Arctic Ecology: What does one need for a sustainable future?

Ian Lerche[1], Alice Newton[2], Björn Kjerfve[3] & Neil A. Bellefontaine[4]

[1]) Ian Lerche, Institut für Geowissenschaften und Geographie, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 3, 06120 Halle, Germany.

[2]) Alice Newton, NILU-CEE-Centre of Ecology and Economics, PO Box 100, 2027 Kjeller, Norway, IMAR-FCT, Gambelas Campus, University of Algarve, 8005-139 Faro, Portugal

[3]) Björn Kjerfve, Chancellor, American University of Sharjah, United Arab Emirates

[4]) Neil A. Bellefontaine, Vice President, Academic World Maritime University, S-20 124 Malmö, Sweden

Schlüsselworte: Arktis, Ökologie, Nachhaltigkeit
Keywords: Arctic, ecology, sustainability

Abstract

The future sustainable development of the Arctic region and its environmental protection require co-operation. Perhaps the greatest challenge is to balance the needs of the local population and the need to maintain the pristine nature of the region against the degradation caused by anthropogenic pressures. Here a short discussion is given of a future that allows both economic exploitation but, at the same time, holds the development in check by balancing all requirements to the overarching good of the whole.

1. Introduction

The seriousness of multiple facets of future and current development of the Arctic region (Fig. 1) and their intermeshing, overlapping and synthesis into an integrated sustainable whole cannot be understated but must be underscored.

A difficulty in trying to present such an holistic picture for the future is the scope of the problem. One has to try to present information on a global scale, involving individual nations and their approaches to what they deem as in their best individual national objectives and interests. One must also try to present an outline of what policies are most relevant with the hope that such assessments are as objective as possible and also with the hope that nations, acting together, will see the worth of such integrated development and so act accordingly. However, not wishing to usurp the sovereign rights of nations nor wishing to pre-empt the directions in which individual nations may plan their involvement in Arctic development either individually or collectively, this position paper deliberately refrains from discussing the behaviour of individual nations. While such a ploy may not please every reader, nevertheless inclusion of such a discussion would make for a very long article indeed and one that would defeat the purpose of presenting a general overview of integrated facets. For that reason such detailed discussions have been eschewed.

A second difficulty is to be aware of the extent of Arctic ice cap melting (Fig. 2) and variations in temperature and rainfall (Fig. 3) throughout the Arctic region as a whole because such influence the sort of development that should be undertaken. Indeed, not only such need to be considered but also the individual ports and routes that should be established for either commercial industries or tourist endeavours. A complete description of all such effects is a massive undertaken and one that would defeat the main purposes of this article, as listed above.

A third difficulty is that there are a myriad of possible strategic and methodological options available for sustainable management and to attempt to categorize even a sampling of such would again defeat the purpose

Fig. 1 The Arctic region. Courtesy of NOAA.

of providing an integrated overview of the various pros and cons that one has to face. Thus while it is appropriate to provide broad and generalized objectives that should be incorporated into a consistent whole, to go into more detail would require massive input from all the Arctic lands and users. Such detail is best left to future international agreements on what is appropriate to undertake as the development proceeds apace. Associated with this sort of problem is also the lack of knowledge, to varying degrees, of how various factors would synergistically interact in forcing new perceptions as time unfolds of mistakes made and corrections to be undertaken. Such a dynamic steering of the overall Arctic development comes only when specific plans are laid and undertaken so that one proceeds with the clear understanding that changes will be needed to achieve what one deems to be acceptable sustainable management. This sort of multi-nation steering requires very high level diplomatic agreements that can often be tricky to agree upon and even trickier to implement.

As a consequence of the above remarks this paper does not identify specific sites of interest in the Arctic (and also does not enter into the debate of to whom the specific sites are of interest and why).

The overall discussion presented here is focused mainly on a broad- brush approach, attempting to identify many of the conflicting and overlapping interests that arise. Therefore, one is attempting to impact policy in the Arctic development with the least amount of detailed “clutter” but with the maximum amount of scientific direction.

To what extent one is successful with such an article is likely to be seen at future meetings and conferences where individual nations collectively set their priorities for sustainable development of the Arctic region.

One analyses the conflicting nature of future resource use in the Arctic, for instance the interplay between fisheries, oil and gas extraction, transport, resource mining, and tourism. Success criteria for Arctic development are given in Table 1. These criteria consider

