High Latitude Sea Ice Environments: Effects on Cetacean Abundance, Distribution and Ecology

Report of the Joint Symposium on High Latitude Sea Ice Environments: Effects on Cetacean Abundance, Distribution and Ecology[1]

A joint Symposium, hosted by the Environmental Concerns Working Group. Held at the Lotte Hotel, Ulsan, Republic of Korea, 28-29 May 2005.

INTRODUCTION

At its 2004 meeting, the Scientific Committee agreed that a proposal for a joint symposium (IA, BRG and E) to review current knowledge of polar sea ice environments and variability with relevance to cetaceans should be given high priority. The joint sea ice symposium was hosted by the Environmental Concerns Working Group as a pre-meeting (28-29 May 2005) to the main SC/57 meeting in Ulsan, Korea. The aim of the symposium was to review information on sea ice environments in the Arctic and Antarctic, and to develop means of incorporating sea ice and similar data into analyses and models used by the Scientific Committee in its work on abundance estimation, determining variance, resolving issues of habitat use and the implications of seasonal, interannual and decadal variability in sea ice on cetacean populations and habitat.

Convenors welcome

Sue Moore and Deborah Thiele welcomed participants to the Sea Ice Symposium. Participants were asked to review the Draft Agenda (dated 29 April 2005), which the conveners noted was purposely left flexible with regard to presentation times to encourage discussion. There were only minor additions to the Draft Agenda; the Final Agenda is provided in Annex A. A list of participants is given in Annex B.

The conveners thanked Peggy Krahn and Teri Rowles for their assistance in note-taking during the symposium and for editorial assistance during preparation of this report.

1. ARCTIC OVERVIEW

1.1 Changes in sea ice and current conditions (Richard Moritz)

There have been large changes in sea ice cover in the western Arctic, especially summer ice retreat during the past 3-5 years. The presentation reviewed published work on change in sea ice over the past 30 years, as well as on current conditions. The presentation did not review forcing factors, relate sea ice conditions to whales, nor project the future. Sea ice variables included ice thickness, draft of first year and multi year ice, age, concentration, extent and area.

A time-lapse movie dramatically depicted interannual variability in sea ice extent. In playing through the movie several times, Moritz was able to illustrate extremes in sea ice retreat or advance for several regions of the Arctic. The extreme seasonal retreats seen in recent years (since 2003) for the western Arctic were also evident in the kinematic data (Rigor and Wallace, 2004) reviewed by Moritz. Here, wind was posited to play a significant role in ice edge extent, given the warming and thinning of sea ice, possibly set in motion by the positive mode of the Arctic Oscillation (AO) described in the late 1990s. Rigor and Wallace (2004) noted that although extreme ice retreats, with a great deal of variability, continue to be seen in the western Arctic, the AO does not seem to be the driver of sea ice loss. The AO seems to have a role to play with regard to anomalies, but AO is the long-term integral of the effects. In other words, it takes a long time to recover sea ice, as the oceans provide a long-term reservoir for heat and mass (i.e., the Arctic marine system has a long memory).

The spatial distribution of various thicknesses of ice can be measured with sonar and these measurements are routinely taken at North Pole station. It is important to remember that ice thickness has a Pan-Arctic distribution that likely influences the underlying marine ecosystem. A long term mean in ice thickness derived from data acquired via submarine cruise tracks in summer and fall (Rothrock *et al.*, 1999) agreed closely with recently completed directed sampling (Rothrock *et al.*, 2003). The distribution of mean annual sea ice thickness captures variability beyond the 'modal slab' concept of Arctic sea ice.

Sea ice changes and conditions in Arctic continental slope and shelf waters, as well as in sub-Arctic seas, may have great relevance to whale habitats, but few studies of sea ice change have been focused there. One exception is a time series of sea ice extent in the Bering Sea that showed a dramatic decrease in sea ice in the southeastern sector concomitant with warming (+ 2°C) (Overland and Stabeno, 2004). Similar declines in sea ice have been noted for the Kara and Barents Seas. Conversely, there seems to have been an increase in sea ice in the Sea of Okhotsk during the later part of the 1990s and 2000s. Large decreases in sea ice have been also noted in the Greenland Sea. However, as elsewhere, the variability in sea ice is a far stronger signal than any specific trend.

An extended summary of this presentation, complete with references, is provided in Annex C.

Questions and Discussion

Do we have the data we need to make forecasts of sea ice conditions in the Arctic?

There are plans for a new satellite that will give better measurements of Arctic ice thickness, but for now we do not have the data needed to make projections for future climate. Long time series are key to the investigation of current

[1] Presented to the meeting as SC/57/Rep5.

trends in sea ice and the re-analysis of the past three decades of data at variable temporal and spatial scales is needed to improve predictive models.

What are bowheads getting out of the Bering Sea, calorically? In other words, can the ecological underpinnings commonly called 'bottom-up' ecosystem structuring in the Bering Sea, as described by Overland and Stabeno (2004), be linked to bowheads and does such structuring have implications further north?

We have not begun to address these questions yet, but the Overland and Stabeno paper provides some interesting observations suggesting ecosystem cascades that can form the basis for hypotheses testing. Future work should be focused on evaluating these hypotheses.

Is it possible to predict the persistence of the open-lead along the Chukchi coast?

Ice conditions in one year are correlated with those the year before/after, at least in the Beaufort Sea, as described in Rigor and Wallace (2004). Of note, there is a study of the shorefast lead and evolution of landfast ice now underway by a team of researchers from University of Alaska, Fairbanks; provisional results are described in Mahoney *et al.* (2005).

Has traditional (i.e., local) knowledge and experience been included in retrospective analyses of Arctic sea ice?

No, not formally. People tend to remember the anomalies, the years when things were very different or the sea ice conditions in years when they landed a whale. Of note, the experience of Native elders with regard to Arctic sea ice is included in the ARCUS 2004 report (see Item 1.3 of this report).

What approach might be taken to do a retrospective analysis of sea ice at the meso-scale to include the basin, slope and shelves; that is, how can we collate and analyse long-term data sets (~ 30 years) for Arctic whales and sea ice?

The temporal and spatial scales of analysis for sea ice and whales are generally quite mismatched (see SC/57/E5). To scale satellite-derived sea ice data down to biological scales will require a means to merge spatial and temporal data statistically, perhaps via landscape techniques. Ideally, a retrospective analysis of sea ice that included spatial scales to tens of kilometers (i.e., mesoscale) could be linked to local observations made at finer scales (see question 4 above).

1.2 Review of Arctic Climate Impact Assessment (ACIA) (Peggy Krahn)

Krahn discussed the relevant findings of the Arctic Climate Impact Assessment (ACIA) study reported in 'Impacts of a Warming Arctic,' a non-technical report (ACIA, 2004). The report indicated that global climate change is a result of increasing greenhouse gas emissions (CO_2 and methane) from the burning of fossil fuels, causing temperature increases that are greater at the poles than mid-latitudes. Increasing temperatures cause many changes in the Arctic, among them retreating summer sea ice, declining snow cover, rising river flows and changes in ocean salinity. Sea ice coverage in late summer in the Arctic has shown a loss of 15-20% between 1979 and 2003, with larger losses predicted by the end of this century. The study reported that loss of sea ice will decrease surface reflectivity, increase humidity and cloudiness and alter ocean circulation patterns. These climate changes are predicted to profoundly affect Arctic cetaceans through altering their foraging bases, increasing their risk of disease, increasing competition from more temperate species that expand northward and degrading their habitat by increased vessel traffic, development and pollution. Cetacean ranges may shift northward and migration patterns will also be altered by increasing temperatures. More details on this ACIA study will be available in the 'Science Report' that is due to be published later in 2005.

Questions and Discussion

Did the non-technical ACIA report go into any detail on cetaceans with respect to sea ice?

No, the ACIA non-technical report deals with the effects of climate change on cetaceans and on sea ice separately, although it is unknown how the (as yet) unfinished chapters of the Science Report will report on these issues.

What will follow the ACIA Science Report? Were there specific recommendations that will be followed-up on? If so, what forums will be used to implement the recommendations?

Follow-up on the ACIA remains a bit uncertain, as the full Science Report will not be available until July 2005, at the earliest. However, it is noted that follow-on research is in active planning stages, including the International Polar Year (IPY), which is seen as a 'kick-off' to the Second International Conference on Arctic Research Planning (ICARPII). There is a strong link between ACIA and ICARPII as illustrated by the fact that the Chair of the ACIA (R. Corell) is now the Chair of ICARPII. ICARPII will plan a decade-long program of research.

1.3 Overview of recent relevant meetings/workshops (Moore)

Moore provided (see below) a listing of recent Arctic sea ice related meetings and stressed the importance of getting whale and sea ice researchers together to refine relevant questions, review available data sets and evaluate prospective compatible sampling schemes. The list of meetings was not meant to be comprehensive, but rather a 'sampling' to exemplify the attention that changes in Arctic sea ice has received in various forums over past year.

