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The SCAR Lecture – Marine Life and Change in the Southern Ocean

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The SCAR Lecture – Marine Life and Change in the Southern Ocean

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The text comprises notes on the numbered slides to be found in Annex 1.

1) Title
2) Is Antarctica still a symbol of the great wilderness and the pristine environment? No, Antarctica is inextricably linked to global atmospheric, oceanographic and climatic processes and therefore exposed to the impact of human activities in the rest of the world!
3) Antarctic organisms have adapted their seasonal cycles to the dynamic interface between ice and water. This interface ranges from the micrometre-sized brine channels within sea ice to the planetary-scale advance and retreat of sea ice. Antarctic marine ecosystems are particularly sensitive to climate change because small temperature differences can have large effects on the extent and thickness of sea ice.(Smetacek et al. 2005)
4) Threats – warming; acidification; invasive species.
5) Though there are no clear downward trends in the southern hemisphere sea ice cover, you have to look more into detail.
6) Linear least-squares trends for the 21year period show an overall lengthening of the sea-ice season throughout most of the Ross Sea, around the coast of much of East Antarctica and in part of the south-central Weddell Sea. They show an overall shortening of the sea-ice season in almost the entire Bellingshausen Sea, most of the Amundsen Sea, the far western Weddell Sea, the northwestern Weddell Sea, the northern portions of the ice pack at about 15'35°E and 85'10°E, and a few small coastal areas between 25°W and 80° E. (Parkinson 2002)
7) CLIMATE CHANGE: Devil in the Detail (Vaughan et al. 2001)
The Intergovernmental Panel on Climate Change (IPCC) confirmed a global mean warming of 0.6 ± 0.2ºC during the 20th century and cited anthropogenic increases in greenhouse gases as the likely cause. However, this mean value conceals the complexity of observed climate change. If the recent past is a guide to the future, regional climate changes will have more profound effects than the mean global warming suggests.
Global maps of observed climate change reveal a complicated pattern. Trends in mean annual air temperature for 1950-98 indicate three areas of particularly rapid regional warming, all at high latitudes: northwestern North America and the Beaufort Sea, an area around the Siberian Plateau, and the Antarctic Peninsula and Bellingshausen Sea. The last area provides a valuable case study, remote from the complications of urban warming and sulfate aerosols.
The mean temperature trend for all Antarctic stations for 1959-96 is +1.2ºC per century, well above the global mean. Regional responses have, however, varied widely. Annual air temperatures have cooled at Amundsen-Scott base at the South Pole since 1958 but have warmed on the Antarctic Peninsula since reliable records began in the 1950's. The longest records from the peninsula show a warming in the northwest Antarctic Peninsula that is considerably larger than the mean Antarctic trend. The shorter records suggest that the warming extends further south and east. Antarctic Peninsula records are too short to show when the rapid regional warming began. However, warming at Orcadas began in the 1930s, and annual temperatures at Orcadas correlate well with the Faraday record. Warming in the Antarctic Peninsula may thus have begun at a similar time.
A survey of seawater temperatures indicates a strong warming trend in the region west of the Antarctic Peninsula. The temperature data were analyzed by Michael Meredith and John King of the British Antarctic Survey, who collated a variety of measurements made between 1955 and 1998, projecting them onto a uniform grid of 1-degree squares. The maps give trends in summer water temperature at three depths—the sea surface, 50 meters and 100 meters. The warming is strongest by far at the surface, suggesting it is brought about largely by atmospheric warming. Another factor is a decline in winter sea ice, which can be both a cause and an effect of warmer seas in summer. (Meredith et al. 2005)

8) Antarctic krill is a key component of Southern Ocean food webs, being the major prey item in the diet of many of the higher trophic level predators, and supporting large populations of air-breathing vertebrate predators, such as penguins, seals, whales, and sea birds. However, the ecosystem is not homogeneous as there is marked spatial and temporal variation in its structure. So, for example, the major species of higher trophic level predators in the food web, the major consumers of krill, change with latitude. At higher latitudes ice-obligate predators, such as crabeater seals and Adélie penguins dominate, while at lower latitudes Antarctic fur seals and chinstrap penguins or macaroni penguins can dominate (Hofmann et al. 2004).