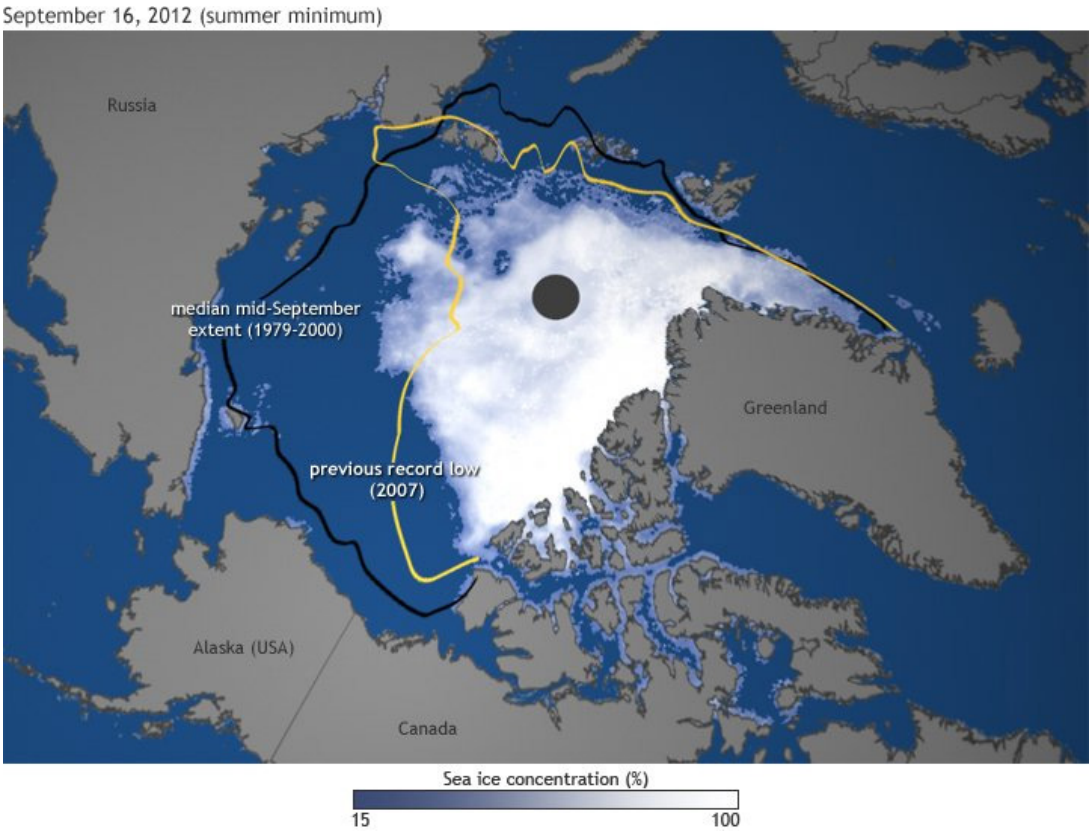

Fig. 2 Sea Ice changes with time over the last 30 years. Courtesy of NOAA.

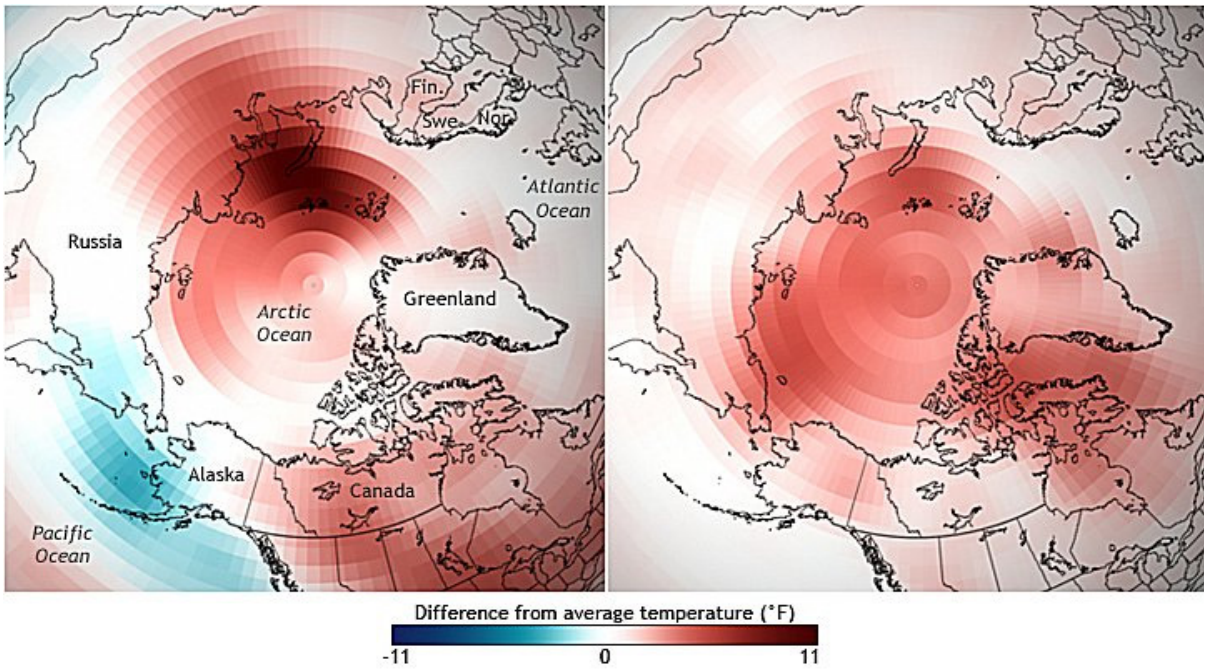

Fig. 3 Changes in temperature from 1970's (left panel) through to 2011 (right panel). Courtesy of NOAA.

