3 Integrated assessment and response to Arctic coastal change

Following the thematic approach adopted in Chapter 2, this chapter introduces an alternative perspective, highlighting the need for integrated approaches to environmental and other changes in the Arctic coastal zone. There are four sections addressing the following topics:

- *integrated approaches to assessment of Arctic social-biophysical systems,*
- *monitoring, detecting, and modelling change,*
- *vulnerability, adaptive capacity, impacts and resilience, and*
- *the need for integrated governance mechanisms to support adaptation.*

3.1 Integrated Approaches to Coastal Change in the Arctic

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Key Findings

- Arctic coasts may be usefully viewed as complex social-ecological or social-biophysical systems. A social-ecological system is an ecological system intricately linked with and affected by one or more social systems and vice versa.
- The health of Arctic coastal and marine ecosystems is increasingly under pressure, putting at risk ecosystem goods and services that support coastal communities.
- There are major feedback loops in the Arctic system associated with rapid changes in the regional climate. For this reason, the impacts of climate change in the Arctic may extend to a global scale.
- There are two general approaches to more integrated understanding considered in this report:
  - Indigenous communities in general embrace holistic perspectives on the environment and culture.
  - The traditional scientific approach can be applied within a system science framework, with the application of integrated assessments to analyze the interactions in social-ecological systems, as outlined in the risk-based management approach.
- The holistic perspective of indigenous culture suggests that efforts to understand, manage, and respond to change in Arctic coastal systems may benefit from the integration and complementarity of both approaches. Recognizing the value of traditional ecological knowledge may contribute to enhanced resilience and adaptive capacity in coastal communities.

Climate change and expected increasing intensity of anthropogenic pressures such as oil and gas exploration and shipping along Arctic coastlines are generating significant environmental and societal effects. Climate change leads to changes in the physical environment, which then lead to changes in ecosystem conditions, thus affecting resource use and ecosystem goods and services. Thus, the health of Arctic coastal and marine ecosystems is increasingly under pressure, putting at risk ecosystem goods and services that support coastal communities. In the Arctic, both the ecosystem and coastal communities are potentially vulnerable to adverse environmental events. Adaptation of communities to these changes can in turn cause changes in community structures and social cohesion. For management and governance structures, this implies challenges, not only concerning local resource management, but in dealing with new economic sectors and tensions between local, national and global interests and needs.

3.1.1 Arctic coasts as complex social-ecological-physical systems

Much attention has been devoted to the impacts on coastal communities of shoreline erosion and sea-level rise (e.g. Johnson et al., 2003; ACIA, 2005; Manson et al., 2005a; Jones et al., 2008). Nickels et al. (2006) describe, from an Inuit perspective, observations of environmental change, with impacts on the way of life and behaviour for several Inuit communities (Fig. 33). Northern communities have much to lose, given their high dependence on goods and services provided by their local ecosystems. In addition to food and

OBSERVATION, IMPACT & ADAPTATION DIAGRAM FOR ALL REGIONS - UNPREDICTABLE WEATHER

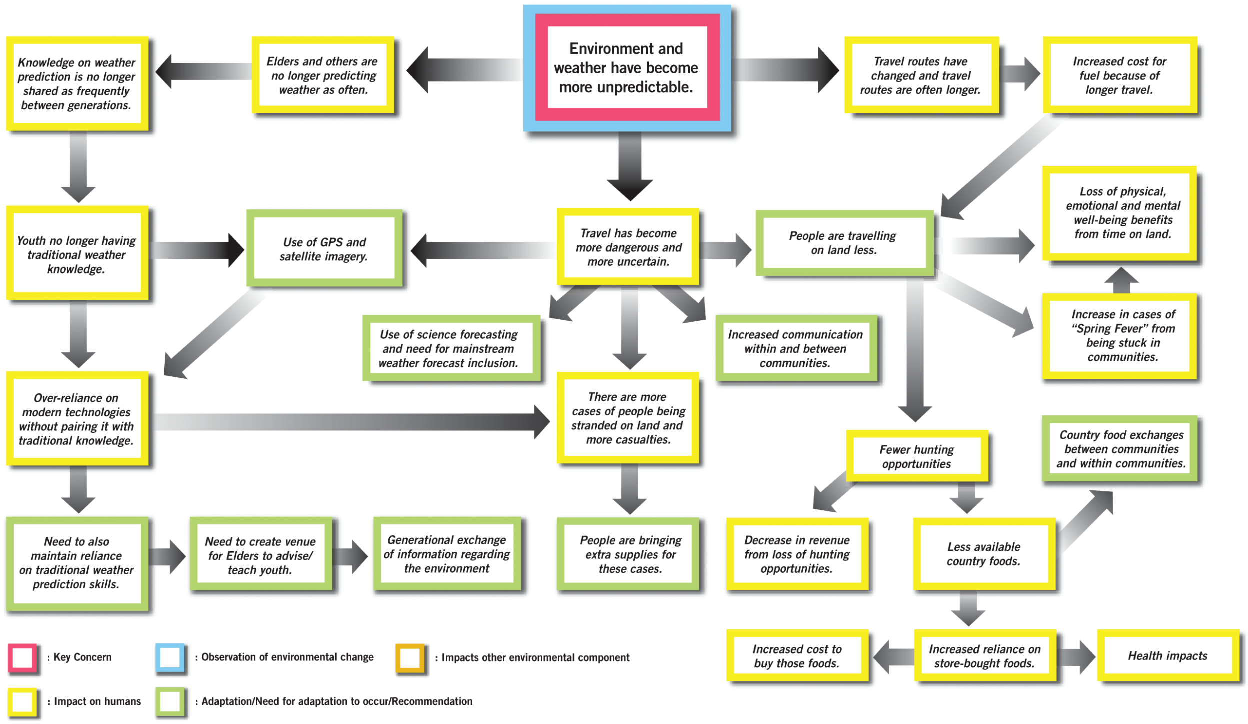

Figure 33. Observation, impact and adaptation diagram for Canadian Arctic regions.
Source: Nickels et al. (2006)

shelter, these goods and services are also tightly linked to the cultural and social fabric of the communities (e.g. Tremblay et al., 2006; Ford et al., 2009, 2010). Economically, ice-free Arctic waters in summer may facilitate increased commercial and industrial access to the Arctic, including petroleum exploration and transport, mining, general shipping, and tourism, but increased volume of traffic will also increase the risk of accidents and release of contaminants. Recognizing the potential for ice-free Arctic summers, two scenario exercises were recently implemented to consider the future of Arctic shipping (Norshipping, 2007; PAME, 2009a). Changing infrastructure needs in response to climate change and variability are widely anticipated (e.g. Canada NRTEE, 2009).