9) Circumpolar distribution of Antarctic krill constructed from data from the KRILLBASE (8789 Stations) (Atkinson et al. 2008). In some regions zooplankton species other than Antarctic krill are the dominant grazers. Salps are considered to be major grazers of primary production in the warmer waters mainly to the north of the seasonal pack-ice zone. Further south, in the more permanent pack-ice zone, a different species of krill, *E. crystalorophias* can be the dominant euphausid. Thus, there are spatial variations in the form of the food web that characterizes the Southern Ocean. (Hofmann et al. 2004)

10) Krill density in the SW Atlantic sector (4,948 stations in years with >50 stations) shows a clear decline over the past 25 years. This is shown in detail on the next slide.

11) Salps, small gelatinous planktonic animals, tend to occupy warmer water than krill and prefer oceanic regions with lower food concentrations. Thus the lower productivity across most of the ACC means that the habitat of salps is much larger than that of krill, with no concentration into one sector. The hotspot of krill in the SW Atlantic—a feature very unlike that of zooplankton—suggests an ability to maintain their 5–7-yr life cycle here, withstanding entrainment into the great current systems encircling Antarctica. (Atkinson et al. 2008).

12) The size of the Krill stocks depends on the extent of the winter ice of the previous winter. The development cycle of the Krill will explain this.

13) The main spawning season of Antarctic krill is from January to March, both above the continental shelf and also in the upper region of deep sea oceanic areas. According to the classical hypothesis of (Marr 1962) egg development then proceeds as follows: gastrulation (development of egg into embryo) sets in during the descent of the 0.6 mm eggs on the shelf at the bottom, in oceanic areas in depths around 2,000–3,000 m. From the time the egg hatches, the 1st nauplius (i.e., larval stage) starts migrating towards the surface with the aid of its three pairs of legs; the so-called *developmental ascent*. The next two larval stages, termed 2nd nauplius and metanauplius, still do not eat but are nourished by the remaining yolk. After three weeks, the little krill has finished the ascent. They can appear in enormous numbers counting 2 per liter in 60 m water depth. Growing larger, additional larval stages follow (2nd and 3rd calyptopis, 1st to 6th furcilia). They are characterized by increasing development of the additional legs, the compound eyes and the setae (bristles). At 15 mm, the juvenile krill resembles the habitus of the adults. Krill reach maturity after two to three years. Like all crustaceans, krill must molt in order to grow. Approximately every 13 to 20 days, krill shed their chitinous exoskeleton and leave it behind as exuvia (Kils, Wikipedia 2005). The larvae of Krill and the juveniles are extremely sensitive against unfavorable food and temperature conditions contrary to the adults which are rather robust. This explains the correlation between the sea ice condition in the previous winter and the size of the krill stocks.

14) The breeding success of krill predators depends on the krill availability.

15) Trends in breeding population of Adélie penguin in the Ross Sea in relation to air temperature. Penguin data from Cape Royd show a clear correlation with air temperature data from Ross Island. Shifts in the penguin population on the western Antarctic Peninsula are attributed to changes in precipitation patterns and sea ice. Adélie penguins are native to the region and are still the most abundant species, but their population has dropped to a third of its level 30 years ago. The birds are adversely affected by spring blizzards and a loss of sea ice. Gentoo and chinstrap penguins *(scale at right),* whose traditional territory is far to the north, have become established in the area near Palmer Station for the first time in at least 700 years. Photographs courtesy of William Fraser. Graph by Barbara Aulicino. (McClintock et al. 2008).

16) The biological community on the western shelf of the Antarctic Peninsula is highly sensitive to environmental change. The ice shelters diatoms and other "ice algae" as well as the juvenile krill that feed on these primary producers. Ice cover is also essential to Adélie penguins, which use it as a thoroughfare to reach isolated feeding "hot spots" nourished by upwellings of the Antarctic Circumpolar Current. Shade from the ice probably limits the territory of the kelp-like macroalgae growing on the sea floor. There is also a thriving community of benthic invertebrates such as sponges and corals. The effects that warmer air and water will have on these organisms cannot be predicted with certainty, but a few likely consequences are

shown in the lower panel. Loss of sea ice will be detrimental to diatoms and krill but may favor the gelatinous, filter-feeding organisms called salps as well as small cryptophytes. Scarce winter ice will also disrupt the foraging habits of Adélie penguins, whereas chinstrap and gentoo penguins prefer ice-free regions. Macroalgae might be able to expand their territory. The most dramatic (but also most speculative) consequence of warming could be an influx of crabs or other predators that feed by crushing their prey. (Cited from (McClintock et al. 2008)

17) Climate Effects on Benthos Reactions on the collapse of the Larson Ice Shelf.