Table 1 Arctic Development Criteria

Success criteria for Arctic development	Worst cases for Arctic development
The rich biotic resources of the Arctic, such as fish and shrimp, are exploited in a sustainable manner and so support a thriving fishing industry	The fish and biotic stocks of the Arctic are not managed in a dynamic way that considers climate change, and as a result they are overexploited and collapse.
The opening of maritime shipping routes through the Arctic Ocean provides opportunities for the development of the Arctic region. Container ports are built in strategic locations and provide sustainable employment for Arctic people.	The Arctic Ocean becomes a convenient short cut for maritime shipping. Ship emissions pollute the Arctic atmospheres. Ships dump garbage at sea. Oil tankers flush their tanks causing chronic oil pollution. Inadequate safety at sea results in acute incidents, as in the Exxon Valdez. Alien species are imported by ballast water.
The exploration and exploitation of abiotic resources, such as oil, natural gas, and other mineral resources, cause the least disturbance possible to the environment and the ecosystem, including fish and sea mammals.	Oil and gas exploration proceeds without considering noise pollution, upsetting both fish stocks and marine mammals. Mining proceeds without proper containment of mine tailings, and these leach into the environment.
Arctic tourism develops in a sensitive manner, respecting the environment and the local populations. The Arctic becomes a model of sustainable ecotourism and provides alternative employment for Arctic people.	Arctic tourism increases rapidly and overwhelms the infrastructure and environment. Ships compete for scarce berthing and mob the sights. Cruisers circle around wildlife, such as polar bears, like the 4x4 vehicles that signal the presence of a pride of lions in African safari parks. Arctic tourists that disembark tread on the fragile soils and buy cheap imitation curios made in factories far from the Arctic. Native people are dressed up in “original” costumes and “perform” to entertain the tourists.
The Arctic population has sustainable livelihoods including low unemployment, i.e. a maximum of 4%, which is considered to be the “natural” rate of unemployment. The development leads to new opportunities for the resident Arctic population.	The Arctic population loses the basis of its livelihood and does not possess the skills necessary for the new economic development. The Arctic is flooded with migrant workers who have no long-term residency or interest in Arctic conservation. There is a rise in the crime rate.
The Arctic population have an equitable distribution of wealth, that is no-one with less than half of the mean income of the rest of the population.	The Arctic population is polarised with rich climate entrepreneurs, “the winners”, and the poor who have lost their livelihoods and failed to adapt to the changing conditions. There is a rise in social unrest.

Table 1 Arctic Development Criteria

Success criteria for Arctic development	Worst cases for Arctic development
Economic development is robust. It is not vulnerable to a single fluctuating resource such as the natural fluctuations of a fish stock, or dependant on a single company, or a single activity such as oil extraction. The build-up of new and diverse business ventures has long-term objectives to provide economic sustainability. The economy is diverse, multi-sectoral and well integrated into the global macro-economy. Communities and settlement grow in a planned manner with the adequate infrastructure.	Investors from outside the Arctic region control the development with short-term gain as a priority and no interest in Arctic regional sustainability. Short-term gain opportunities lead to a cycle of boom and bust, as one resource is exhausted and another exploited. "Boom" towns spring and after an economic downturn are full of unemployed workers. Communities depend on a single activity or company for their livelihood and collapse when the company moves away or the resource is exhausted.
Appropriate governance structures are in place at all levels, from International conventions to local best practices. These ensure that the Arctic society develops into a law abiding community, living in a spirit of democracy and respecting human rights. Transparency and competition ensure that licensing is reasonable and fair.	Lack of suitable governance structures lead to bribery and corruption, lack of transparency, unfair licensing, cartels and monopolies, little respect for the law, human and democratic rights.
The geopolitics of the Arctic is stable and the Arctic Nations participate in joint governance of the Arctic and its resources.	There is an increase in geopolitical tensions in the Arctic region leading to a new "cold" war.

aspects that are fundamental to a desirable future. The well-being and health of people living in the High North depends not only on employment opportunities and adequate public service but also on the recognition of cultural characteristics, overall political participation and the utilisation of local knowledge in planning and policy development. The success criteria are aspects fundamental to a socially and environmentally viable Arctic future. Some of the contrasting "undesirable developments" for future Arctic sustainability are also presented in Table 1.

The historic evidence for the vulnerability of a society to the depletion of its resources is overwhelming (Helm & Hepburn 2009). Modern society has a great capacity to understand and document the process of resource degradation but struggles to develop the governance to reverse these trends, many of which are irreversible on human time-scales. The choice is stark: self-destruction or active reorganization. Reorganizing towards sustainability in the Arctic represents a challenge in its extent and complexity, but also presents a strong advantage in that experimentation and cooperation can be realized at a geopolitical scale.