There are major feedback loops in the Arctic system associated with rapid changes in the regional climate. One example is the melting of snow and sea ice due to rising temperatures, which reduces the surface reflectance (albedo) and increases solar absorption, leading to further temperature increase (e.g. Cohen and Entekhabi, 2001; Wang et al., 2006; Zhang et al., 2008). Another example is thawing permafrost and the resulting gradual increase of methane emissions, which could contribute to acceleration of climate change (Lawrence and Slater, 2006; Schuur et al., 2008; Tarnocai, 2009). Due to such feedback loops, the impacts of climate change in the Arctic will not be restricted to local or regional scales, but will extend to the global scale as well.

These processes contribute to the characterization of Arctic coasts as complex social-ecological systems. A social-ecological system is an ecological system intricately linked with and affected by one or more social systems (Anderies et al 2004). Berkes and Folke (1998) used the term social-ecological system to emphasize the integrated concept of humans in nature and to stress that the delineation between social and ecological systems is artificial (Folke et al. 2005), an inherent perspective in holistic indigenous perceptions of the environment (e.g. Nickels et al. 2006; Sable et al., 2007; Huntington and Pungowiyi, 2009).

3.1.2 The need for an integrated approach to Arctic coastal change

As previous chapters have demonstrated, the conventional western science approach in recent years has considerably enhanced our understanding of processes in the Arctic. The strengths of conventional science include a detailed understanding of specific processes and the provision of quantitative assessments and models. On the other hand, the available data and specific knowledge from conventional disciplinary science cannot be readily translated into the understanding of complex system behaviour, and existing models cannot project the complexity of changes in social-ecological systems, including feedback loops between social and natural parts of complex systems (e.g. Janssen et al., 2003; Chapin et al., 2004; Norberg et al., 2008; Armitage et al., 2009; Huntington et al., 2007b). While disciplinary science can generate precise pictures of parts of the whole, a more generalist perspective can focus on the whole, although possibly with lower precision and higher uncertainty (Carpenter et al. 2009). The main problem is how to deal with missing information and uncertainty in the frame of traditional science and its models. Specifically, the conventional approach faces limitations when

- interactions between physical and biological processes need to be understood together for an assessment of ecosystem changes, often including dealing with missing information on specific system components and feedback loops;
- social issues need to be taken into account in order to understand impacts of ecosystem changes for human quality of life, specifically when different customs, values, needs, and cultures are involved;
- institutional issues need to be taken into account in order to understand decision-making and the criteria used by different groups, e.g. groups within indigenous communities or societies, government authorities at various levels, multinational corporations, or society at large;
- projections of changes are required in order to develop mechanisms and tools for adaptation to change including the problem of uncertainty and non-linear relationships.

On the other hand, an integrated approach aims to improve understanding of interactions at the system level in order to inform transparent and scientifically guided decision making. Therefore, integration has to build on results of disciplinary and multi-disciplinary research, but needs to put these results into a wider context. “To understand sustainability in social-ecological systems (SESs) we need to build a coherent understanding of how systems are progressively linked to ever larger systems and how upward and downward causation linkages occur within SES as well as across diverse sectors and scales” (Ostrom, 2008: 249).

Examples of integrated approaches at a global scale include the Millennium Ecosystem Assessment (UNEP, 2005, www.millenniumassessment.org) and the UNEP Global Environmental Outlook (UNEP, 2002). Both apply the DPSIR framework (Driver-Pressure-State-Response) (e.g. Turner et al., 1997; EEA, 1999; Bowen and Riley, 2003;

UNEP, 2005, 2007) to structure information and, like the IPCC, employ a scenario approach in order to frame potential future changes (UNEP, 2002, 2007). Even though the DPSIR framework does not allow full modelling of complex cause-effect chains, it seeks to connect causes (drivers and pressures) to environmental outcomes (states and impacts) and to activities (policies and decisions, response). The approach therefore provides a methodology to structure available information (and based on this, also indicators) into five categories: driving forces (drivers), pressure of use (pressure), a description of the status quo (state), the effects of pressure on that state (impact) and institutional options for taking action (response). Building on the DPSIR approach as well as ecosystem services, the accompanying box describes an analytical integrated risk-based decision-making approach currently under development in Canada.

For the Arctic, the Arctic Climate Impact Assessment (ACIA, 2005), commissioned by the Arctic Council, provides a comprehensive overview of climate-change impacts in Arctic regions including impacts on humans and indigenous societies. Nevertheless, the ACIA focuses on the Arctic as a whole and its subregions, but does not distinguish Arctic coastal areas with their specific pressures, changes and impacts. Other assessments commissioned by the Arctic Council such as the Oil and Gas Assessment focus on single sectors, again not elaborating on the specific vulnerabilities of Arctic coasts and coastal communities. Similarly, the Arctic Human Development Report (AHDR) provides a comprehensive overview of data and information related to human issues including economics, demographics, education and institutional regimes, but at rather broad scales and without looking into land-sea interactions.

An integrated approach to analyze the social-ecological systems of Arctic coasts needs to cover a range of interactions and issues such as

- interactions between physical and biological processes at global to local scales;
- land–sea interactions (e.g. river fluxes, resource use, cultural relations);
- forms of knowledge and information (scientific and traditional);
- timelines from past to present to future (monitoring, modelling, scenarios);
- interactions between ecosystems and humans (impacts on local communities, socio-economics at regional, national and global scales);
- the relations between system change, adaptation and governance structures.