18) The scientific framework of the Census of Marine Life comprises a global information system assimilating data and information from field projects investigating what now lives in six ocean realms (Human Edges, Hidden Boundaries, Central Waters, Active Geology, Ice Oceans, and Microbe) and projects designed to investigate the history of marine animal populations and to forecast the future of marine populations and ecosystems. The Census of Antarctic Marine Life (CAML) investigates the distribution and abundance of Antarctica's marine biodiversity, how it is affected by climate change, and how change will alter the nature of the ecosystem services currently provided by the Southern Ocean for the benefit of mankind. The CAML is a five-year project that will focus the attention of the public on the ice-bound oceans of Antarctica during the International Polar Year (IPY) in 2007/08. Its objective is to study the evolution of life in Antarctic waters, to determine how this has influenced the diversity of the present biota, and to use these observations to predict how it might respond to future change. The CAML collaborates with biological oceanographers in its work, for at its heart lies the integrated nature of ecological and biological change.

19) An ice shelf is a thick, floating platform of ice that forms where a glacier or ice sheet flows down to a coastline and onto the ocean surface. Ice shelves are found in Antarctica, Greenland and Canada only. The boundary between the floating ice shelf and the grounded (resting on bedrock) ice that feeds it is called the grounding line. When the grounding line retreats inland, water is added to the ocean and sea level rises. The thickness of modern-day ice shelves ranges from about 100 to 1000 meters. The density contrast between glacial ice, which is denser than normal ice, and liquid water means that only about 1/9 of the floating ice is above the ocean surface. The world's largest ice shelves are the Ross Ice Shelf and the Filchner-Ronne Ice Shelf in Antarctica (Wikipedia).

20) The Larsen Ice Shelf is a long, fringing ice shelf in the northwest part of the Weddell Sea, extending along the east coast of Antarctic Peninsula from Cape Longing to the area just southward of Hearst Island, named for Captain Carl Anton Larsen, the master of the Norwegian whaling vessel *Jason*, who sailed along the ice front as far as 68°10' S during December 1893 (Wikipedia).

21) In finer detail, the Larsen Ice Shelf is a series of three shelves that occupy (or occupied) distinct embayments along the coast. From north to south, the three segments are called Larsen A (the smallest), Larsen B, and Larsen C (the largest) by researchers who work in the area. The Larsen A ice shelf disintegrated in January 1995. The Larsen B ice shelf disintegrated in February 2002. The Larsen C ice shelf appears to be stable for the time being, though scientists predict that if localized warming (possibly caused by anthropogenic global warming) continues at the rate it is now, the shelf could disintegrate at some point within the next few years. During 2002-01-31 to 2002-03-07 the Larsen B sector collapsed and broke up, 3,250 km_ of ice 220 m thick disintegrated, meaning an ice shelf covering an area comparable in size to the state of Rhode Island disappeared in a single season. Larsen B was stable for up to 12,000 years, essentially the entire Holocene period since the last ice age. By contrast, Larsen A was absent for a significant part of that period and reformed beginning about 4,000 years ago. (Wikipedia)

22) The term benthos is derived from the Greek, meaning 'depths of the sea' and refers collectively to organisms which live on, in, or near the bottom of the sea. The benthic community includes of a wide range of plants, animals and bacteria. The diversity of marine life at the sea bottom depends on how it has been protected against the shelf ice. Here some impressions of benthic communities in less than 200m depth.

23) The effect of ice berg scratching is devastating.

24) The soft bottom areas beyond the effects of the ice shelf (>200m) are poorly populated.

25) It takes time for ascidians to settle in newly released areas.

26) As well as other sessile organisms like sponges need much time to settle there.

27) Sea urchins are fast mobile immigrants and opportunistic settlers.

28) Minke whales and seals will occupy the released areas immediately.

29) The future development can be derived from scientific results gained from studies of the re-settlement after ice berg scratching.