The outcomes include a quantification of climate change impacts on economic sectors in the Arctic. To enable good policy-making and practical budgeting one needs to anticipate rather than react to the risks and costs of the environmental state-change in the Arctic Ocean.

Sustainable development is a major cross-cutting dimension of EU policies. The EU policy relevance to the Arctic includes the

Bird and Habitat directives, Agenda 21, Lisbon and Göteborg Strategies, Water Framework Directive, Sustainable Impact Directive, ICZM recommendations, the Maritime Strategy Directive and forthcoming ICZM directive. These policies interact with most other thematic or sector strategies (rural or urban development, resources management). A sustainable development framework in the Arctic Ocean must consider the need for better integration of scientific knowledge with policies at the most appropriate level.

Research needs to make sustainability a reality include:

- 1.To quantify and enhance knowledge of fish resources and fishery impact responses to climate change in key Arctic fishery regions, including primary production and the consequent fishery industry economic impacts, particularly at ice edges; to examine potential impacts of marine pollution from increased marine transport on Arctic fisheries and resources.
- 2. To examine and quantify economic/market opportunities from the opening of the Arctic sea routes for the shipping sector and for the socio-economic development of Arctic regions; to provide an improved knowledge base for marine transportation and routing in the Arctic, and including environmental impacts and responses to protect arctic marine ecosystems; to define requirements to ensure sufficient monitoring of environmental and other standards, and to draft concepts regarding monitoring and reporting procedures for vessel traffic in the Arctic considering maritime security, safety and protection of the environment and their potential impacts to the socio-economic development of the region; to assess the state of Arctic ports and infrastructure (i.e. stable roads, contingency planning, etc.) impacts of climate change (i.e. permafrost loss, wildlife migrations) on the socio-economic development of Arctic communities.
- 3. To assess and quantify the development of marine tourism (geographical, ecological and adventure), including evolving tourism activity driven by climate change and consequent marine safety and security risks in specific areas; and to investigate the maritime safety and environmental issues related to increased tourism cruise vessel activity and how emergency and environmental response capabilities will need to be enhanced.
- 4.To assess the potential economic growth areas for oil and gas development and potential linkages to existing/new arctic sea routes; to link the understanding of potential impacts to the arctic marine ecosystems of resource extraction (principally gas and oil) to baseline biological resources and an understanding of environmental and economic threats from shipping, of the risk of spreading invasive species and of petroleum hydrocarbons including PAHs, heavy metals, and potential conflicts/impacts with other sectors such as fisheries and tourism; and to assess potential local economic/community impacts of increased oil and gas vessel activity on marine mammals (i.e. noise/ship strikes), polar bears, arctic birds, and local marine ecosystems.
- 5. To develop an integrated GIS-based database to quantify the Arctic resources and national boundaries - not an easy task in view of conflicts which have already been identified (e.g. Denmark-Canada, Norway-Russia).

2. Research and Development Gaps

Knowledge is needed to strengthen international efforts that address climate change impacts and to inform policy directions and decision-making at the local community, national, European and international levels with respect to the sustainable development of the Arctic. Knowledge gaps include:

2.1 Fishery Resources and Fisheries

Evaluation of climate impacts on several key fishery resources and marine mammal populations, including vessel noise impact affecting their aggregation, distribution and movements, assessment of commercial fishery benefit gains/losses due to opening of the Arctic to increased fishing vessel activity (Fig

5) and potential reduction to traditional ice fish/mammal harvesting.

2.2 Maritime Transport in the Arctic

An economic assessment of the potential opportunities for the shipping sector in the Arctic and its potential impacts on the socio-economic development of the Arctic regions, a comparative study on legal aspects of vessel traffic in Arctic regions and comparisons with other regions (i.e. Antarctica), technical infrastructure and operational challenges in the Arctic, consideration of monitoring and reporting requirements, necessary amendments and modification to ensure maritime security, safety, protection of marine environment and monitor compliance with standards, and case studies to investigate existing and application of best operational practices. A study of training and educational needs and the conceptual design of maritime educational modules for crews operating in Arctic regions are necessary.

2.3 Tourism/Cruise

A survey and economic assessment on maritime requirements specifically arising from tourism and cruise activities in the Arctic. An economic assessment of the primary tourism interests in the Arctic and how such are shifting due to recent and on-going climate change (e.g. examination of Svalbard as a case model for cruise vessel tourism).

2.4 Port/Infrastructure

Assessment and quantification of current port infrastructure in the Arctic and identification of future needs, including a survey of port state control and flag state regimes to ensure maritime security/safety, environmental and socio-economic needs and requirements for Arctic ports, and including the capacity to address oil spills (preparedness and response) and the need for reception facilities.

2.5 Resource Extraction

Assessment and quantification of the expansion areas for the gas and oil industries and their transport linkages to new/old shipping routes, community/port infrastructure growth expectations with their potential environmental implications as well as for coal mining, and potential conflict areas with existing fisheries, hunting for marine mammals, and other traditional activities of local indigenous peoples.