ARCUS 2004

The Arctic Research Consortium of the United States (ARCUS) hosts the US Arctic Forum each year, with the goal that Arctic researchers in all disciplines be able to interact with colleagues and agency representatives. The theme for the ARCUS 2004 Arctic Forum was 'Recent Decrease in the Arctic Sea Ice: Its Causes, Consequences and Historical Perspective.' Warren Matumeak, an Alaskan Native Elder and Mark Serreze, a sea ice biologist from the University of Colorado gave keynote addresses. Moore noted that presentations on cetacean (Suydam) and polar bear (Stirling) responses to changes in sea ice were also part of the program. The program abstracts were available for review by symposium participants (available from *www.arcus.org*).

Sea Ice Mass Budget in the Arctic (SIMBA) Workshop

Current knowledge of Arctic-wide sea ice mass balance and variability were reviewed at a workshop held in Seattle, Washington, USA, 28 February-2 March 2005. Goals of the workshop were to: (1) understand the current state of the art in modeling and observations of the Arctic sea ice mass budget and variability; and (2) determine knowledge and data gaps and outline resolution and accuracy of sea ice mass balance analysis required by various communities. Approximately 50 scientists from a variety of disciplines attended the workshop; a final report of the proceedings is due by the end of June 2005 and will be available via the IARC website (*www.iarc.uaf.edu1workshops/SIMBA_2005index.php*).

Arctic Science Summit Week (ASSW)
The Arctic Science Summit Week (ASSW) was held 17-24 April 2005 in Kunming, China. The Arctic Ocean Science Board (AOSB) opened the meeting with two days of overview of Arctic science, including presentations from researchers associated with the International Arctic Polynya Project (IAPP). The Pacific Arctic Group (PAG) specifically targeted sea ice in their discussions of an international project in development for the International Polar Year (IPY), upcoming in 2007. The central theme of the PAG project will be to investigate biophysical dynamics associated with the retreating sea ice margin in the Bering, Chukchi and Beaufort seas, utilising four research cruises, one each season in 2007. An overview of ASSW and links to Arctic research planning is available at *http://www.aosb.org*.

Arctic Marine Transport Workshop
Growing concern over the rapid climate changes occurring in the Arctic precipitated a three day workshop to create a research agenda and identify key issues related to the future of Arctic shipping. The workshop, held at the Scott Polar Research Institute from 28-30 September 2004, was co-sponsored by the Arctic Council's Circumpolar Infrastructure Task Force, the US Arctic Research Commission and the International Arctic Science Committee. The workshop covered a broad array of topics, with potential impact on marine life 'particularly marine mammals (sound routes)' and 'the impacts to indigenous and coastal Arctic communities' noted in 'Theme D: Environment' of the workshop report, which was made available to symposium participants (*www.arctic.gov/files/AMTW_book.pdf*).

1.4 Bowhead, Right, Gray (BRG) Whale Focus Questions
Moore reviewed the BRG Focus Questions developed during SC/56 (see Annex A) and noted that population dynamics records for the BCB stock of bowhead whales and the eastern Pacific stock of gray whales basically overlaps the era of 'good' sea ice data from satellites (i.e. late 1970s to present). This holds promise for potential finer scale analytical investigations on the effect of sea ice variability on these whale populations. In addition, for BCB bowheads, long-term records of body condition exist that provide another avenue for investigation. The participants **recommend** that additional ways to mine the existing sea ice data in analyses relevant to gray and bowhead whales be sought.

1.5 General Discussion and Questions
Moore then opened the floor for general discussion and as an opportunity to raise any outstanding questions. Five questions were discussed.

Were bowhead and gray whales from the Okhotsk Sea stock meant to be excluded from the Arctic focus questions?

No, it simply reflects the strong focus that the BCB and eastern North Pacific gray whale stocks receive in the BRG sub-committee discussions. In fact, a pan-arctic perspective, including effects of sea ice variability on bowhead and gray whales in the Sea of Okhotsk, would be preferable.

Are there autonomous instruments available (e.g., sea gliders, recorders or acoustic tags) that could help census cetaceans to determine their distribution and abundance in the Arctic? Further, are cetaceans considered in development of various schemes for Arctic Ocean Observing System (AOOS), such as the international multi-disciplinary DAMOCLYES project?

Yes, autonomous instruments including acoustic recorders and satellite telemeters exist and are in use now. There are basically three types of passive acoustic recorders in use in the US, which have returned surprising results on large whale seasonal occurrence in both Arctic and Antarctic waters. Similarly, tagged small cetaceans (narwhal and beluga) have provide novel records of excursions into areas of heavy sea ice cover. Acoustic recorders, satellite tags and potentially autonomous sea gliders hold great promise for better integration of cetacean numbers and patterns of occurrence into polar ecosystem research. However, improvements to all of those instruments (e.g., CTD, flurometers on tags; acoustics on sea gliders) will be required to achieve this goal.

Is there corresponding sea ice data to accompany the long-term census and health study on bowheads at Barrow?

Sea ice observations (including % ice cover, direction, speed and lead type) have been made during each census conducted at Barrow between 1978-2001, but there are large gaps in this data record. Integration of these datasets have not been fully explored.

One participant queried the floor regarding two potential problems: a) What is the effect of ice on the ability to get an accurate bowhead count? and b) What is the relationship between count to upstream ice conditions (e.g., light, medium, heavy) during periods of whale migration?

Concern that whales were missed during heavy sea ice conditions (i.e., when the lead is closed) led to the integration of acoustics to the census in the late 1980s – this method has proven very satisfactory with regard to investigating the effect of ice on the ability to detect bowheads. More recently, with significant variability in shorefast sea ice, concern about the stability of the census platform led to the development of aerial photo-ID mark recapture study (SC/57/BRG16). With regard to the effect of 'upstream' ice conditions, there are no broad scale data on this, however, work during the acoustic census has shown that bowheads will deviate their swimming path around ice with deep keels, but swim through new ice cover as if it were open water (see Ellison *et al.*, 1987)

2. ANTARCTIC OVERVIEW

Thiele opened the session on Antarctic sea ice and introduced the invited participants.

2.1 Overview of Antarctic sea ice – seasonal and inter-annual processes; local, regional and circumpolar patterns (Anthony Worby)
Sea ice environments in the two polar regions are vastly different. While the Arctic pack is dominated by thick multi-year 'old' ice, the Antarctic pack is predominantly thin, mostly single-year ice and thick ice is relatively rare. A broad pattern of sea ice dynamics in the Antarctic can be identified: sea ice extent is at a minimum in late summer (February) with the maximum in September. December through January is a highly dynamic and complex period, as sea ice warms up to the point that it is superheated, instigating large scale, rapid changes in the structure, but not

thickness of the ice cover. The Antarctic sea ice environment is complex and dynamic, ocean atmosphere heat exchange drives the constant formation-melting processes, while the effects of wind and currents produce deformation and a complex structure of many types of ice. Lead systems can be extensive and are continuously changing in size and extent due to the melting and deformation of the surrounding pack.

Changes in the overall extent of sea ice have been a focus of many recent studies (see SC/57/E14). Parkinson (2004) has investigated the passive microwave data record and found a net increase in the extent of Antarctic sea ice. However, if data from the 1973-77 period is added, the overall trend becomes negative (Cavalieri *et al.*, 2003). Thus, the trend in Antarctic sea ice depends on the time record of analysis. There are problems with interpreting passive microwave data, particularly during summer when the data is compromised since it cannot 'see' the complexity of the ice (e.g., one pixel (25 km^2)) can make a difference in trend). Resolving trends will require much longer time series than are currently available from the passive microwave satellite record, and so longer time series of data are needed.

The Antarctic Peninsula is the only region that has experienced a significant change in ice extent (see Vaughan *et al.* (2001) for an explanation of warming in the Peninsula). Trends are apparent in all seasons, but are particularly evident in the summer. There has also been a change in the length of the sea ice season, decreasing by 2-4 days/year (Parkinson, 2004). The ENSO effects in the Peninsula and cyclical changes in the Bellingshausen, Amundsen and western Weddell Seas add further complexity and are important to consider (SC/57/E14).

Proxy records for sea ice have been used to provide data for longer periods. Proxies for sea ice extent that have been used to date include:

(1) Methanesulphonic acid MSA (1850s to present) – sea ice algae produce methane sulphide that oxidises in sea ice to produce MSA. Ice cores from Law Dome have been used to calculate a proxy for sea ice extent on the basis that greater sea ice extent = more algae = more DMSA. This proxy has been used for parts of East Antarctica, and may also apply in other areas of the Southern Ocean (SC/57/E14);
(2) Diatom assemblages in deep sea sediment cores (last glacial maximum, the period 25,000 years ago when the average temperature of the Earth was approximately 5°C cooler than present) reveal that sea ice around Antarctica in winter covered twice the area of the Southern Ocean, with ice extent significantly further north than it is today (SC/57/E14);
(3) Whaling data have been used as a proxy for the location of the ice edge in the pre-satellite era (as used by de la Mare, 1997). However, recent comparisons between satellite derived sea ice edge data and ship observations indicate a significant summer bias between the two data sets of similar magnitude to the reported decrease (Ackley *et al.*, 2003; Worby and Comiso, 2004).