There are two general approaches to more integrated understanding considered in this report:

- Indigenous people in general embrace holistic perspectives on the environment and culture.
- The traditional scientific approach can be applied within a system science framework, with the application of integrated assessments to analyze interactions in social-ecological systems, as outlined in the risk-based management approach (see accompanying box).

Analytical integrated risk-based decision-making

Roland Cormier

Conventional environmental assessments can only project the potential effects of a given project onto its local environment. Mitigation and control measures can then be implemented to reduce or eliminate effects. As development moves forward, the increasing number of projects eventually results in cumulative residual effects even though regional regulatory requirements and best management practices were adhered to. By design, project assessments are not effective at considering cumulative effects. An integrated approach is needed where the pressures of relevant land and aquatic based drivers are assessed as a whole against the vulnerabilities of ecosystem components. Using geo-spatial and temporal analysis, the severity and likelihood of the effects are assessed for each intersecting zone of influence occurring between drivers and components. Here, ecosystem components are valued in terms of their significant function within the ecosystem as well as the goods and services provided to the dependent communities. This level of integration ensures that all risks are considered equitably within a transparent decision-making process. It also facilitates priority setting where mitigation strategies can be developed for the components that are most at risk. A Community Viability Environmental Dependency (CVED) analysis provides the necessary integrated profile of the goods and services that are vulnerable to the drivers occurring within a geo-spatial and temporal unit (Fig. B3). The CVED establishes the pathways of effects between drivers, pressures, stressors of ecosystem health and impacts to goods and services and subsequent impacts to the dependent human activity.

In this discussion, an ecosystem component is considered to be the measurable or observable aspect of the biological, physical or chemical aquatic environment. In an Arctic context, goods and services are resources or processes of the ecosystem that sustain coastal communities. Goods can be considered as food, hunting ranges or ice links between landmasses while services are the natural processes of recycling and renewal. However, some components also have aesthetic and cultural significance. It is at this point of the discussion that values are attached to various ecosystem components. A valued ecosystem component (VEC) is considered as the environmental element of an ecosystem that is identified as having scientific, social, cultural, economic, historical, archaeological or aesthetic importance. A VEC may be determined on the basis of cultural ideals or scientific concern. In an integrated assessment, each VEC is considered on its merit equitably in line with the pathways of effect between the drivers of anthropogenic activities, the pressures caused by the drivers and the vulnerable ecosystem component.

Arctic communities are tightly linked to ecosystem goods and services for their well-being and prosperity. However, these goods and services need to be considered as more than the typical economic values of natural resources. Most of the goods and services have cultural and social values and are dependent on a variety of ecosystem components. In addition, these components are also tied to the geo-spatial and temporal changes of the northern seasons. Although climate change is perceived as having potential impact on the coastal zone resulting in the displacement of people, the impact will also have significant adverse effects on the valued ecosystem components that provide and support economic, cultural and social goods and services to these communities. The intensity of development in the Arctic is at an early stage, but Arctic ecosystems are vulnerable to environmental change. The Arctic will benefit greatly from such integrated assessment and planning.

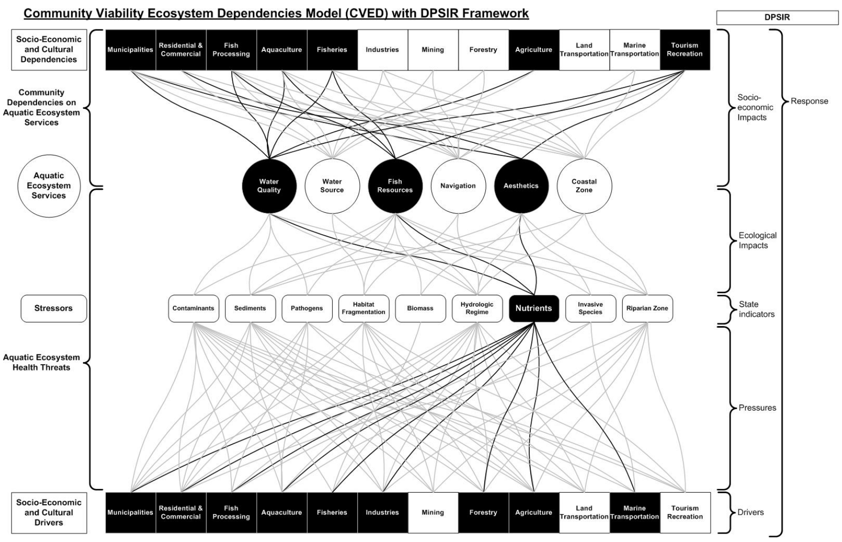

Figure B3. The Community Viability Dependencies Model for the example of impacts of nutrients.
Source: Roland Cormier, Canada Department of Fisheries and Oceans, Moncton

3.1.3 Combining western science and traditional knowledge for enhanced understanding of change

The western scientific tradition provides a powerful approach for understanding the natural world. It involves the testing of theory or hypotheses against objective observations and other data. However the questions asked, the hypotheses developed, and the observations collected inevitably (and often subconsciously) reflect the experience, knowledge, and perceptions of the researchers.

Traditional knowledge, or traditional ecological knowledge (TEK), reflects long-standing personal and cultural experience in a particular biophysical environment, providing insights from a large body of experience and observations (Fig. 34). "Inuit [or other northern indigenous] knowledge did not develop in a context requiring comparison with the parameters of science, but compares well when challenged with these parameters. Inuit knowledge is consensual, replicable, generalizable, incorporating, and to some extent experimental and predictive" (Bielawski, 1992, n.p.). Inuit knowledge has much in common with other traditional knowledge systems in that it is never divorced from moral or practical relevance (Overing, 1985; Bielawski, 1995).

Gearheard et al. (2006: 203) have noted that scientific and indigenous knowledge of sea ice is "generally in agreement or complementary …[but often reflect] different perspectives and emphases" such that drawing general conclusions about impacts may be difficult. *Inuit Qaujimajatuqangit* (IQ, an Inuktitut phrase roughly translating as 'Inuit way of knowing') has emerged over the past decade as an encapsulating term for Inuit TEK in the Canadian Arctic (Tester and Irniq, 2008). An important aspect of this is the recognition that the way in which northern peoples view animal-human relations (or relationship to the land) is as important as what is known (Wenzel, 2004).