2.6 Data Fusion

Integration of all sector data compiled into a GIS database of all sources of data, for example monthly sea ice coverage from available remote sensing sources, and including port infrastructure, commercial trans-Arctic shipping and traffic, fishing activities, and cruise ship operations, data, etc., and fused into an integrated database.

In order to achieve the overall objective, the thrust is to:

• Synthesize International Polar Year findings relevant to Arctic economic development,

• Make an analysis of climate change scenarios enabling Arctic development;

• Identify opportunities for the development of Arctic fisheries, maritime transport,

shipping and tourism;

• Develop a trans-sector quantification of Arctic economic development;

• Assess the environmental Impact of Arctic development;

• Develop guidelines for the protection and conservation of marine mammals in the context of Arctic development;

• Quantify the Arctic economic growth and vulnerability in the context of the global economy;

• Develop guidelines for social adaptation to climate change in the Arctic;

• Provide a roadmap for governance of the Arctic;

• Develop guidelines for deliberation and conflict management in Arctic development;

• Develop a strategy for adaptation to climate change in the Arctic;

• Construct a framework for ecosystem based management of the Arctic;

• Make an analysis of Arctic development in the context of policies, including opportunities and constraints;

• Provide recommendations for social stability and security of the Arctic.

NOTE: *Now follows a more in-depth look at each of the points summarized in this section. This repetition is deliberate so that one can obtain a more detailed idea of some of the many factors involved in each aspect of Arctic ecology. These descriptions run from section 3 through section 8 and can be skipped by those more interested in the summary list of needs for a sustainable future given in section 9.*

3. Maritime transport

Several factors control maritime transport including:

• Natural endowment, i.e. the availability of a good or service in one region, e.g. tea growth in China, such also includes relative labour costs;

• The relative and absolute price differences for goods in different parts of the world;

• The balance between supply and demand.

Costs have been decreasing as the design of ships has improved, but also because of the economy of scale from large cargos and the improved logistics in container ports. However, further reductions are possible because of shorter routes.

The three possible routes in the Arctic are the North East passage, along the coast of North Russia; the North West passage through the Canadian Arctic archipelago, and the transpolar route that cuts right across the Arctic Ocean. Of these, the North East passage is already practicable in the summer months in some years (2009), whereas the other two routes may become practicable in the future. The opening of the different routes benefits different regions, for example the North East passage would benefit principally the trade between Asia and Europe. Nevertheless, the use of the North East passage is conditioned by several factors that need investment, including:

• The number of ships in the cargo fleet that are fit for the purpose, i.e. with the necessary fetch and hull characteristics;

• Operational logistics such as the availability of icebreakers.

• Infrastructure such as adequate port facilities and rescue services.

The cooperation of the Russian government will be necessary for this route to be truly viable and to guarantee free and safe passage under International Maritime conventions.

4. Fisheries

The objective for Arctic Ocean fisheries is ecological sustainability, socially and economically. An increasing proportion of fish consumed in Europe is from aquaculture and the development of this activity in the Arctic (Fig. 4).

The Arctic economy relies on only a few commercial species, such as cod, herring, shrimp, and pollack. Climate change is expected to impact marine fishing in the Arctic Ocean in several ways. Changing temperatures will increase the stocks of some commercial species while reducing the stocks of others. Expected impacts may include: changes in stocks and species, alteration of migration routes, uncertain harvesting costs, and increased stock productivity.

Some species, such as cod, are shifting their migratory routes northwards, and new species are emerging in the north (e.g. mackerel, blue whiting). Fish stocks are sensitive to variations in temperature and the timing of phytoplankton blooms, and such may be aggravated as a result of changing climate conditions. In addition to bio-physical changes, expected impacts also include uncertain harvesting costs in terms of distance to fishing grounds, and new and different technologies.

At present, the Arctic Ocean fishery is dominated by large ships that bring the catch

Fig. 4 Typical coastal waters Arctic fishing boat. Courtesy of Norwegian Tourism Council.

of shrimp and fish back to distant ports, for example in Denmark or Norway, where the catch is processed and marketed.

There are major information gaps on fishing yield because of the unresolved issue of Illegal Unreported and Unregulated (IUU) fishing highlighting the need to examine options for future management within the wider context of ecosystem constraints integrating such into the wider marine socio-ecological system in order to investigate trade-offs and synergies with other legitimate uses of the Arctic Ocean, and environmental factors including climate change.

The capacity to sustain revenues and employment implies that high value predator species fisheries should be maintained through careful management and that the social dimension of fisheries as a source of employment should continue. This goal coincides with that of ecologists who have shown that high mortality of top predator species may lead to ‘trophic cascading’ that unbalances ecosystems and damages resilience and diversity. On the other hand, climate change is resulting in a northward movement of many stocks and it may not be possible to conserve the same top predator species when trying to achieve social and ecological goals.

The current management of fish is distinct from the management of their habitat, (often through the regional seas commissions and environment ministries or their equivalent). Management decisions on the marine environment are currently made on the basis of compliance with relevant regulations, voluntary targets and short-term economic considerations. There is a small element of collaborative goal setting and problem management, but such is usually confined to very small areas.