Sea ice data coverage for Antarctica remains sparse. Additional sea ice data has recently been extracted from the Russian fishery and will be archived in the Antarctic Sea Ice Processes and Climate (ASPeCt) database (Worby, 1999). The ASPeCt Ship observation data has been collected since 1980 and covers approximately 85 voyages, across seven national polar programs. The ASPeCt data have been particularly useful in determining patterns of regional and seasonal ice thickness distribution at a circumpolar scale. The full potential of the ASPeCt data has yet to be realised, and is likely to be an important resource for IWC analyses.

Worby finished by giving an example of the types of effects that climate change processes can have on the Antarctic ice shelves and the implications for ocean circulation and ecology of the region: the dramatic collapse of the Larsen B ice shelf occurred from January to March 2002, icebergs in the Ross Sea resulted from the collapse, blocking off the Terra Nova polynya, icebergs prevented sea ice from moving out and forming Antarctic bottom water, which drives the global ocean conveyor belt.

A summary of this presentation is provided in Annex D (see also SC/57/E14).

Discussion focused first on the apparent decrease in sea ice extent in the WAP and the extent of inter-annual variability in ice extent in other regions of the Antarctic. Worby noted that a great deal of attention is currently focused on whether or not there have been changes in Antarctic sea ice extent over the past several decades, particularly in light of changes that have been observed in the Arctic. He then referred to Parkinson (2004) which shows extremes in seasonal variability and the scale of changes in length of ice season for different areas of the Antarctic. The current assessment of the satellite passive microwave record, which provides global, daily coverage of sea ice extent, is that there has been an increasing trend from 1978 to 2002 (Parkinson, 2004). Next, the issue of definitions of the 'ice edge' was discussed. Worby noted that there are really two answers, one for satellite data and one for observational data. Passive microwave imagery, the best tool for looking at concentration of sea ice, defines the ice edge as 15% surface cover, but not for any ecological reason. However, this method does not pick up nilas or grease ice, which can form large portions of the outer pack ice at times. A diffuse ice edge is very hard to define, it is really a Zone and not a Line, there are no hard and fast rules. There was further discussion of the use of proxies for sea ice, particularly the potential for proxy data could be used for the warm inter-glacials, and although a variety of methods are being investigated, none have yet been found for that period.

Overview of ecosystem links with sea ice: krill, oceanography and implications for cetaceans (Nicol)

Nicol began by emphasising the massive scale of the Antarctic, and describing the geographic regions, wind and ocean regimes and sea ice processes that make up this system. He discussed the role of sea ice as a integral driver in this system and the complexity and variability of Antarctic sea ice processes (see SC/57/E14). Sea ice has a number of ecological roles: as a platform for larger animals to rest; as habitat for whales; as a substrate on which communities can develop; as a major production zone and a source of phytoplankton for the spring algal bloom. It also acts as a physical, chemical and biological barrier between the atmosphere and the ocean. Collaborative research projects such as Southern Ocean GLOBEC have revealed that the linkages between sea ice, primary productivity and krill population dynamics are complex, and result from environmental conditions over a number of preceding seasons.

In a broad sense, the more sea ice is present in an area over winter, the more algae available to seed the spring bloom as ice melts and retreats, and this in turn results in the larger numbers of juvenile krill, and greater krill productivity. The spring bloom develops in the lee of the retreating pack ice, readily apparent on satellite images in spring. There is strong evidence for this model in the East Antarctic, but, there are large areas of the Antarctic where this model of sea ice retreat and strong spring bloom does not occur due to different combinations of conditions (e.g. geographic, topographic, oceanographic, position of shelf break). Work in the Antarctic Peninsula (Loeb *et al.*, 1997) shows periods of several years where greater sea ice cover is *not* followed by higher abundance or survival of krill. Sea ice extent and proportional cover is very low in the WAP, yet this is an area of peak krill abundance. Thus, although sea ice extent can be critical to krill abundance, it is not the only driver. The majority of Antarctic models have been developed using data from the southwest Atlantic (South Georgia and Western Antarctic Peninsula), where the greatest concentration of research effort has occurred, and it is not clear whether these models reflect processes in other regions.

The Antarctic has been portrayed as a very simple ecological system: diatoms fed on by a vast krill population and krill in turn consumed by large and mostly migratory populations of whales, seabirds and seals. It is now clear that only a restricted (approximately 25%) part of the Southern Ocean has this 'krill based ecosystem', and that within this system there are a range of complexities (e.g., the scale of microbial activity) in primary and secondary production that went unnoticed in the past. The 'krill based ecosystem' is only one of many ecosystems within the Southern Ocean.

A summary of this presentation is provided in Annex E (see also SC/57/E14).

The group discussed a reported (Atkinson *et al.*, 2004) decline in krill abundance based on krill data mainly collected in the SW Atlantic sector (net and acoustic samples). Questions were raised as to whether this could be attributed to the increasing numbers of humpback whales. Nicol stated that the level of decline would indicate that it could not be due to any one species. The decline in this area is more likely related to the number of extensive sea ice years compared to light ice years. The frequency of 'good' sea ice years is now roughly one in five, so there is at least one 'good' ice year in a krill's lifetime. A decreased frequency of high sea ice years might have a disproportionate effect on the krill population because it could de-couple the life cycle from the scales of environmental variation. The magnitude of the reported decline (80%) was queried by the group, and Nicol agreed that a calculation of total tonnage of krill argues against this being likely. Nicol stressed that absolute values of suggested change in krill abundance is difficult to obtain because of a lack of long term data, as well as uncertainty associated with abundance estimation methodology. Arrigo and Thomas (2004) have presented a series of calculations for various possible scenarios. While they do not support the 80% decline, they do note that a permanent open ocean zone (POOZ) would actually increase overall production. However, krill would likely decrease in such a system. Despite this, the krill fishery will likely continue to expand due to demand for aquaculture products.

2.2 In-depth Assessment/Environmental Concerns (IA/E) Focus questions

Thiele reviewed the list of focus questions from IA and E subcommittees developed during SC/56 (see Annex A). Participants agreed that some of the questions had overlapping themes and a suggestion was made that the questions be rephrased as hypotheses.

2.3 General Discussion and Questions

Thiele opened the floor to participants for discussion. Much of the discussion focused on ways to refine the list of focus questions. Of particular note was the question of the importance of polynyas. There are at least 28 persistent polynyas around the Antarctic coast and their importance to whales is uncertain. The minke whale group size issue also generated discussion as minke whales have been reported to occur in much smaller groups now than in earlier years (CP data). Groups of 100-120 whales are still seen, but very rarely. The idea that ice motion and thickness may be related to group size was raised. Opportunistic observations suggest that areas where large groups of minkes have been seen have had a reasonable proportion of large thick floes of ice that do not melt until late in the season. A suggestion was made that a study be conducted to focus on locations where large groups of minkes have been seen and investigate correlations to thick, late-melt sea ice, via a retrospective look at sea ice from satellite imagery. Data on sea ice concentration and extent are available from the 1970s on, so this type of retrospective approach is possible. Finally, a suggestion was made to adopt similar terminology for sea ice features (i.e. ice edge, marginal ice zone) between Arctic and Antarctic communities. However, participants agreed that rather than work on a definition for ice edge, for example, it would be best to record the complexity of ice observed and let the analyst determine what type of ice boundary or habitat is present. Fundamental information that should be included in all sea ice observations is ice type and detail of ocean surface cover, but use of the full suite of ASPeCt classifications is preferable.

2.4 Review of submitted papers related to the Arctic

2.4.1 Summary SC/57/E13 (George)

Bowhead whale body condition was examined with reference to sea ice concentrations in the Beaufort Sea. Whale data from both the spring and autumn hunts at Barrow were used. Body condition index was estimated as the mean residuals from a fitted model to a body mass index. The body mass index uses body length and the animal's axillary girth. Ice density was calculated as the mean monthly sea ice concentrations in a series of pixels (resolution = 25 km^2) within the known summering range of bowhead whales. The estimates are based on daily ice concentrations from the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I) satellites. There was a high negative correlation between bowhead whale body condition and sea ice cover in the eastern Beaufort Sea. One suggestion is that a reduction of sea ice in the eastern Beaufort Sea enhances feeding opportunities for bowhead whales that summer there.

Questions and Discussion

It was noted that blubber thickness *does* change in minke whales, in reference to the statement that blubber thickness does *not* change appreciably in bowheads. However, although girth does change, significant changes in blubber depth have not been observed in subsistence harvested bowheads. It has been speculated that the hypodermal and visceral fat drive changes in observed girth. Further, in a discussion regarding the term 'blubber', it was noted that blubber is 'a whaling term' that is not standardised, so it is difficult to use as an adequate measure of nutritional status. Lipid content in blubber does change with nutritional status and health and it is hypothesised that water content may increase when lipid content decreases. Lipid content is a more sensitive measure of nutritional status than blubber depth alone, with the most mobile lipid layer found near the muscle in bowhead whales.