Efforts to understand, manage, or respond to change in Arctic coastal systems may benefit from an effort to integrate these two ways of knowing (e.g. Gearheard et al., 2010). They may complement each other, in that TEK or IQ can provide not only a long-term perspective but an understanding of the connections between people and the coastal environment, while western scientific approaches can generate projections of future change in the context of a broader global scientific network and quantitative data analysis and modelling. While scientific knowledge might be better suited to assess future ecosystem changes, traditional knowledge helps to understand (and eventually enhance) the resilience and adaptive capacity of local communities.

Language is a critical component of culture and collective memory, thus it needs to be considered in the context of traditional knowledge. As noted in the box on SLiCA findings (Section 2.3.3), the Inuit language remains strong in Greenland and parts of the Eastern Canadian Arctic. In Canada, the 2006 census showed that 69% of Inuit across Canada had knowledge of an Inuit language, a reduction from 72% in 1996 (Gionet, 2008). The distribution of use was highly variable, with 99% and 91% Inuit speakers in Nunavik (Québec) and Nunavut, respectively, while only 27% retained knowledge of the Inuit language in Nunatsiavut (Labrador) and 20% in the Inuvialuit Settlement Region (ISR) (Northwest Territories). The overall conclusion of that study was that Inuktitut remains strong in Canada but is declining. Use of the indigenous language drops even further proceeding west from the ISR into Alaska and Chukotka (SLiCA box, Section 2.3.3).

Figure 34. King Island Iñupiat elders Gabriel and Edward Muktoyuk (centre and right) clarify place names on a map of King Island, Alaska, with Matt Ganley, an archaeologist, cartographer, and Vice President for Land and Resources with the Bering Straits Native Corporation.
Source: Deanna Kingston

In relation to cognition, language, and orientation, the speakers of Inuit languages use an orientation system that can be classified as a combination of an absolute and a landmark system (Levinson, 2003a). For example, the knowledge of wind directions and navigation in relation to the coastline has played a significant role in the traditional way of living (Levinson, 2003b; Gearheard et al., 2010). This can be considered an inherent part of the indigenous culture in the Arctic. The highly localized systems of demonstratives and the correlation between demonstratives and the natural terrain reflect indigenous knowledge of the surrounding area and highlight the indigenous sense of place.

Huntington et al. (2007a), from an analysis of five case studies in the Arctic, recognized that the answers obtained during surveys and workshops influenced the perception of the analyzed system. “The interactions between researchers and human subjects flow in both directions. For example, project goals must sometimes be modified in order to reflect participant input, insights, or expectations” (Huntington et al. 2007a: 182). On the other hand, seeking input and regular feedback from local leaders and residents helped broaden the research perspective, adding valuable knowledge and insights. They conclude from the example of Barrow (Alaska) that it “was evident early in the project that sound policies to reduce Barrow’s vulnerability must go beyond science to incorporate the profound uncertainties, the multiple values of the community, and the resources available. The primary role of the researchers was to bring a broader range of alternatives to the attention of community members to expand the range of informed choice. Some alternatives previously considered became more attractive to community members as the context evolved” (Huntington et al. 2007a: 182).

An emerging development over recent years has been the growth of partnerships and institutions to support the preservation, recognition, and sharing of traditional knowledge. This has ranged from local initiatives such as the Ittaq Heritage and Research Centre in Clyde River, Nunavut (www.ittaq.ca), to web-based, global-scale, data-sharing projects such as ELOKA (Huntington et al., 2008; McNeave et al., 2010; Pulsifer et al., 2010). Arctic-based or oriented centres of knowledge such as universities, cultural and research centres, as well as networks of local museums have evolved as champions and custodians of indigenous knowledge and have contributed to the strengthening of indigenous self-identity in the Arctic.

3.1.4 Integrating science into Arctic policy and decision-making

Integrated assessment approaches such as those described above typically aim to improve understanding of interactions at the system level in order to inform transparent and scientifically guided decision making. An integration effort is needed on one hand to build on results of disciplinary research, but on the other to put these results into a wider context. Specifically in complex unstructured problems for which the available knowledge is uncertain and stakeholders perceptions diverge, classical rational decision-making based on strictly scientific support has limitations (Hommes et al., 2009). While assessments with multidisciplinary perspectives might help to overcome barriers between scientific disciplines, their impact on future policy formulation is often more at a strategic level. Integrative analyses are by their design and nature better suited to trigger ideas and concepts into medium- and long-term policy processes than to provide short-term technical support. Their role is to stimulate debate about policy formulation. A range of barriers to various dimensions of integration exist at different policy levels, including dominating paradigms of development and institutional constraints (Turnpenny et al., 2008) (see Section 3.4).

3.2 Monitoring, Detecting and Modelling Coastal Change

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Contributing authors: E. Andreeva, J. Ford, A. Kannen, J.P.M. Syvitski, A. Yefimenko

Key Findings

- Reduction of negative impacts through adaptation to climate change requires new approaches in monitoring strategies to detect and track changes in the Arctic coastal environment. Understanding and prognosis of change is an essential component of resilience in Arctic coastal communities.
- Biophysical and human monitoring both clearly demonstrate that the Arctic environment is changing rapidly – sustained observation and monitoring is essential to document change and validate projections.
- Field-based monitoring in the Arctic coastal zone is challenged by remoteness, accessibility, communications, and instrument performance in extreme cold, but new survey technologies, instrumentation, and higher resolution of remotely sensed data are revolutionizing monitoring capabilities.
- These new techniques, decreasing costs, and higher resolution are enabling better spatial and temporal coverage of coastal change.
- Models represent key tools for understanding current changes and projecting future changes and associated impacts on Arctic coastal ecosystems and human communities.
- Models provide a means of interpolating between periods or locations of observation, a valuable capacity in times of reduced research and monitoring budgets.