The concept of Ecosystem Based Management focuses on management, and recognition of the role of humans within present day ecosystems. One includes:

- Management objectives as societal choice;
- Management decentralised and multi-sectors;
- Appropriate temporal and spatial scale;
- Conservation of ecosystem function and resilience;

• Appropriate balance between conservation and use;

• Management within system limits;

• The outward vision (respect interconnectedness) and long-term vision (change is inevitable);

• Broad use of knowledge, scientific and traditional; and

• Incorporation of economic considerations (e.g. costs and benefits).

. Two aspects are emphasized in particular:

• the need for multidisciplinary science to support the implementation of EBM; and,

• the fact that nature is not stable; natural and global change must be understood and accommodated in any effective policy framework.

5. Resource Extraction

The Arctic Ocean and surrounding coasts are rich in abiotic resources (Fig. 5) including natural gas, oil and oil sands as well as methane hydrates. There is also a wealth of mineral resources, such as rare-earth minerals, lead, silver and uranium in Greenland; coal in Svalbard, diamonds in Alrosa (Russia), gold and mercury near Pevek (Russia). All are potentially important sources of pollution, as are mine tailings and climate change feedback from fossil fuels.

However, these resources are not distributed evenly across the Arctic region. Oil and gas fields have already been identified off Alaska, Russia, Norway and Greenland. Examples include the Shtokman natural gas field in the Barents Sea and the oil and gas fields of the Lofoten Islands. Nevertheless, exploration continues in the Arctic Ocean and generates conflicts with both the fishing industry, as in the case of the Lofoten Islands, and wildlife conservation especially of marine mammals.

The exploitation of these resources implies the development of infrastructure in the Arctic Ocean and also along the Arctic coast. Apart from the investment in infrastructure, the operational risks in Arctic waters are even greater than in other offshore exploitations.

There are also additional issues such as whether gas will be pipelined or whether Arctic industries will grow to use the resource in situ. The latter would make the region rich in cheap fossil fuel energy, as well as providing the potential of using hydropower from melt-

Fig. 5 Coal mining on Svalbard with attendant detritus. Courtesy of NOAA.

ing glaciers, and would support industrial development in the Arctic. Further research and technological developments are necessary to enable the economic exploitation of the enormous methane hydrate resources.

6. Tourism

What do Arctic tourists “seek”? And what do Arctic inhabitants gain from tourism? What about the perspective of the inhabitants of the Arctic? What about the local impacts of tourism? What is the benefit for social and cultural sustainability in the region and recipient communities? Tourism must not focus solely on the needs and requirements of the visitors, while ignoring the local inhabitants.

Most Arctic tourism occurs in the summer months when tourists benefit from the long daylight hours; the “midnight sun” or “white night” experience. There is a shorter winter season for which the main attractions are the Aurora borealis “Northern lights”, ice hotels, ice sculpture and Christmas tourism with visits to “Santa’s workshop” on reindeer sleighs.

The huge media focus on climate change issues and the plight of iconic species, such as polar bears, serves as an enormous publicity campaign for Arctic tourism. The Arctic Ocean and coast have different endowments with respect to tourist attractions. While some areas have spectacular ice-sheets and glaciers, polar bears (Fig. 6) and walruses, others have musk-ox, reindeer, geysers and volcanoes. Cetaceans, especially whales and narwhals (Figs 7 and 8), are an added attraction and, in some cases, whale watching may replace commercial whaling.

Archaeological sites, traditional lifestyles and crafts are an added attraction with dog sleighs and igloos being an attraction while seal and narwhal hunting are not, at least not for many visitors. While some tourists want to participate in activities such as sport fishing and reindeer hunting, many want to preserve the illusion of “Ecotourism” while avoiding any discomfort. Cruise tourism, as one form of marine tourism, is a favoured option (Fig. 9). However, very little money is then spent locally, mainly on curios (such as soapstone carvings) when a ship calls into port. The labour is also not local, as the crew accompanies the ship. The main requirement for cruise tourism is ports that can accommodate the huge cruise ships. Some tourists fly into the Arctic requiring a greater investment

Fig. 6 Habitat-threatened polar bear species as a consequence of sea ice shrinkage. Courtesy of NOAA.

Fig. 7 Narwhals as a tourist attraction.

Fig. 8 Whale watching as a tourist attraction, but whales are also slaughtered by certain Arctic countries. Courtesy of NOAA.

in infrastructure for airport, hotels and other land-based developments.

The WWF nature program has developed 10 principles of action and a code of conduct for Arctic tourism and infrastructure. Infrastructure for rescue operations is largely lacking and unfortunately incidents have already taken place, such as that of M/S Explorer off Antarctica in 2007.