30) Conclusions: after an ice shelf collapse it will take a long time to settle the sea bottom and to develop a stable ecosystem. The pelagic open ocean will be utilized much faster.

31) Ocean acidification, caused by increased levels of atmospheric carbon dioxide (CO_2) dissolving in the ocean, is likely to have serious consequences for marine ecosystems and biodiversity in the Southern Ocean over this century. Ocean acidification differs from global warming in that its impact derives from the chemistry of carbon dioxide) in seawater, rather than from its physical action as a greenhouse gas in the atmosphere. This means that even if the climate does not warm, increasing atmospheric CO_2) will inevitably increase ocean acidity. The CO_2 has increased from 280 to 380 ppm in the last 200 years. The pH – the acid value – decreased 0.1. Within the next 90 years the pH is projected to decrease by 0.5, possibly 0.7 (Fabry et al. 2008; Fabry et al. 2008; Feely et al. 2008). The surface ocean absorbs as much as 30% of anthropogenic (human-made) CO_2 emissions, and the gas dissolves through a well understood chemical process, forming a weak acid that raises the acidity of the oceans. Atmospheric CO_2 is absorbed by the ocean faster than natural processes can neutralise the increased acidity it causes.
32) The Southern Ocean is particularly vulnerable to the phenomenon, due to the higher solubility of CO_2 in cold water. As a result, the current trajectory of carbon emissions will cause a change in ocean acidity during this century that is greater in extent than anything likely to have occurred for millions of years. Calcium carbonate exists in two major forms: calcite and aragonite. Aragonite is produced by molluscs such as pteropods (planktonic marine snails) and reef-building corals. Calcite is produced by planktonic organisms such as coccolithophorids (microscopic marine algae) and foraminifera (single-celled marine animals). Both forms of calcium carbonate dissolve more easily under conditions of higher CO_2, lower temperatures and higher pressures due to depth. Aragonite is less stable than calcite, however, so organisms with aragonite shells are likely to be impacted first by changing conditions.
33) The surface water aragonite saturation state (Omega arag) is shown for the pre-industrial ocean (nominal year 1765), and years 1994, 2050, and 2100 being a scenario for the World oceans. _arag describes the availability of carbonate ions for shell construction. In regions where _arag is >1.0, the formation of shells and skeletons is favoured. For values <1.0, seawater is corrosive to $CaCO_3$ and, in the absence of protective mechanisms dissolution will begin. The scenarios show that in the Southern Ocean aragonite saturation will become critically low from 2050 onwards.
34) Pteropods may become extinct in Antarctic waters due to ocean acidification 2050 to 2100. Pteropods occur in the upper 300 m They be more abundant than krill with densities of 105m-3 in the Ross Sea Pteropods are accounting for large amounts of the annual export flux of CO_3^{2-} and organic C. South of the Polar Front they dominate the export flux of $CaCO_3$. They are an important member of the food web being the food of carnivorous zooplankton, fish (myctophids & nototheniids) and other zooplankton, e.g. gymnosome pteropods.
35) Like many phytoplankters, coccolithophorids can form immense blooms. When the coccoliths from these blooms settle down to the ocean floor, they create thick deposits, which, through geological processes, form chalk. The famous white cliffs of Dover, UK, are the result of coccolithophorid blooms and coccolith deposits (Wikipedia).
36) CO_2 influences also the physiology of marine organisms as well through acid-base imbalance and reduced oxygen transport capacity. The few studies at relevant pCO_2 levels impede our ability to predict future impacts on foodweb dynamics and other ecosystem processes. Research into the impacts of high concentrations of CO_2 in the oceans is in its infancy and needs to be developed rapidly. A major, internationally coordinated effort be launched to include global monitoring, experimental, mesocosm and field studies. Models that include the effects of pH at the scale of the organism and the ecosystem are also necessary. The impacts of ocean acidification are additional to, and may exacerbate, the effects of climate change. For this reason, the necessary funding should be additional and must not be diverted from research into climate change. (The Royal Society 2005, Ocean acidification due to increasing atmospheric carbon dioxide)
37) The routes for colonization have increased substantially recently thanks to human traffic to Antarctica, first by ship, and now by aircraft too. Thus, humans have introduced a wide range of alien, and in many cases invasive, species to Antarctica and the sub-Antarctic islands. These include microbes, algae, fungi, bryophytes, vascular plants, invertebrates, fish, birds and mammals. These species have come to survive, and in some cases dominate, terrestrial, freshwater, and marine habitats, and in the sub-Antarctic are causing considerable damage by way of local species extinctions and wholesale alteration of ecosystems. *IPY Aliens in Antarctica* is an international project sponsored by SCAR that will assess the pathways for transfer of propagules (seeds, spores, eggs), and the extent to which people from many nations unintentionally carry propagules of alien species into the Antarctic region. The project is based on an invasion model in which