Monitoring enables us to determine what changes are taking place in a system and how rapidly they are occurring. Only then can we begin to understand why they are taking place, what the implications are, and what measures may need to be taken to deal with them. In designing and developing coastal monitoring and observing programs, there is a need to consider several systems -- marine, terrestrial, and atmospheric – as well as their impacts on humans and how they are in turn impacted by humans. While Arctic coasts currently may be less affected by anthropogenic activities than their counterparts elsewhere, they can experience greater variation in environmental forcing due to the rapidity and scale of the climatic warming at high latitudes (IPCC, 2007a, 2007b). Monitoring is made more complex by the fact that observations are being made at the boundaries of the systems where interactions with other systems occur.

3.2.1 Monitoring and detecting biophysical Cchanges

Monitoring of biophysical parameters forms the basis of most observation programs because they are the ones which govern most other components of the coastal environment. A variety of monitoring strategies is required in order to capture changes in different elements of the systems, and at different temporal and spatial scales.

Data mining and re-analysis

In coastal monitoring, data collection is carried out in one of three ways: through data mining or re-analysis of existing databases, through direct field-based measurements, or by from analysis of remote-sensing imagery (Fig. 35). Because there is such a continuum in coastal studies, there is considerable overlap between disciplines and geographic areas. From a data gathering perspective, this means that information from existing monitoring activities or programmes can be utilized or refined to address questions directly related to coastal processes. Global and regional programmes collect data such as wind, air and water temperatures, currents, waves, tide and river levels, and sea ice concentrations. Information on phenomena such as storm events and wave energies can then be extracted and used in coastal process studies (e.g. Eid and Cardone 1992; Shaw et al. 1998; Hudak and Young 2002; Atkinson 2005; Manson and Solomon 2007). Currently, much of the data can be located through international or national operational agencies (e.g. WMO, NOAA), on portal web sites such as the Arctic Portal or the Ocean Portal, or downloaded directly from a number of thematic data centres (e.g. NSIDC, AMAP). Relevant data are also increasingly being aggregated by large regional projects such as the European-based DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies), the Canadian-based ArcticNet, and the U.S.-based SEARCH (Study of Environmental Arctic Change). Ultimately, Arctic data should be accessible through pan-Arctic integrated databases encompassing all fields of science. The scientific research community is putting considerable effort into ensuring that existing and future data are widely available, both through making the data as accessible as possible and ensuring that they comply with international metadata standards. Enhanced data access is an area that has been strongly emphasized recently by programmes such as the International Polar Year (IPY) which has generated and continues to generate large volumes of data. Given the interdisciplinary nature of coastal investigations, re-analysis of previously collected data will continue to play an important role in furthering research.

Field-based monitoring

Field based monitoring may involve the collection or inventory of physical samples such as water, sediment, or biota, or direct *in situ* measurement of the variables of interest, such as water temperatures or active layer thickness. Data may also be collected with the goal of ground-truthing remotely sensed observations. Coastal monitoring often involves mapping using remote sensing imagery or repeated ground surveys to determine changes in shoreline position and erosion rates (e.g. Mars and Houseknecht 2007; Aguirre et al. 2008; Forbes 1997; Lantuit and Pollard 2008; Jones et al., 2009a; Solomon 2005; Vasiliev et al., 2005; Ziaja et al., 2009). Recently the use of time-lapse photography has proven valuable in understanding the processes and quantifying rates of coastal change in the Arctic as well as in communicating with the public (Revkin, 2008; Carroll, 2009). Field efforts utilizing autonomous data collection methods such as these could be important in developing models of present and future coastal change. Field activities may also consist of observations of coastal thaw layer, permafrost and ground-ice conditions and shore-zone processes including nearshore dynamics, sediment transport and erosion processes, to help in understanding the dynamics of change. Because a primary goal of monitoring is to detect change, in most cases field measurements are undertaken at the same location, be it a research station, a community, or a specific site of interest. This makes it easier to ensure that there is good baseline data from previous studies. In certain situations however, it may be more suitable to make measurements in different

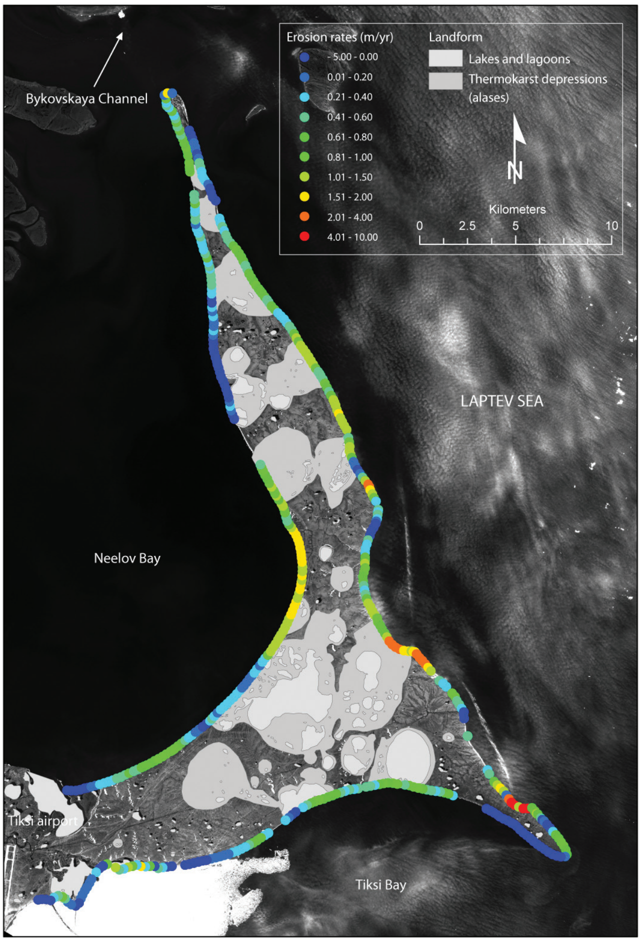

Figure 35. Monitoring of coastal erosion on the Bykovsky Peninsula, Russia, using remote-sensing data from 1951 to 2006.
Source: Hugues Lantuit, AWI

locations. This might be the case, for example, if the research goal is to compare the response of different shore types to a storm event (e.g. cliff vs. beach vs. marsh, or ice-rich vs. ice-poor sediments), or else to examine specific phenomena (such as ice-push events, algal blooms, or iceberg scouring) that do not necessarily occur in the same location. In an Arctic setting, factors taken into account in site selection are often quite different from those in other locations. Considerations can include the remoteness and accessibility of the site and the costs required to transport material and personnel there. This can change dramatically from season to season as conditions for air, land and sea travel are quite variable. These factors will often play a role in the sustainability of the observations over time. Personnel and equipment must be able to withstand the extremes of temperature. The dynamic nature of the coastal interface can have consequences for onshore instrumentation that may be eroded away, or nearshore equipment that can be crushed by ice. Additional challenges and opportunities are presented by variations in daylight length in the Arctic (i.e. solar power for equipment, period of time available for work, aircraft movements).