The question arose as to the thickness of ice that bowhead whales can break through? Ice hardness is a function of temperature and likely affects the thickness of ice that bowheads can break through. Direct observations of scientists and whale hunters report breakthrough of ice to 20cm and 100cm thick, respectively, probably in late spring when temperatures are higher.

2.4.2 Summary of SC/57/E5 (Moore)

To explore the importance of ecological scale to analyses of marine habitat change concurrent with global warming, trends in sea ice cover over 24 years (1979-2002) were examined in four months (March, June, September and November) for 4 large (~100,000 km²) and 12 small (~10,000 km²) regions of the western Arctic, based on habitats used by bowhead whales (*Balaena mysticetus*). Significant changes in sea ice cover were identified in eight regions of seasonal importance to this ice-adapted species. In large regions, increases in open water occurred during March in the East Siberian Sea (0.04% per year, P=0.003) and during September in the East Siberian, Chukchi and Beaufort seas (0.71 to 1.29% per year, P=0.06 in each test). In small regions, significant increases in open water occurred during: (1) June, along the northern Chukotka coast, near Wrangel Island and along the Beaufort slope; (2) September, near Wrangel Island, the Barrow Arc and the Chukchi Borderland; and (3) November, along the Barrow Arc. Bowhead whales have been observed feeding in, or oceanographic models predict prey entrainment to, each of these regions. Conversely, there was no change in sea ice cover in four small regions that represent wintertime refugia in the northern Bering Sea, nor in two regions that include the primary springtime migration corridor in the Chukchi Sea. The effects of sea ice loss on biophysical processes leading to bowhead prey has not been studied, so there are no empirical measures of impact. However, consistent shifts to longer (i.e., June to November) ice-free or light-ice conditions in regions where bowhead whales feed likely extends foraging time and may alter prey composition and availability. This evaluation of sea ice cover at spatial and temporal scales linked to bowhead whale natural history provides a basis for research on specific regions critical to investigation of the effects of climate change on this pagophilic species.

Questions and Discussion

The links between reduction in sea ice, primary production and availability of food for bowheads in the Arctic seem less clear than the sea ice-krill relationship in the Antarctic. There is no empirical data for these linkages in the Arctic, but in the case of bowheads it seems that they prey on advected zooplankton (euphausiids) in the western Beaufort Sea near Barrow, Alaska and on produced zooplankton (copepods) in the eastern Beaufort Sea near Kaktovik, Alaska. Variability in sea ice cover may affect the copepod link more directly, as a decrease in sea ice will lead to an earlier spring bloom in the high Arctic and potentially better conditions for copepods (and therefore bowhead whales) the spring bloom becomes decoupled from copepod life history. In addition, one model of the Arctic system proports that a retreat of sea ice off the Beaufort shelf will cause advection of copepods from the Arctic basin onto the shelf, a process that would also benefit bowhead whales. Conversely, whales feeding on euphausiids in the autumn near Barrow are likely feeding on prey affected by sea ice conditions in the Bering Sea. Those linkages are simply not worked out yet.

2.5 Review of availability of Antarctic data series

2.5.1 Summary of SC/57/IA7 (Shimada)

Shimada presented the results of analyses on the relationship between the distribution the Antarctic minke whales and sea ice coverage using satellite data for the 2nd (1988/89) and the 3rd (1998/99) IDCR/SOWER circumpolar surveys in Area IV (Shimada and Murase, 2003). To compare with 1988/89, 1998/99 was characterised as colder sea surface temperature, more northerly-located ice edge and smaller area of the continental slope without pack ice. The number and school size of minke whales was small in 1998/99 compared with 1988/89. High density of minke whales was observed along the ice edge over the continental slope. Open water area in the south of ice edge line observed and set up by the research vessels was calculated. There was an obvious relationship between sea ice coverage and the minke whale abundance estimates in IDCR/SOWER.

Shimada went on to report on a sighting survey of Antarctic minke whale within the ice field conducted by the Ice Breaker, *Shirase* in 2004/2005 (SC/57/IA7). The dedicated sighting survey within the ice field was firstly conducted under the 46th Japanese Antarctic Research Expedition in austral summer season, 2004/2005, to explore Antarctic minke whale distribution and density within pack ice. As the IDCR/SOWER research vessels have not been able to cover areas inside the pack ice, the present survey is an important step towards to filling this gap. Whale sightings were made on board the ice breaker *Shirase* (11,600 tons). The survey was conducted in the waters south of latitude 60°S and between longitudes 35°E (east part of the Area III) and 150°E (west part of the Area V). Two sectors were established as Sector A (40°E-50°E) and Sector C (73°N-85°N). Total number of primary sightings of Antarctic minke whales was 25 schools (33 animals) during the cruise, of those 23 schools (30 animals) were seen in polynia within the ice field, no other cetacean was seen there. As for other major large cetacean species, (fin, humpback), 76 schools (173 animals) were seen during the entire cruise in the Antarctic. Also aerial sighting survey using helicopters on board *Shirase* was conducted; three flights were within the ice field on 28 December, 8 and 12 February. Total number of sightings of the Antarctic minke whales was 10 schools (19 animals) within ice field. Six schools (13 animals) of humpback whales were confirmed outside of ice edge. *Shirase* also made a collaboration with two IWC/SOWER vessels simultaneously in Sector A (40°E-50°E). While *Shirase* conducted the sighting survey inside the pack ice, the SOWER vessels surveyed for the minke whales outside the pack ice from 10 to 22 February. The effective searching distance was 127 n.miles and the primary sightings of the minke whale were six schools (seven animals) in polynya within ice field during the collaboration.

In discussion, Worby asked whether ASPeCt data were collected from the *Shirase*. Shimada said that the National Institute of Polar Research of Japan (NIPR) had collected comprehensive sea ice data on the cruise and that he expected to continue to use the NIPR system in the future. Worby strongly encouraged the use of the ASPeCt system on these types of cruises and also noted the important contribution these data make to studies of sea ice in the Antartic.

The group strongly **recommended** the continuation of collaborative work in the pack ice on the *Shirase* and other icebreakers.

2.5.2 Census of Antarctic Marine Life (CAML) (Gales)
Gales reported on the Census of Antarctic Marine Life (CAML) which is a multi-year project leading up to the cooperative international projects during the International Polar Year (IPY) in 2007/08. CAML will form a major focus for the biological work to be conducted within the IPY and focuses on a broad range of Antarctic biodiversity. A major component of this work is a focus on Antarctic top predators; a group which is chaired by Diego Rodriguez (Argentina; *dhrodri@mdp.edu.ar)* with Vice-Chair Randy Davis (USA) and an ad hoc working group of D. Costa, J. Croxall, N. Gales, J. Gedamke, P. Tratham and H. Weimerskich. Rodriguez is presenting a broad proposal for the top predator work to the Scientific Steering Committee of CAML from 27-30 May 2005. Broadly CAML aims to produce a near-real time and more refined knowledge of seasonal use of geographical areas and the habitat characteristics essential for Antarctic seabirds and marine mammal foraging. The work will include shore-based and ship-based instrumentation of animals, along with ship-based surveys. Current plans include a circumpolar, sonobuoy deployment to attain a synoptic measure of whale vocalisation densities, coordinated by J. Gedamke and N. Gales. Suggestions, input and collaborations from the IWC and its participants will be welcomed and should be addressed.

It was **recommended** that opportunities to collect simultaneous cetacean and sea ice data during the CAML/IPY activities should be pursued by Gales.

2.5.3 CCAMLR (Nicol)
Steve Nicol outlined relevant data series held by CCAMLR. Since 1981 CCAMLR have managed fisheries in the Southern Ocean and hold long-term data sets of catch and effort. The data sets of most relevance for IWC analysis and modeling are from the krill fishery concentrated in the South Atlantic. There is some degree of confidentiality with the use of these records, and anyone wishing to use these data must work through their national CCAMLR scientific committee representative. There are also long time series of data from the CCAMLR Ecosystem Monitoring Program (CEMP) that include black browed albatross, seals and penguins.

Prior to the 2004 IWC meeting, the Southern Ocean Collaboration Working Group (SOC WG) (Thiele/Reilly) were invited to participate in a series of workshops being conducted by CCAMLR – WG-EMM. The objective of these workshops is first to assess the suitability of existing CCAMLR Ecosystem Monitoring Program (CEMP) data series to provide predictive capacity to models; and second to review and integrate other relevant data series. The initial assessment of CEMP data is not yet complete. The CCAMLR WG-EMM have requested that IWC participation in this process begin at the next stage, when the focus of the workshops will be on reviews and analyses of non-CEMP data series that may be useful in modeling efforts.