Arctic economic development in the context of climate change may also affect the tourism sector. While tourists find the calving of icebergs from glaciers spectacular, the muddy runoff of melting permafrost is less attractive. Ugly cities in beauty spots that spring up after rapid urban development, such as Ushuaia (Tierra del Fuego, Argentina), are also unattractive to tourists. Grey, dirty snow, oil slicks, garbage and flotsam, mining activities and mine tailings all spoil the tourist illusion of the “pristine” Arctic as does red, blood-stained snow and water from hunting activities. Most of all tourists want to see and photograph their experience and Arctic fog is a problem that may become more pronounced as a result of climate change.

7. Trans-sector approach

Development of the 4 economic sectors focused on can become the source of trans-sector conflicts, such as with the exploitation of oil and or gas and on-going fisheries activity, or between tourism and industrial development.

The importance of fisheries in the Arctic Ocean has led to international conflicts. There is also the tension between the fisheries sector and conservation interests.

Guidance on conflict resolution should be an integral part of a wider mechanism for implementing adaptive management. Objective information on costs and benefits can assist but there is no ‘one size fits all’ for conflict resolution. Collaborative problem solving is one of the most promising techniques developed.

8. Issues of Scale:

Scales are important to consider. For example, if the global price of oil is so high that a distant fishing ground becomes unviable a local manager cannot address such an issue. Introduction of invasive species by ship ballast water has also to be considered.

Development of private companies in the Arctic will depend on four principal production factors: labour, capital, natural resources as well as management and entrepreneurial skills.

The availability and allocation may not be the same across the four economic sectors thus favouring the development of particular sectors. So, the allocation efficiency of the four production factors will determine the production efficiency of individual companies and sectors. Public investment will also be necessary to enable the initial development, for example by enabling the construction of better port facilities.

9. Sustainable Future Objectives

9.1 Fishery Resources and Fisheries

To quantify and enhance understanding of fishery resources and fishery impacts in response to climate change in key Arctic fishery regions, including primary production and the consequent fishery industry economic impacts, particularly at ice edges; to examine potential impacts on fisheries and resources from increased maritime activities in the Arctic.

9.2 Maritime Transport in the Arctic

To examine and quantify economic market opportunities from the opening of Arctic sea routes for shipping and its impact on the socio-economic development of Arctic regions; to provide an improved knowledge-base on marine transportation and routing in the Arctic, including environmental impacts and responses to protect Arctic marine ecosystems; and to develop concepts related to monitoring and reporting of procedures for vessel traffic in the Arctic, taking into account maritime se-

Fig. 9 Arctic tourist ship giving some idea of the sizes of tourist groups.

Fig. 10 The World Seed Bank on Svalbard to preserve as many sorts of seeds as possible in case of extinction. Courtesy of Norwegian Research Council.

curity, safety, and protection of the environment and the potential impacts of maritime transport on socio-economic development of the Arctic region.

9.3 Cruise/Tourism

To assess and quantify the development of marine tourism (geographical, ecological, and adventure) and cruise vessel activity in the Arctic (Fig. 9), including evolving tourism activity driven by climate change and consequent marine safety and security risks; and to investigate the maritime safety and environmental issues related to increased tourism and cruise vessel activity, and develop protocols for enhancement of emergency and environmental response capabilities.

9.4 Port/Infrastructure

To assess the state of Arctic ports and supporting infrastructure (i.e. stable roads, harbours, reception facilities, contingency planning), and the impacts of climate change (i.e. permafrost loss, sea level rise, wildlife migrations) on the socio-economic development of Arctic communities and peoples.

9.5 Resource Extraction

To assess economic growth areas for non-renewable resource (i.e. oil and gas) development and its potential linkages to both existing and new Arctic sea routes; to link resource extraction to potential impacts on Arctic marine ecosystems; to inventory biological resources needed for human sustenance. This aspect is partially addressed pragmatically by the Svalbard Food Bank (Fig.10) where seeds are held to ensure an ongoing supply in case of need. Quantify environmental and economic threats from shipping (i.e. the risk of spreading invasive species) and petroleum hydrocarbon exploration and extraction (i.e. polycyclic aromatic hydrocarbons, heavy metals), and potential conflicts/impacts on other maritime sectors; and to assess local economic/community impacts of increased oil and gas vessel activity on marine mammals (i.e. noise/ship strikes), polar bears, Arctic birds, and local marine ecosystems.

9.6 Data Synthesis

To develop an integrated GIS-based database for quantification, analysis, and synthesis of all data.

10. Conclusions

The overview provided here should act as a stimulus for those actively involved in Arctic ecology and sustainability. While much more could be said about the policies of nations and the desirability of controlling and limiting individual aspects of such Arctic development the authors are not the right people to address such issues because political involvement is not our metier. Suffice it to say that the basic principles and tenets laid out here on a scientific basis should serve as a blueprint for all future endeavours. As the years go by we will be curious to see to what extent our thinking is included in Arctic evolution and sustainability and to what extent unorganized and uncontrolled development takes place to the benefit of none but to the detriment of all.

11. Acknowledgements

The research leading to these results has received funding from the European Community's Sixth Framework Programme grant agreement 036992 (SPICOSA) and from the Seventh Framework Programme under grant agreement number 226675 (Know Seas). The SPICOSA and Know Seas projects are affiliated to LOICZ.