Remote sensing

Because of its remoteness and the sparseness of *in situ* observations, a particularly valuable tool for monitoring in the Arctic is remote sensing , from satellite, airborne, or surface-based platforms (Lantuit et al., 2010). However, the uptake and utility of remote sensing products can be limited for reasons such as weather, priority acquisitions, prohibitive costs or lack of processing capacity. Several recent initiatives have sought to help offset some of these difficulties, including a program of the European Space Agency (ESA) to provide free earth observation data to IPY projects, and a joint effort ('MORSE') of ESA and the Canadian Space Agency (CSA) to develop earth observation opportunities for monitoring specifically in Arctic coastal regions. The number and wide variety of sensors currently in operation or planned allows for the collection of most of the variables of interest to coastal research (UNESCO, 2006, 15-20), but coverage is not always available or at the desired temporal or spatial resolution. Examples of applications which have yet to be fully exploited in the Arctic include:

- interferometric synthetic aperture radar (InSAR) for coastal subsidence studies (e.g. Sharov et al., 2000; Forbes et al., 2007a);
- Jason-1 and replacement satellite altimetry for sea-level and storm-surge monitoring;
- SeaWIFS and MODIS for coastal productivity measurements (e.g. chlorophyll);
- ICESat laser altimetry for sea ice concentration and thickness;
- Aquarius/SAC-D for sea surface salinity;
- Terra-ASTER and other satellites providing land and sea surface temperatures;
- MODIS data enabling estimation of evapotranspiration;
- satellite-borne SSM/I instruments for measurement of daily rainfall;
- MODIS, SAR, and other sensors for sea ice, river ice, breakup, freeze-up, flooding and other observations.

Coastal change analyses using historical aerial photography and satellite imagery have been undertaken in various Arctic locations (e.g. Solomon, 2005; Manson et al., 2005a, 2005b; Mars and Houseknecht 2007; Lantuit and Pollard, 2005, 2008; Lantuit et al., 2008a; Jones et al., 2008, 2009b; Ziaja et al., 2009). Several space agencies and companies have increased their polar coverage during IPY so that a number of good baselines are being established for future work. Good spatial resolution is particularly important for detecting changes in shoreline position, which can be <1 m/a, or in immediate nearshore areas where conditions within one pixel can be quite variable. Another challenge to such studies is the look-angle of the sensor, because shadows or high coastal cliffs can obscure the land-water interface. With optical sensors, 24-hour darkness in winter or a snow cover can make it difficult to distinguish the terrestrial-marine boundary, and strong temperature gradients between land and water during open water periods mean that clouds often obscure the coastline. Technologies such as topographic and bathymetric LiDAR provide new opportunities for rapid, timely, and extensive observation and quantification of many aspects of coastal systems. Innovative applications of existing remote sensing technology can also yield additional information; an example is the use of synthetic aperture radar imagery to detect bottomfast ice and incidentally glean data on water depth and bathymetry (e.g. Hirose et al., 2008; Solomon et al., 2008a, 2008b; Stevens et al., 2008).

3.2.2 Monitoring change in human communities and populations

The challenge of monitoring and change detection in the Arctic has traditionally rested with the biophysical sciences, building upon a long tradition of studies focusing on sea ice conditions, permafrost, atmospheric conditions, marine and terrestrial biology, toxicology, and hazard assessment.

While many early studies sought to provide information on changing conditions relevant to government, institutional, and community decision making, the majority of this work has been driven by a scientific agenda with the purpose of advancing scientific understanding. This research has significantly increased our knowledge of how the Arctic is changing and improved our understanding of susceptibility of biophysical systems to climate change, but its relevance to decision making has been challenged by both the scientific community and policy makers (Duerden, 2004; Ford et al., 2008a; Pearce et al., 2009; Smit et al., 2008; Gearheard and Shirley, 2007; NTI, 2001, 2005; Riewe and Oakes, 2006). In this context, biophysical change assessments and monitoring are increasingly focused on biophysical conditions and systems of relevance to community, government, and industrial stakeholders. Major research projects have actively worked with stakeholders to identify relevant biophysical conditions which need to be monitored. It is noteworthy that many such initiatives are still led and directed by scientists and scientific objectives, but aim to focus on concerns identified by Arctic inhabitants (e.g. Forbes et al., 2007b). This 'applied' research complements the 'pure science' research which remains a major feature of research programs and research publications.

Community-based monitoring

Residents of Arctic communities are the first to register the changes in their habitats due to environmental change (Figs. 34 and 36). Indeed, the alteration of the environment implies changes to the conditions in which traditional use of the surrounding environment have been performed for years. The behaviour and availability of wildlife, the seasonal activity and the subsistence strategies are all dramatically impacted by the changing environment. As climate change has emerged as a major issue affecting Arctic inhabitants there has been a corresponding increase in research initiatives and projects engaging community members to detect and monitor change. This trend is driven by scientific, ethical, and regulation trends (Pearce et al., 2009), and involves Arctic inhabitants in three main ways: Arctic inhabitants and stakeholders as research assistants; local people as sources of information; and community/stakeholder-led research.