2.5.4 Summary of SC/57/E2 (Thiele)
Intersessional work for the Southern Ocean Collaboration Working Group (SOC WG) included the development of an integrated database for simultaneously collected cetacean, sea ice and other data from field work conducted in collaboration with multidisciplinary research since 2001 (CCAMLR, SO-GLOBEC and other collaborations). So far, cetacean sighting and effort data have been validated and entered into the database for: all eight US SO-GLOBEC cruises in the Western Antarctic Peninsula (WAP); one German SO-GLOBEC cruise in the WAP; two US ANSLOPE cruises in the Ross Sea; one German SO-GLOBEC cruise to the Lazarev Sea fine scale study site in the Weddell Sea; and eight of sixteen Australian Southern Ocean Cetacean Ecosystems Program (SOCEP) cruises. ASPeCT sea ice classifications (along track and at sightings) have been completed for all cruises where this data was available, and cruise track files and maps of effort and sightings have been linked to the database. The extensive data validation process began with the original data checked against all available data and information sources from the surveys by one person, with a further random validation check by a second person. Sighting and effort data were plotted on cruise track data obtained independent of the cetacean surveys to further check the accuracy of positions. Completion of the database requires validation and entry of sighting and effort data from a number of cruises (CCAMLR 2000, SOCEP and BAS) and a range of additional data fields and links of importance (e.g. photo identification records, maps of cruise tracks, records of other wildlife (biodiversity index), resightings, biopsy records, video footage, links to collaborative multidisciplinary data series contacts, photo and video logs, behaviour logs). The database is currently being used in: two US NSF SO GLOBEC synthesis and analysis projects; modelling studies in collaboration with Eileen Hofmann (Old Dominion University CCPO); and other analysis projects under the direction of Thiele and Moore. The SOC Database is already proving to be an important tool for exploring the seasonal and interannual variability in cetacean distribution in relation to physical and biological processes at local to circumpolar scales, and we expect that it will become a valuable resource in analyses to inform the development of the scientific plans for a new Antarctic multidisciplinary program under the ICCED initiative.

Support to complete the Southern Ocean Cetacean Database was **strongly recommended**.

2.5.5 Integrated Analysis of Circumpolar Ecosystem Dynamics (ICCED) (Nicol)
The ICCED initiative is linked to SCOR, UOceans + Scientific Committee of Antarctic Research. This program will conduct analysis projects during the IPY period and begin field work in 2007/8. ICCED is a follow on to SO-GLOBEC and other multidisciplinary ecosystem programs coming to an end. Three primary foci: (1) climate affects on ecosystem dynamics; (2) ecosystem structure and biogeochemical cycle; (3) how to include ecosystems in resource extraction plans. A meeting was held in Cambridge (24-26 May 2005) to begin developing the science plan and coordinating analysis projects. Thiele is on the steering group for ICCED and Reilly attended the meeting to represent the interest of the IWC SOC working group. A meeting report will be available soon and will be forwarded on to the IWC Secretariat by Thiele.

2.6 Review of submitted papers related to the Antarctic
2.6.1 Summary of SC/57/IA6 (Murase)
The impact of unsurveyed polynya observed in 1997/98 IWC/SOWER in Area II (0°-60°W) on the abundance estimate of Antarctic minke whale was examined using a GAM based spatial model. The IWC conducted the sighting

survey in Area II in 1986/87 as CPII and 1996/97 and 1997/98 as CPIII. Estimation of abundance was carried out for each year for comparison purposes. Environmental variables, satellite derived SST and chlorophyll-a concentration, bottom depth and distance from ice edge as well as longitude and latitude were used in the initial model. Selected covariates were different among three years and shapes of the functional forms for covariates used in the models showed quite complex shapes. The result indicated that distribution patterns of Antarctic minke whales in relation to the environmental variables were heterogeneous year to year in Area II in contrast to previously reported spatial modeling analysis in other Areas. It was reported that abundance estimates using the IWC standard method in Area II in CPII and CPIII were 131,177 and 43,592 individuals, respectively. Abundance of Antarctic minke whale in the polynya was estimated as 63,364 individuals using the spatial model. Abundance estimates using GAM-based spatial modeling in CPII and CPIII were 144,793 and 110,859 individuals, respectively including the estimate in the polynya in 1997/98. The result suggested that the abundance estimate in the CPIII would be underestimated because of the presence of the large polynya. The results also indicated that year to year environmental change could affect the estimation of abundance.

2.6.2 Summary of SC/57/IA20 (Leaper)

Some possible environmental covariates that may relate to whale population dynamics in the Southern Ocean are examined in SC/57/IA20. The use of indicators of global climate processes were considered in addition to more localised measurements around feeding grounds. Sea ice indices may be used as indicators of global processes but sea ice is also known to be important in the mechanisms underlying krill abundance and distribution. Previous work had identified correlations between southern right whale breeding success in the SW Atlantic and El Nino sea surface temperature indices in the western Pacific as well as sea surface temperature anomalies on the feeding grounds. These results indicated that time delays of several years may occur between the measured variable and the response. Some potential relationships with sea ice were also investigated. Although some significant correlations were found these were only with sea ice indices that were believed to be indices of global climate and for these cases the selected time series of SST anomalies were slightly better able to explain the variance in whale breeding success.

2.6.3 Summary of SC/57/E1(Thiele)

Many cetacean species are found in association with sea ice in the Antarctic. This is a dynamic and complex region of the Antarctic marine ecosystem in both physical and biological terms. Understanding the role of sea ice as marine wildlife habitat, and its impact on patterns of distribution requires targeted ecological experiments, long term data series and rigorous, comprehensive data collection standards. Sea ice physicists use a standard shipboard data collection system around the Antarctic that measures complexity in sea ice structure (ASPeCt sea ice program). Whale surveys are often conducted on Antarctic vessels that enter the sea ice, but few of these have incorporated standardised sea ice data collection protocols for simultaneous collection despite the apparent association of some species with particular ice 'types'. None have attempted to determine the extent to which sea ice can be categorised in an ecologically meaningful way for whale species, particularly how the patchiness of whale distribution in ice relates to the heterogeneity of the ice landscape. In Thiele *et al.* (2004) we used past whale survey data series (from East Antarctica and the Western Antarctic Peninsula) and matched both search effort and whale sightings with all available photo and video stills images taken in and around sea ice. All stills were then used to record sea ice conditions using the ASPeCt sea ice format. Surveys were conducted in the Weddell Sea and the Ross Sea in the 2003/04 Antarctic season, with whale sightings collected simultaneously with a combination of digital still images of sea ice and ASPeCt sea ice data fields. The analysis has been improved and now includes an additional set of survey data from the Ross Sea. To investigate the relationship between minke whale distribution and sea ice characteristics we fuzzy coded the classifications for a subset of the data, and then used multiple correspondence analysis to explain variability at a high temporal sampling resolution. Marginal frequencies for fuzzy-coded ice variable modalities were examined to characterise ice in each data set: marginal frequencies for records where minkes were sighted indicated potential habitat. Ordination through multiple correspondence analysis explained variability among the fuzzy-coded records according to the influence of the original ice variables: complexity was high with samples at a ten minute temporal resolution, and relatively many ordination axes were required to explain >50% of variance in the data. Hypotheses were tested in the Ross Sea by deriving canonical functions from axis scores, i.e. discriminating ice records associated with minke whales, and from different locations/times. Although some potential for classifying minke habitat was found, multivariate tests were not significant. However, different seasons and locations had clearly different ice characteristics. Fuzzy coded sea ice modality frequencies were used to define habitat types for Ross Sea surveys for calculation of available minke whale habitat in a range of bathymetric zones.

2.6.4 Information in SC/57/E8 (Parsons)

Parsons noted that the State of the Cetacean Environment Report (SOCER) for this year focuses on the Arctic and Southern Ocean regions, summarising key papers and articles that have been published in 2003, 2004 and 2005. The report remains a work in progress until the end of the Scientific Committee meeting.

3. WORKING GROUPS

Participants broke into two working groups to discuss focus questions and future research directions for the Arctic and Antarctic.

3.1 Arctic sea ice – focus questions and intersessional projects

The Arctic sea ice break out group reviewed the focus questions developed at the SC/56 meeting with an eye towards what might be accomplished by SC/58. Intersessional work and action items that will be reported on next year are identified below beneath each focus question.

How will loss of sea ice affect the census of BCB bowhead whales? The concern is that the landfast sea ice platform, including pressure ridges, may no longer provide a safe or effective platform from which to conduct a count. Two actions were identified to address this concern:

(1) develop a BCB bowhead whale population estimate from photo-ID data via mark-recapture techniques to evaluate suitability for management; and
(2) IWC delegates should participate in Arctic Marine Transport workshops, especially with reference to ship strikes and underwater noise that may accompany increased vessel activities in the Arctic.

How important is sea ice in structuring habitat for bowhead and gray whales in the BCB seas?