12. Literature Used

NOTE: *A seemingly infinite number of articles is available concerning Arctic sustainability, perhaps so serving to indicate the seriousness of issues involved. We list below a small sampling of such articles that we have found particularly helpful in writing the present paper. By a quick Internet search the reader can extend almost effortlessly the list enormously.*

ACIA 2005, Arctic Climate Impact Assessment. Cambridge University Press 1020 p.

Arctic Council, 2009, Human Health in the Arctic. Arctic Monitoring and Assessment

Programme (AMAP), Oslo.
Arctic Council, 2007, Arctic Oil and Gas Assessment. Arctic Monitoring and Assessment Programme (AMAP), Oslo.
Arctic Council, 2009, Arctic Marine Shipping Assessment 2009 Report. Protection of the Arctic Marine Environment (PAME), Akureyri.
Berkman, P.A., 2009, Arctic Ocean State-Changes: Self Interests or Common Interests. In: Alfredsson, G. Koivurova, T. and Leary, D.K. (eds). Yearbook of Polar Law. Volume 1. pp. 527-541.
Berkman, P.A., 2010, Environmental Security in the Arctic Ocean. Royal United Services Institute, Whitehall Paper
Berkman, P.A. & Young, O.R., 2009, Governance and Environmental Change in the Arctic Ocean. Science 324: 339-340.
Downing, T. E., Moss, S. & Pahl-Wostl, C., 2000, Understanding Climate Policy Using Participatory Agent-Based Social Simulation Proceedings of Multi Agent Based Simulation (MABS), Lecture Notes in Artificial Intelligence pp.198-213, Springer Verlag, Berlin.
Glomsrød, S. & Aslaksen, I., 2006, The Economy of the North. Statistical Analyses 84. Oslo: Statistics Norway.
Goosse,H.,Arzel,O.,Bitz,C.M.,deMontety, A., & Vancoppenolle, M., 2009, Increased variability of the Arctic summer ice extent in a warmer climate, Geophys. Res. Lett., 36, L23702, doi:10.1029/2009GL040546.
Helm, D., & Hepburn, C., 2009, The Economics and Politics of Climate Change, Oxford University Press, Oxford, 538 pp.
Hoel, A.H. (ed.), 2009, Best Practices in Ecosystem-based Oceans Management in the Arctic. Report Series No. 129.The Norwegian Polar Institute, Tromsø.
Holland, M. M., Bitz, C. M., & Tremblay, B., 2006, Future abrupt reductions in the summer Arctic sea ice, Geophys. Res. Lett., 33, L23503, doi:10.1029/2006GL028024.
Huntington,H.P.,2009,Apreliminaryassessment of threats to arctic marine mammals and their conservation in the coming decades. Marine Policy, 33 (1): 77-82.
Johansen, P., Pars, T., & Bjerregard, P., 2000, Lead, cadmium, mercury and selenium intake by Greenlanders from local marine food. Science of the Total Environment, 245: 187-194.
Kruse, J., Poppel, B., Abryutina, L., Duhaime, G., Martin, S., Poppel, M., Kruse, M., Ward, E., Cochran, P. & Hanna, V., 2008, Survey of Living Conditions in the Arctic, SLiCA. In: Møller, V., Huschka, D, & Michalos, A. C. (eds.): Barometers of Quality of Life around the Globe. Springer Social Indicators Research Series. Springer Verlag, Berlin.
Millennium Ecosystem Assessment, 2005, Ecosystems and Human Well Being: Synthesis. Island Press, Washington, D.C.
National Research Council, 2003,Cumulative environmental effects of oil and gas activities on Alaska’s North Slope. National Academies Press, Washington.
Peterson, C.H., 2001, The “Exxon Valdez” oil spill in Alaska: Acute, indirect and chronic effects on the ecosystem. Advances in Marine Biology, 39: 1-103.
Ridley, J., Lowe, J., Brierley, C. & Harris, G., 2007, Uncertainty in the sensitivity of Arctic sea ice to global warming in a perturbed parameter climate model ensemble, Geophys. Res. Lett., 34, L19704, doi:10.1029/2007GL031209.
Serreze, M.C., Holland, M.M. & Stroeve, J.C., 2007, Perspectives on the Arctic’s shrinking sea-ice cover. Science 315, 1533-1536.
UNESCO, 2009, Climate Change and Arctic Sustainable Development: Scientific, Social, Cultural and Educational Challenges. UNESCO, Paris.
Wang, M. & Overland, J.E., 2009, A sea ice free summer Arctic within 30 years? Geophysical Research Letters 36, L07502.
Wilkinson, A., 2009, Scenarios Practices: In Search of Theory, Journal of Futures Studies, February 2009, 13(3): 107 – 114.
Wilkinson, A.J. & Eidinow, E., 2008, Evolving practices in environmental scenarios: a new scenario typology, Environ. Res. Lett. 3 (2008) 045017.