Figure 36. School children in Ilulissat, Greenland
Source: Vincentvan Zeijst

The most common situation in which communities are engaged in monitoring and change detection is through measuring changes in the Arctic environment (e.g. measuring sea ice characteristics, seal monitoring, surveying etc.). In this context, community engagement often takes the form of hiring and training local people as field researchers. It may also include involving local people as informants, interpreters, guides, and research partners. Though a standard and essential practice in research for many years, the employment of locals as research assistants has often failed, however, to integrate local and traditional knowledge into project formulation and interpretation and analysis of the information collected (Laidler, 2006, Pearce et al., 2006; Gearheard and Shirley, 2007). It also does not guarantee that the conclusions drawn from the research will reflect local involvement.

Secondly, communities are increasingly being engaged to share traditional and local knowledge to identify and characterize changing biophysical conditions. These studies have used participatory research methods including community workshops, semi-structured interviews, focus groups, mapping, stakeholder meetings, and guided trips on the land/sea-ice, to enhance knowledge on how the Arctic is changing. In particular, this work has sought to improve the spatial and temporal resolution of change detection which is often constrained in studies of instrumental datasets, which are spatially and temporally coarse in resolution (Riedlinger and Berkes, 2001; Berkes and Jolly, 2002; Gearheard et al., 2006; Laidler, 2006; Laidler et al., 2008; Catto and Parewick, 2008).

Initial efforts to engage local and traditional knowledge in Arctic change detection took place in a North American context, where indigenous peoples have been engaged in co-management of resources and the settlement of land claims for decades, and have taken an active role in shaping the research agenda. Many of the early studies in this regard involved collaborations between indigenous peoples' organizations and scientists, including: "Voices from the Bay" (McDonald et al., 1997) which documented traditional knowledge of Hudson Bay Inuit and Cree on biophysical changes; the International Institute for Sustainable Development's "Inuit Observations on Climate Change" (IISD, 2001), one of the first projects to explicitly obtain traditional knowledge on a changing climate; and "Uikkaaqatigiit" (Nickels et al., 2006), a project documenting Inuit observations on climate change from 17 Inuit communities in Canada. With increasing acceptance of traditional and local knowledge as a valid and meaningful source of knowledge for climate change detection and characterization, recent years have seen a proliferation of scientific research with indigenous and non-indigenous communities across the Arctic (Krupnik and Jolly, 2002; Fox, 2004; George et al., 2004; Norton and Gaylord, 2004; Pearce, 2005; Ford, 2006a, 2006b; Laidler, 2006; Meier et al., 2006; Riewe and Oakes, 2006; Tyler et al., 2006; Berkes et al., 2007; Gearheard and Shirley, 2007; Huntington et al., 2007a, 2009a, 2009b; Woo et al., 2007; Carmack and Macdonald, 2008; Crate, 2008; Ford, 2008a; Ford et al., 2008b; Keskitalo, 2008a, 2008b; Laidler and Elee, 2007; Laidler and Ikummaq, 2008; Laidler et al., 2008, 2009; Lipovsky and Yoshikawa, 2008). Over the last decade indeed, Arctic residents and indigenous peoples have participated in community-based monitoring involving traditional knowledge throughout the Arctic coastal rim and made significant contributions to the understanding of recent environmental change (Huntington et al., 2007a, 2009b). During the International Polar Year, the main goals of community-based monitoring were formulated and launched in 2007 within the framework of the international project ELOKA (Exchange for Local Observations and Knowledge of the Arctic). ELOKA was started in the Canadian communities on Hudson Bay and Baffin Island and in Greenland, and expanded to include other Arctic areas (Huntington et al., 2008). In Russia, community-based monitoring using local and traditional knowledge is now starting in the Murmansk region, in the Yamal-Nenets Autonomous Okrug, and in the eastern coastal zone of the Chukotka peninsula. This work has significantly improved our understanding of how the Arctic is changing, has figured in the ACIA and IPCC AR4 (ACIA, 2005; IPCC, 2007b), is important in national / regional climate change assessments and projects (Lemmen et al., 2008; ArcticNet; HARC; BALANCE; Lange, 2008), and forms the basis of many projects being conducted as part of the International Polar Year.

Notwithstanding progress made in recent years in involving communities in detecting change, traditional and local knowledge in many instances is treated as one source of data contributing to western scientific research with minimal local involvement in other aspects of the research such as topic selection, interpretation and application (Pearce et al., 2009). In other cases, community engagement is limited to meetings in which scientific information is shared and feedback sought from local representatives. This has resulted in the emergence of a third way in which communities are being engaged in change detection and monitoring: community-led or -driven research, where communities identify research questions and hypotheses. In these projects, scientists may be involved but at the request of communities and on their terms. Examples of community led projects are limited, a notable exception being the book "Watching Weather Our Way" (Oozeva et al., 2004), a collaboration between Yupik communities in Alaska and northern scholars to document changing biophysical environments. There are, however, an increasing number of projects being led by communities, including IPY projects, and funding agencies and governments are increasingly viewing community-led research as an important component of future research endeavours (e.g. Kelman and van Dam, 2008). Initiatives are also underway to allow communities to communicate changing conditions to the global community through the internet (e.g. the "Many Strong Voices" initiative; Crump, 2008).

Health monitoring

Several studies have been conducted under the umbrella of the Arctic Human Health Initiative (AHHI), an IPY Fully Endorsed Program that focuses on human health concerns of Arctic peoples. AMAP (2009a) provided an overview of human health in the Arctic. However, the information base remains inadequate and Krümmel (2009) highlighted the vital need for Inuit-specific (and, by extension, other population-specific) health data as a foundation for the development of culturally relevant action plans.

People living and working in Arctic areas, including coastal communities, face a wide range of health issues (Hild, 1995). Work and survival at high latitudes present challenges to human physiology and all Arctic residents are impacted by long-term exposure to challenging climatic conditions (Furgal and Séguin, 2006; Furgal et al., 2008a, 2008b). Along with low temperatures, seasonal extremes of ultra-violet radiation, and variability of polarized electro-magnetic fields (Chernouss et al., 2001; Cherry, 2002), human-sourced contaminants are a major concern (Kraemer et al., 2005). Many originating outside the Arctic, these are concentrated in upper food-web marine and terrestrial species consumed by residents of Arctic coasts (e.g. Polder et al., 2003). Social, cultural, technological and economic changes imposed from outside over several centuries and particularly over the past 100 years have had severe consequences on the health of Arctic residents. Infectious diseases caused massive mortality in previously unexposed indigenous communities after first contact with Europeans, but no longer pose such a threat. Nevertheless, the incidence of infectious disease remains anomalously high in Arctic indigenous populations (Parkinson, 2008), while chronic diseases (e.g. diabetes, cardiovascular disease, tuberculosis) are on the rise, combined with high levels of accidents, violence, substance abuse, and suicides (Bjerregaard et al., 2004). Krümmel (2009) has summarized some of the "stark differences" in health indicators between Inuit and national averages in the circumpolar region, in terms of life expectancy, infant mortality, suicides, and disease.