Investigate potential for competition between gray and bowheads – potential for northward shift of other mysticete species (competition); killer whales (predation) do BCB bowheads need ice as a refuge?

Arctic whale biologists should seek collaboration with oceanographers to investigate the role of sea ice in structuring habitat – active participation in science planning.

How to integrate large whales/IWC work into IPY, ICARPII, SBE?

IWC delegates should participate in the science planning meetings for these activities and invite planners of IPY and ICARPII, SBE to whale research planning meeting.

The Arctic sea ice working group then went on to identify future directions regarding further integration of the importance of sea ice for cetaceans in the Arctic.

Expansion of research to other species (e.g. fin, humpback and minke whales) and to other Arctic regions (e.g., Okhotsk, Baffin Bay, Spitzbergen). Specifically, large whales should be included in Pan-Arctic research plans now ongoing for the International Polar Year (IPY) and the Second International Circumpolar Arctic Research Program (ICARP II), the next planning meeting of which will occur in Denmark, November 2005.

Develop active working links to other lines of research, including Arctic Marine Health Assessment and Ecosystem investigations and development of Ocean Observing Systems (e.g. DAMOCLYES).

Recommend making sea ice observations on all Arctic research cruises (e.g., ASPeCt; WMO standards).

3.1.1 Arctic intersessional work

From the summary above, two proposals for intersessional work were developed.

(a) Sea ice – whale population dynamics: retrospective analyses from basin to regional to fine scale

This project would seek to accomplish a retrospective analysis of sea ice from satellite imagery with reference to BCB bowhead and ENP gray whale population trajectories for years 1979-2004. This project should identify inter-annual variability in sea ice from the continental shelf to the Canadian Basin in the Bering, Chukchi and Beaufort seas to at least the meso-scale (10-100km). Further, this project should include investigations of traditional ecological knowledge (TEK) regarding sea ice from Native inhabitants of coastal communities that border those seas to incorporate fine scale (1-10km) observations of sea ice wherever possible. Further, this project would link to ongoing fine-scale analysis of shorefast ice (Mahoney *et al.*, 2005) and to a planned retrospective (1953-1986) analysis of ice charts underway as part of NOAA's Climate Database Modernisation Program. It is anticipated that this project would leverage results of population dynamic studies already completed on the bowhead and gray whale populations, although some finer scale of analyses may be needed. The primary focus would be revisiting satellite sea ice data time series to provide a regional analysis for the western Arctic region. Simultaneously, TEK records would be sought from communities that border the Alaskan Arctic, primarily though extant whaling organisations such as the Alaska Eskimo Whaling Commission (AEWC) and the Alaska Beluga Whaling Committee (ABWC) among others. Students would be sought to accomplish both satellite and TEK ice analysis tasks. We **recommend** that this unprecedented retrospective work be initiated soon, so as to complement ongoing population dynamics, stock identity and health assessment studies.

(b) Sea ice and whale body condition and health

In order to detect and monitor health changes in bowhead whales and gray whales as a direct and indirect function (e.g., change in non-point source pollution) of sea ice change, a long-term monitoring and assessment program should be implemented in both species. Of particular importance are: nutritional status or body condition, contaminant loads, skin health, injuries (e.g., evidence of increased human interactions and increased predation), disease, presence of biotoxins, and reproductive and immunological status. To facilitate moving forward, historic data on bowhead and gray whale health should be compiled and evaluated with an epidemiologist so that a health model and a strategic monitoring plan is developed in cooperation with the sea ice community and native hunters and as part of the overall assessment of these populations. Exchange of information on bowhead whale body condition, including observations by whalers and evaluations by epidemiologists, would be a core part of this project. These models and plans will build upon the results of two workshops, the bowhead health and physiology workshop held in 2001 and the gray whale health workshop held in 2002. Minimal health criteria should be developed that can be monitored on Arctic large whales. In addition, health of other species that may be more sensitive to these environmental changes should also be evaluated to serve as indicators for baleen whale health (such as the discussion of black guillemots on Cooper Island – prey shifts). We **recommend** that the retrospective and prospective data be assimilated in a common database that could be accessed by Arctic scientists and that the compiled retrospective data be evaluated with sea ice data.

3.2 Antarctic Sea Ice – focus questions and intersessional projects

The Antarctic group considered the focus questions and attempted to refine these into a smaller set of tasks that could be accomplished for IWC/58. The group agreed that the scale (local, regional, circumpolar) of data required for each analysis needed to be clearly identified before extraction and integration of multidisciplinary data series could occur. Next, a brief clarification of the major sea ice related issues for IA was noted (reduction in minke whale group size from CPII to CPIII and calculating the proportion of minke whales inside and outside the pack ice for surveys where vessels cannot enter the pack). The group agreed that a useful approach to the group size issue would be a collaborative effort with the invited participants to combine all records of large groups of minke whales (CP, IWC SOC, SOCEP and other data) to test whether the same reduction in group size is observed in surveys other than CP, and also to investigate similarities in environmental variables at sites where large groups occur. Next, krill sampling and abundance estimation were discussed. It is not yet possible to sample krill in the pack ice, and so there are no krill data series from this region. Even abundance estimates for krill from open water should be used with caution, as net and acoustic sampling techniques do not give comparable results. The distribution of krill and other euphausiids relative to features such as the shelf break are relatively well understood, but any interpretation of prey and whale associations in the pack ice can only be inferential at present. Krill data only exist from the 1930s to present. The concept of a 'krill surplus' was discussed, and although members suggested possible evidence for this theory (i.e. a decrease in the minke whale population) it was also noted that despite the large number of long term krill predator monitoring programs (CCAMLR) there has been no ecological signal to support this theory. Next, the group noted data rich areas with historical and recent environmental data series were available, particularly for krill and sea ice, ice edge and polynyas. The IP's stressed the difficulties of defining the boundaries of features like polynyas and the 'ice edge' that are highly dynamic. Analyses that include such features should be done in consultation with sea ice physicists to ensure accuracy of analysis and interpretation.

There was some discussion of the importance of developing some covariates for Southern Ocean whale species (SC/57/IA20), and the need to incorporate these into modeling efforts such as those presented in SC/57/IA6 that could explain population dynamics and the distribution of whales and krill. The group also agreed that resolving many of the ecological linkages would require studies over longer temporal scales, which are possibly best addressed using techniques, such as satellite tagging and acoustics.

The group noted that integrating data series across disciplines and scales was not simple, but that existing historical time series (i.e., circumpolar scale sea ice, sea ice proxies, whale catch and circumpolar sighting survey data) have considerable potential, particularly for initial investigations of patterns and linkages to inform more refined analyses. Discussion of analysis approaches ranged from simple hierarchical investigations of associations (shelf edge vs cetacean distribution) to comprehensive modeling of all available data series. It was clear from the discussions that there were regions and time periods with concurrent data series, and that one of the intersessional tasks would involve extraction of these data segments from existing data sources. Useful data series include: ice drifter buoy data for currents (good data from the 1980s to present); krill (best coverage South Georgia, Antarctic Peninsula/Elephant Island, Palmer LTER, East Antarctica Jan/Feb 1995 to present); large scale physical data series are available for most of the Southern Ocean; ASPeCt ice data; sea ice proxies (1850s to present – methane sulphonic acid); and general circulation maps. Collaboration with people who have expertise in disciplines other than cetacean research (e.g. sea ice physicists, oceanographers, krill biologists) will be critical to the accuracy of these types of analysis. Familiarity with data collection methods used in other disciplines is particularly important. The invited participants offered to assist the group to access and analyse relevant data for the proposed analyses.

A core set of analysis projects were developed from the initial focus questions for the Antarctic group. Analysis projects were considered on the basis of the availability of appropriate whale and environmental data series at appropriate scales, relevance to the work of IA and E sub-committees, potential to contribute towards resolving high priority issues in the Scientific Committee, and the interest and willingness of invited experts and symposium participants to source data series and conduct the work intersessionally.

3.2.1 High priority intersessional analysis tasks

Areas of high minke density – source all sighting data (CP, IWC SOC, SOCEP) to extract records of high minke density and analyse for correlations with remote and/or simultaneously collected environmental variables to determine whether these densities occur under identifiable physical and biological conditions (this analysis will contribute to work outlined as cruise objectives for the 2004/05 SOWER cruise and recommended by the SC at its 2004 meeting (IWC, 2005).

Data source and/or analysis involvement: Ensor, Nicol, Worby, Thiele.

Shelf break position correlate with whale distribution – use krill fishery data (as in Ichii, 1990) as a starting point and source similar data for other local sites and regions to test this relationship.

Data source and/or analysis involvement: Palka, Nicol, others.

Data rich regional comparison of variables affecting distribution (spatial analysis of data from study sites such as Gerlache Strait, Marguerite Bay, Ross Sea, Weddell Sea and Scotia Sea to investigate commonality and differences in features and processes that affect whale distribution).

Data source and/or analysis involvement: Thiele, Friedlaender, Hofmann, Moore, Secchi, Reid, Reilly, Sirovic and others.

