scientific Committee and especially the work of the sub-committee on small cetaceans, the standing working group on environmental concerns and the working group on ecosystem modelling are made clear in the report, as is the need for the RMP and AWMP scenarios to be re-examined and, if necessary, modified In addition, it was noted that the agreed incorporation of the conservation management plan approach in the work of the Scientific Committee should also take climate change issues into account. Gales noted that issues related to climate change arising out of this Workshop would also be considered at the forthcoming Southern Ocean Partnership meeting.

With respect to the Commission itself (including the Conservation Committee and the Aboriginal Whaling Sub-Committee), the Workshop refers in particular to its recommendations made under Item 8.1.

As the Scientific Committee has stressed on many occasions before, work on the possible effects on climate change and indeed all work related to ecosystem modelling (and the necessary datasets) is not something that can be dealt with by the IWC in isolation. Clearly there is a need for major international multi-disciplinary efforts and the Workshop **recommends** that collaborative work with other relevant bodies (e.g. CCAMLR, SO-GLOBEC and others) continues and is expanded. In most cases this needs to be at

a greater level of involvement than simply an exchange of observers.

8.4 Implications for other international organisations and initiatives

With respect to the Arctic Council, its ongoing work on monitoring arctic biodiversity under CAFF Circumpolar Marine Biodiversity Monitoring Program (*http://www.cbmp.is*) and of the Arctic marine shipping assessment (PAME) was noted, and that it was important to maintain a dialogue with this body[3]. The same applied to CCAMLR[4], including interactions at the level of ongoing working groups, and, more generally, it was noted that many bodies were currently looking at climate change but rarely include consideration of cetaceans. The workshop felt that this should be encouraged not only for the sake of cetacean conservation and management but also because cetaceans are potentially good indicator species.

An ongoing dialogue with IUCN[5] on the development of sensitivity indicators was also recommended.

It was agreed that it would be desirable to indentify large-scale science programmes into which cetacean monitoring could be integrated. It was noted in this context that the oceanographic ENSO monitoring program by the Permanent Commission for the SE Pacific (ERFEN[6] which includes the countries from Colombia to Chile), could provide an opportunity to monitor cetaceans too.

8.5 Plans for publication

Gales noted that the report of this Workshop will be available to the 2009 Scientific Committee and Commission meetings. The Workshop report will also be published in the 2010 supplement to the *Journal of Cetacean Research and Management.*

Since many of the papers submitted to the Workshop were reviews or amalgamations of previous work, the Workshop agrees that there was not sufficient material at this stage to warrant a special issue of the *Journal.* However, it may be that this may be an appropriate option in the future, particularly if sufficient progress is made on recommended work. Another option that may be considered is to group together papers in a regular issue of the *Journal*.

9. ANY OTHER BUSINESS

No other business was raised.

10. ADOPTION OF REPORT

The report was adopted on 25 February 2009 subject to final editorial matters that would be handled by Donovan. The Chair of the Workshop in particular wished to thank Christina Fossi and Sylvia Maltese for their magnificent work in co-ordinating the practical aspects of the Workshop in such beautiful surroundings. He also wished to thank the rapporteurs and working group chairs for their hard work. The Workshop thanked Gales for his fair and efficient Chairmanship and Simmonds and Moore for their vital contributions to the preparations for the Workshop.

[3]*http://www.arctic-council.org/*
[4]*http://www.ccamlr.org/*
[5] *http://www.iucn.org/*
[6]*http://www.cpps-int.org/init.htm*

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Annex A

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Annex B

Agenda

1. Introductory items
   - 1.1 Welcome and introduction
   - 1.2 Terms of reference
   - 1.3 Election of chair and appointment of rapporteurs
   - 1.4 Meeting procedures and time schedule
   - 1.5 Adoption of agenda
   - 1.6 Documents available
2. Review of outcomes from relevant meetings
   - 2.1 Workshop on Climate Change and Adaptation in the Eastern Pacific
   - 2.2 CCAMLR-IWC workshop
   - 2.3 The implications of climate change for arctic marine mammals: US MMC monitoring framework/CAFF Marine Expert Monitoring Group
   - 2.4 Other meetings
3. Setting the scene
   - 3.1 Cetacean populations' response to direct and indirect effects of climate change
     - 3.1.1 The development of climate change sensitivity indicators
     - 3.1.2 Impacts on cetaceans from the interaction of climate change with persistent organic pollutants (POPs)
   - 3.2 Changes in the biological environment
     - 3.2.1 Baleen whales and climate change in the Southern Ocean
     - 3.2.2 Baleen whales and climate change in the Pacific Arctic Region: bowhead and gray whale focus
     - 3.2.3 Climate change and small cetaceans

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3.3 Modelling the impacts of climate change on management strategies: examples from fisheries
4. Empirical techniques to investigate linkages between whales and their environment: some examples
4.1 Biochemical tools and physiological indicators and their use in retrospective studies of archived material
4.2 Ancient DNA and climate change: examples from bowhead and gray whales
5. Cetaceans and climate change: case studies
5.1 Large cetaceans
5.1.1 Long-term cetacean datasets in the Southern Hemisphere
5.1.2 Southern right whales and climate change: example from the western South Atlantic and Southern Ocean
5.1.3 Assessment of the eastern stock of North Pacific gray whales; incorporating calf production, sea-ice, and stranding data
5.1.4 B-C-B bowhead whale body condition and sea-ice in the western Arctic
5.1.5 Climate change in West Greenland and its consequences for cetaceans
5.2 Small cetaceans
5.2.1 Cetacean assemblages in the riverine and shallow waters of Bangladesh
6. Evaluation of analytical and modelling approaches to investigate linkages between whales and their environment, with an emphasis on climate change
6.1 Uses and types of models
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7. Regional working groups
7.1 Large whales
7.1.1 Southern Ocean (with linkages to lower latitudes)
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7.2 Small cetaceans
8. Conclusions and recommendations to the Scientific Committee
8.1 Current state of knowledge on the effects of climate change on cetaceans
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8.2.1 Modelling (see Items 3 and 6)
8.2.2 Southern Ocean with linkages to lower latitudes (see Item 7.1.1)
8.2.3 Arctic (see Item 7.1.2)
8.2.4 Small cetaceans (see Item 7.2)
8.3 Implications for the work of the IWC
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9. Any other business
10. Adoption of report

Annex C

List of Documents

SC/F09/CC

1. George, J.C., Nicolson, C., Drobot, S., Maslanik, J. and Rosa, C. Update on SC/57/E13: Progress Report: sea ice density and bowhead whale body condition.
2. Ferguson, M., Zerbini, A.N. and Leaper, R. Identification of long term datasets on southern hemisphere baleen whales with potential utility in climate change research.
3. Hoffman, J. The concept of adaptation and adaptation of ecosystems on which cetaceans depend.
4. Aguilar *et al.* Biochemical tools to investigate effects of climate change on cetaceans.
5. Brandon, J. and Punt, A. Assessment of the eastern stock of North Pacific gray whales: incorporating calf production, sea-ice and strandings data.
6. Wells *et al.* Small cetaceans and climate change in shallow habitats.
7. Simmonds, M. Cetaceans and climate change – the tertiary level: changing human interactions.
8. Simmonds, M. and Smith, V. Cetaceans and climate change – assessing the risks.
9. Lysiak, N.S. Marine mammals stable isotope records as indicators of climate change: a call to re-examine previous conclusions.
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