there are 4 barriers in the process of invasive species colonisation: 1) transport barrier; 2) establishment barrier; 3) invasion barrier, 4) transformer barrier.

38) Pathways for alien species include:

- Marine traffic between ports and bays; introductions via fouled vessels, small boats (tourism and science)
- Transport of simpler life forms over terrestrial landscapes and inland waters such as isolated regions of the Dry Valleys or isolated nunataks, via hiking, surface vehicles, camping, sampling, air traffic.

SCAR and COMNAP are working pro-actively developing guidelines for shipping and land-based expeditions.

39) Evolution and Biodiversity in the Antarctic: The Response of Life to Change or EBA is an international, multidisciplinary programme that has been approved by the Scientific Committee on Antarctic Research (SCAR) for 2006 - 2013. EBA seeks to:

Understand the evolution and diversity of life in the Antarctic;

Determine how these have influenced the properties and dynamics of present Antarctic ecosystems and the Southern Ocean system;

Make predictions on how organisms and communities are responding and will respond to current and future environmental change; and

Identify EBA science outcomes that are relevant to conservation policy and communicate this science via the SCAR Antarctic Treaty System Committee.

SCAR Action Groups:

Census of Antarctic Marine Life (CAML): Antarctic marine biodiversity knowledge is patchy: benthic fauna of a few parts of the continental shelf and near-shore regions have been relatively well studied, as well as the biology of some pelagic species, such as Antarctic krill. For the most part, almost nothing is known about the mesopelagic, bathy/abysso-pelagic and deep-sea benthic fauna of the slopes and abyssal plains, nor about the tiny organisms (bacteria, archaea, eukarya, viruses, nanoplankton) in the sea wherever they occur and in whatever their habitats. Knowledge of life under the sea ice is, at best, fragmentary. Moreover, most of the existing biodiversity information is widely scattered, not easily accessible and sometimes vanishing, although the use of this information for scientific, monitoring, management, and conservation purposes could reach its utmost potential once the required data become highly available in digitised format through integrated information networks.

The SCAR-MarBIN (Marine Biodiversity Information Network) project aims at establishing and supporting a distributed system of interoperable databases, which will form a coordinated network, placed under the aegis of SCAR (Scientific Committee on Antarctic Research). SCAR-MarBIN will compile the existing information and manage new information by co-ordinating, supporting, completing and optimizing such database networking. SCAR-MarBIN will integrate these efforts in order to give a single and easy access to the marine biodiversity information and to maximize the exploitation of these resources. This network will leave a highly valuable legacy for future generations, in the form of a powerful information tool, which will provide a baseline reference for comparison with the future and past. In the framework of the IPY, SCAR-MarBIN will constitute the information component of the SCAR-Census of Antarctic Marine Life (CAML) (EoI 83), and the Antarctic node of the Ocean Biogeographic Information System (OBIS), the information component of the world-wide programme Census of Marine Life (CoML). CAML is a 5-year project that will focus the attention of the public on the Antarctic ice-bound oceans during the International Polar Year (IPY) in 2007/08. Its main objectives are to conduct a collaborative, large-scale survey of species diversity, abundance and distribution in the Southern Ocean, to study the evolution of life in Antarctic waters to determine how this has influenced the diversity of the present biota, and to use these observations to predict how it might respond to future change. Before starting new field censuses, it is however imperative to make widely available the existing information on Antarctic marine biodiversity, a task SCAR-MarBIN is intended to accomplish. By presenting and linking CAML and other related IPY projects' data resources, SCAR-MarBIN will allow the exploitation of data emerging from a matchless multi-scale investigation effort, which will lead to a comprehensive assessment and a better understanding of the actual diversity and status of Antarctic marine life.

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ANNEX 1: The SCAR Lecture Slides, in order of appearance.