Analysis of minke whale distribution and relative proportions inside and outside the pack ice (extract data from various surveys – SOCEP, IWC SOC);

Data source and/or analysis involvement: Bravington, Worby, Thiele, others.

Integrating historical and recent whale catch/sighting data (all cetacean species – initial focus minke and blue whales) with sea ice data to investigate relationships between whale distribution and physical features/processes (sea ice extent, ice edge location, sea ice proxies 1850s to present, bathymetry in the Southern Ocean) across local, regional and circumpolar scales.

Data source and/or analysis involvement: Worby, Moore, Thiele.

The group noted the importance of identifying contacts and collaborative arrangements between IWC SC members and scientists from other disciplines who hold data series that will be needed to pursue these types of analysis projects. This process has already been initiated through: participation of Invited Participants with expertise in sea ice physics and krill ecology at IWC/57; participation of IWC SOC WG (Thiele and Reilly) in CCAMLR Working Group on Ecosystem Monitoring and Management; and in the development of the Southern Ocean Collaboration Database (SC/57/E2). We **strongly recommend** that these efforts be strongly encouraged and supported to ensure the timely availability of data series and facilitation of collaboration with other scientists necessary to the analyses.

4. SUMMARY

In summary, the symposium provided an excellent means for scientists that typically work at either pole to meet and exchange information on sea ice variability with respect to whale habitats. The three Invited Participants (IPs) provided a foundation of understanding of decadal changes and current conditions at both poles, which the conveners here wish to again acknowledge with gratitude. Themes common to all IP presentations included the: (1) extreme variability in sea ice conditions at both poles, (2) complexity of both polar ecosystems and (3) great dearth of data with regard to retrospective and forward-looking investigations. There are some tools that can augment future studies at both poles, including: (1) passive acoustic recorders, both short and long-term instruments (i.e. sonobuoys and moored recorders); (2) satellite telemeters for attachment to cetaceans, augmented with oceanographic instrumentation (e.g., CTD, flurometers) and (3) sea ice analytical tools to provide routine application at the temporal and spatial scale of whale habitats (i.e., days to months; 1 to 1000s km). We **strongly recommend** the application of these tools to future research in the Arctic and Antarctic and that researchers seek means to continue the collaborative exchange initiated at this meeting.

Finally, we note that the International Polar Year (IPY) affords an unprecendented opportunity for collaborative multi-disciplinary research in both polar regions. The aforementioned tools provide the means to fully integrate cetacean studies into broadscale programs of marine ecosystem research in ways unthought of only a few years ago. For these reasons, we **strongly recommend** urgent attention to integration of cetacean research in upcoming polar research.

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Annex A

Agenda

28 May 2005: Morning
Convenors' Welcome: Thiele and Moore

Overview presentations of current understanding of sea ice conditions in the Arctic; reminder of BRG Focus Questions provided at IWC/SC 56; review of available papers; general discussion of linkages between cetaceans, sea ice, habitat and prey, with specific relevance to possible changes/effects on cetacean distribution and abundance.

I. Arctic Overview – Overland and Stabeno, 2004; Rigor and Wallace, 2004; Mahoney *et al.*, 2005 and SC/57/E5, E13.

Changes in Sea Ice and Current Conditions (Moritz, APL-UW).

Review of Arctic Climate Impact Assessment (ACIA): sections relevant to changes in Arctic sea ice and cetacean habitats (Krahn, NOAA-NWFSC).

Overview of recent relevant meetings/workshops (Moore):

ARCUS 2004 Arctic Forum: Recent Decreases in Sea Ice
Sea Ice Mass Balance in the Arctic (SIMBA) Workshop
Arctic Science Summit Week (ASSW)
Arctic Marine Transport Workshop

II. BRG Focus Questions provided at IWC/SC 56

How will loss of sea ice affect the census for BCB bowhead whales?

How important is sea ice in structuring habitat for bowhead and gray whales in the Bering, Chukchi and Beaufort seas?

How can the IWC/SC work to integrate large whales into upcoming Arctic marine ecosystem multi-disciplinary research programs (e.g., IAPP – International Arctic Polynya Project; NSF/SBE – National Science Foundation/Shelf Basin Exchange; IPY —International Polar Year)?

III. General Discussion and Questions

28 May 2005: Afternoon

Overview presentations of current understanding of sea ice conditions in the Antarctic; reminder of IA and E Focus Questions provided at IWC/SC 56; review of available papers; general question time and discussion session to focus on linkages between cetaceans, sea ice, habitat and prey, with specific relevance to possible changes/effects on cetacean distribution and abundance.

I. Antarctic Overview (Nicol *et al.*, 2000; Ackley *et al.*, 2003; Constable and Nicol, 2003; Worby and Comiso, 2004 and SC/57/E14, E15)

Overview of Antarctic sea ice – seasonal and interannual processes; local, regional and circumpolar patterns (Anthony Worby/Antarctic CRC)

Overview of ecosystem links with sea ice: krill, oceanography and implications for cetaceans (Steve Nicol/AAD).

II. IA and E Focus Questions provided at IWC/SC 56

Can we identify and collate data and published information on open water areas within pack ice, such as polynyas that will be useful in analyses to determine use of these areas by whales?

Can we use historical sea ice and other data on areas within ice (particularly polynyas) to determined densities of whales in these areas?

What happens to the distribution and density of whales as the nature of the ice edge changes?

Can sea ice variability explain the decrease in group size for minke whales at the ice edge found in the analysis of the Circumpolar survey (CP) data?

Can the E group use the abundance estimate (AE) data that has been collected and validated in sea ice and ecosystem modeling approaches?

What sea ice, and other related physical and biological data are available to be used to address questions of importance to the sub-committees and what analysis methods are appropriate for these data?

How do whales use the different types of 'ice edge' eg. diffuse, solid, MIEZ and how is this likely to affect densities in different seasons and years?

How will the variability in sea ice cover and structure in different parts of the Antarctic affect the results of future AE survey efforts?

What changes can be made to the way AE surveys are conducted in the Antarctic to ensure the effects of seasonal, inter-annual and regional changes in distribution of whales and links to sea ice variability are measured?

How does the structure of sea ice habitat affect the distribution of minke, humpback and other whales? What will likely be the impact of loss of sea ice cover and changed structure of sea ice on cetacean distribution at local, regional and circumpolar scales and how can we measure or predict such effects?

How is the IWC/SC working to integrate studies that address these issues into upcoming Antarctic marine ecosystem multi-disciplinary research programs (e.g. ICCED and IPY)?

III. General Discussion and Questions

29 May 2005: Morning

I. Presentation of Arctic focused papers submitted for consideration at the Symposium

SC/57/E13 (George) and SC/57/E5 (Moore).

II. Presentation of Antarctic data series available from relevant multi-disciplines for integrative analysis

SC/57/IA7 (Shimada); ASPeCT (Worby); CCAMLR (Nicol); Southern Ocean Collaboration Database (SC/57/E1 – Thiele); ICCED initiative (Nicol); IPY (Gales).

III. Brief review of Antarctic-focused papers submitted for consideration at the Symposium

SC/57/IA6 (Murase); SC/57/E2 (Thiele); SC/57/IA20 (Leaper) and SC/57/E8 (Parsons).

IV. Working Groups formed to determine further data sharing and specific analyses to be conducted intersessionally to address issues raised and not resolved

29 May 2005: Afternoon

Working groups convene to determine best approaches to the specific questions raised by BRG, IA, E and during workshop, and to initiate outline of work to be conducted intersessionally. Outline should include: (1) recommendations specific to support of work in IA, BRG and E; (3) likely outcome by SC/58; (3) responsible SC member for integration. Re-convene in plenary after coffee to discuss and compare priorities between Arctic and Antarctic working groups.

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Annex B

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Annex C

Arctic Sea Ice: A Review of Current Conditions and Recent Changes

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The current state and recent changes of Arctic sea-ice were reviewed, based on published papers and datasets. Emphasis was given to these variables: total ice concentration, total ice area, multiyear (MY) ice concentration, ice age, ice thickness and ice draft.

Arctic ice-covered seas include the Arctic Ocean, marginal seas and adjacent seas. Measurements of surface brightness and temperature made by passive microwave radiometers on satellites provide good time and space coverage of ice extent, ice concentration and area, and MY ice concentration since the late 1970s. The climatological (1987-2003, NASA TEAM – all SSM/I) mean total Arctic sea-ice area exhibits a large annual cycle with a minimum of about 5 million sq km in September and a maximum of about 11.5 million sq km in February. The range of variability (ROV) varies regionally on interannual to interdecadal time scales. ROV is defined as the Max-minus-Min area anomaly for 1987-2003, divided by the Mean Maximum area. For the entire Arctic, the ROV is approximately 15% and about half (8%) of this appears as a 17-year negative, linear trend (LT). In individual marginal and adjacent seas, the ROV ranges from about 50-100% of the mean area. LT's over 1987-2003 appear in the Greenland Sea (-20%), Baffin Bay/Davis Strait/Labrador Sea (-35%), and the Sea of Okhotsk (+20%). LT's in the Bering, Kara/Barents and Canadian Arctic Archipelago (CAA) were relatively much smaller in magnitude during this period. It is clear that trends vary on smaller, sub-regional spatial scales, and depend significantly on the period of record analysed. In particular, the spatial grouping of Baffin Bay/Davis Strait/Labrador Sea is too coarse for some applications to whale habitat. The ROV in the marginal and adjacent seas tends to exceed 50%, i.e. differences between ice area anomalies in different years can exceed half the mean maximum ice area. The two largest ROV's occur in the Sea of Okhotsk (105%) and the Bering Sea (95%). It is important to emphasize the time interval studied and the region.

Seasonally, the largest negative LT for the Arctic as a whole occurs in summer. This is consistent qualitatively with independent analyses of a downward trend of -14% over 20 years in winter MY concentration. Ice age estimated from time series of ice motion and ice edge location shows maximum values exceeding 10 years in the Canadian Basin and north of Greenland. The area covered by this old ice decreased dramatically in the late 1980's in association with positive anomalies of the Arctic Oscillation (AO) index. Surface winds associated with the positive AO diminished the size of the Beaufort anticyclonic ice circulation, and increased the export of old ice through Fram Strait. Although the AO index has fluctuated around zero during the past 7 years or so, the summer ice extent has continued to be anomalously low. It has been proposed that the effects of the late 1980s to early 1990s AO anomalies accumulated and persisted in the ice cover (Rigor and Wallace, 2004), so that continued negative anomalies in sea ice cover after the return of the AO to climatology does not preclude the AO as the primary driver of the anomalies. The relationship between the AO and global warming is a topic of ongoing research and discussion.

The observations of sea ice draft (and inferred ice thickness) are much spottier in space and time than the observations of ice concentration. Ice draft is estimated from upward looking sonar (ULS) profile data acquired from moving submarines and, more recently, from bottom-anchored moorings. The moored data show a pronounced annual cycle of the ice draft distribution, including annual range at the North Pole of approximately 1m, and one interannual variation of 50cm in the annual mean ice draft. The submarine ULS data show spatially and temporally coherent changes in the central Arctic of minus 1 to 2 meters in mean ice draft, comparing the 1958-1976 period with the mid 1990's (Rothrock *et al.*, 1999). An overall downward trend of approximately minus 1m has been estimated for the decade of the 1990s (Rothrock *et al.*, 2003).

In the SE Bering Sea upper ocean temperature increased and sea ice area decreased in association with a major change in the ecosystem (Overland and Stabeno, 2004). Episodes of change in the mid-1970s and around 2000 appear abrupt in some aspects, suggestive of possible shifts between distinct climate regimes. Analysis of ice concentration near Bering Strait shows that the dates on which the ice retreats (advances) to the Strait in spring (autumn) vary by 35 days over the period 1978-2003. The largest anomalies of late retreat occur before about 1985, while the largest anomalies of late advance occur after 1999.

The large variability and persistence of both positive and negative ice area anomalies may be of interest in connection with changes in populations of cetaceans. To better understand and predict how cetaceans are affected by sea-ice requires long time series of accurate sea-ice data, and fundamental understanding of the causes of sea-ice variations. In this connection, it is important to extend existing passive microwave time series data on ice concentration, and existing ULS and altimeter data on ice draft and thickness. In addition, research is needed to determine the proximate (local wind, temperature, radiation, ocean fluxes) causes of ice anomalies on interannual to multidecadal time scales, and to relate this to both internal dynamics of the ocean-atmosphere-land-ice system, and to fundamental forcing functions such as anthropogenic changes in atmospheric concentrations of greenhouse gases and aerosols, volcanic aerosols, and solar output.

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Annex D

Antarctic Sea Ice Overview

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Sea ice is a fundamental component of the Southern Ocean system, affecting both physical and biological processes. The presence of sea ice affects ocean-atmosphere interaction, water mass modification through brine rejection, and results in a net northward transport of fresh water as a result of ice drift. Most of the sea ice around Antarctica is less than 1 year old; at minimum extent in February sea ice covers an area of approximately 4 million km^2, while at maximum extent in September the cover expands to almost 20 million km^2, an area 1.5 times that of the Antarctic continent (13.2 million km^2). This change from open ocean to ice cover represents one of the greatest seasonal changes in physical properties anywhere on earth, and has an extraordinary influence on oceanic and atmospheric circulation and marine ecosystems.

During the satellite era of global, daily coverage by satellite sensors, a slight increase in sea ice extent has been reported by numerous studies. This is in stark contrast to the Arctic, where a significant decrease in summer sea ice extent over the past several decades has been observed. Trends in sea ice extent may be linked to climate change, or to changes in oceanic and atmospheric circulation in the polar regions. However the only sustained change observed in Antarctica is in the Peninsula region where a decrease in mean air temperature of approximately 0.6^0C per decade has been observed since 1950. Various proxies for sea ice extent, including whale catch data and the concentration of methanesulphonic acid (MSA) in glacial ice cores, have suggested a decline in Antarctic sea ice extent over the past 50 years, but these results are inconsistent with the modern satellite record. Regional changes in Antarctic sea ice extent have been reported by various studies, but these have not reflected a change in total extent because of compensating changes in different regions. These anomalies reflect, at least in part, teleconnections to lower latitude climate phenomena such as the Southern Oscillation, and highlight the sensitivity of sea ice to anomalies in climate forcing. There is substantial evidence that year-to-year variations in sea ice cover in the Bellingshausen, Amundsen and Ross Seas are linked to variations in surface air pressure, air temperature and sea surface temperature that occur during El Niño events. On much shorter time scales the location of the sea ice edge is influenced by wind and ocean currents, and may move north- or south-ward by tens of kilometers per day under strong wind conditions. Over the longer term however, the ice edge is determined more by thermodynamic processes and reflects the location of the freezing isotherm, which is influenced by longer-term changes in oceanic and atmospheric temperature and circulation.

The first-year sea ice is regionally variable, but on average grows to approximately 0.5-1.0m thick, significantly less than in the Arctic. Dynamic processes (i.e., wind, waves, ocean currents and tides) play a very important role in the development of the drifting pack ice, and as a result the ice is not a uniformly level sheet but rather a complicated mixture of different ice types, thicknesses and open water that is constantly in motion and changing.

Annex E

Overview of Ecosystem Links with Sea Ice: Krill, Oceanography and Implications for Cetaceans

Steve Nicol, Australian Antarctic Division

The Southern Ocean exhibits considerable regional variability, both meridionally and latitudinally. There are a range of distinct marine ecosystems that accord with this regional heterogeneity. The krill-based ecosystem on which most Southern Ocean baleen whales depend is centred on the continental shelf break around the Antarctic continent and the island groups of the South Atlantic, an area comprising some 9 million km^2. Most of this region, with the notable exception of South Georgia, is directly affected by the seasonal advance and retreat of the sea ice. Sea ice is thought to be intimately related to biological productivity in the marine ecosystem. Sea ice offers a refuge for some animals and a platform for others. Sea ice also provides a substrate under which microbial communities can grow and develop and these communities can provide a food source for herbivores, particularly during late winter and spring. The melting sea ice can also stabilise the surface waters and can inoculate the surface layer with algae that can form the basis for the spring bloom offshore of the retreating ice edge. Relationships between the physical features of the environment and biological productivity at all levels have been shown to vary regionally and interannually. Changes have been reported in the extent of sea ice in particular regions and in its rate of retreat and its properties. The effect of these changes on biological productivity have not yet been quantified. Changes in the community structure of the phytoplankton associated with warmer conditions have also been reported for the Western Antarctic Peninsula which is the region where the greatest warming and the most significant sea ice declines have occurred. Changes, including density reduction and range contraction, have also been reported for krill populations in the South West Atlantic and these have been associated with sea ice declines. There are, however, methodological issues associated with the absolute values of the suggested changes and careful interpretation of the results is currently underway. Krill populations are being affected by a number of changes simultaneously including: sea ice declines, changes in the community composition of their algal food supply, increases in springtime UV-B, alterations to the current systems, changes in relative abundance of their chief predators and by the direct and indirect effects of fishing. Future declines in sea ice may actually increase overall productivity of the Southern Ocean but productivity in the sea ice zone may be greatly reduced and this is likely to adversely affect krill populations. Current biomass estimates for krill amount to ~90-400 million tonnes and the Precautionary Catch Limits set by CCAMLR amount to ~5 million tonnes. Expansion of the krill fishery will affect krill populations but the management regime set in place by CCAMLR is designed to minimise this impact of the fishery on the target species and on the dependent and related species. Despite the absence of long-term data on most elements of Southern Ocean ecosystems, there is a current research effort to construct conceptual models of elements of the system and to progress from these to more rigourous and quantitative descriptions of regional ecosystems that can be used for management or for predicting the effects of climate change.