Changes in climate and the biophysical environment may lead to physical and psychological stress (Young and Bjerregaard, 2008). Currently emerging climatic change is associated with a number of negative impacts on human health, including potential outbreaks of new insect-borne diseases during warmer summers, as well as enteric and other infections (Parkinson and Butler, 2005). Small communities on Arctic coasts also face problems related to food preservation and access to clean drinking water as a result of changing temperature regimes, thawing of permafrost and, in some places, the resultant exposure of dangerous buried wastes. Arctic areas that are likely to be potential hot spots for infection and disease may require greater access to medical services, including laboratory facilities for detecting any changes in environment related to health. Efforts to build social, cultural and economic resilience to climate change may have positive effects on social cohesion and support with resulting health benefits (e.g. Richmond et al., 2007; Richmond, 2009). Nevertheless severe challenges remain in the small remote communities of the Arctic. Documentation of health issues from local residents' perspective is an important recent development (e.g. Bird et al., 2008, 2009).

3.2.3 Integration of monitoring strategies in local to global scale frameworks

The importance of Arctic coastal observing was recognized early at national levels, albeit in very different fashions in the various countries along the Arctic coastal rim. In Russia, coastal investigations and monitoring essentially started with the inception of the Northern Sea Route Department (*Glavservmorput*) in 1932. This provided a structure for organized integration across all branches involved in the economic development of the Arctic coastal zone, resulting in a progressive and unique top-down and integrated coastal management system. This system was later abandoned to favor a more traditional organization around state departments focused on industrial needs (Andreeva, 1998). The current monitoring system on Russian coasts is a result of later fragmentation and involves state departments, federal agencies and research institutes. Recent efforts to develop effective integrated coastal area management are progressively being turned into laws which should help define a framework compatible with international management norms and standards and avoid conflicts between relevant stakeholders (Andreeva et al., 2003). Nevertheless, the early heavy utilization of the Russian coastal zone prompted considerable scientific investigation which provided the background and unique long-term datasets for today's monitoring of coastal biophysical processes (e.g. Vasiliev et al., 2005). However social and environmental issues were secondary to industry objectives during Soviet times and have only recently begun to be integrated into the Russian coastal framework (Andreeva, 1998; Andreeva et al., 2003). A pioneering program, Land-Ocean Interactions in the Russian Arctic (LOIRA), was initiated at the end of the 1990s to integrate and study these issues (IASC, 2000). More recently, in accordance with the national "Strategic Plan of Action in the Russian Arctic" elaborated in 2007, the task of establishing social-ecological monitoring networks in Arctic communities is planned to be completed by 2012.

In the USA, the Arctic coast is entirely located in Alaska. The state has been conferred with wide-ranging powers and duties that relate to the implementation of federal laws or the development, implementation and enforcement of coastal management strategies. Up until the second half of the twentieth century, the use of the coastal zone was focused on local and regional economic needs with little consideration for hazard planning (Mason, 1997). In 1977, however, the Alaska State Legislature created the Alaska Coastal Management Program (ACMP) in response to the federal Coastal Zone Management Act (CZMA). It prompted the elaboration of planning documents in 33 coastal districts in a participatory fashion, involving and greatly empowering local communities in the decision making process (Mason, 1997). Coastal monitoring efforts stem from these plans and today involve a series of actors from the state and federal administrations as well as universities and private industry, with the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) at the forefront of biophysical monitoring in the coastal zone (e.g. Jordan et al., 2008; Jones et al., 2008). The recent changes in the ability of coastal districts to enforce integrated strategies at the local level will most likely impact the way local communities are involved in the process, and may also transform coastal area management from a merely environment-protecting approach to one of natural resource management, involving a very large suite of stakeholders.

In Canada, several federal government departments have mandates that relate to coastal management with no one department being responsible for all aspects of managing the coastal zone. However, the Department of Fisheries and Oceans (DFO) is the lead agency (Muir, 2001). Environment Canada (EC) also has a role in the management of coastal areas in preserving water resources and ecosystems. Provincial and territorial authority for integrated management is limited to coastal features, such as the intertidal zone, dunes, salt marshes, mud flats and estuaries (Muir, 2001). However, there is no single provincial or territorial department that is solely responsible for managing these areas. Land claim agreements between the federal government and the Inuit, the Inuvialuit and other indigenous groups are superimposed on this constitutional division of powers. Consequently, these agreements have established separate regimes for the management of coastal wildlife, environment and resources. Despite this detrimental fragmentation of powers and mandates in the coastal zone, Canada has rapidly implemented pioneering programs in Arctic coastal monitoring and management. The Geological Survey of Canada (GSC) program is a prime example, despite being limited to biophysical and engineering issues (Prior and Pickrill, 1997). In this framework, survey work was undertaken at 282 Arctic coastal sites established at various times between 1912 and 2007, but the coastal monitoring program is not currently funded as a distinct activity. The Tuktoyaktuk Declaration (2006) called for the establishment of a northern coastal zone organization to strengthen the capacity for integrated management in the Canadian Arctic.

Scandinavia formalized coastal management and coastal monitoring early on, following on centuries of industrial and economic use of the coast. In Norway, the Integrated Management Plan for the Lofoten and Barents Sea areas calls for protection of the environment and regulation of fisheries and shipping in a zone starting one nautical mile off the coast (Olsen et al., 2007). The rest of the coastal zone is covered by the EU Water Framework Directive (2000) which focuses on coastal waters and coastal biodiversity. Several institutions are active in conducting monitoring in the coastal zone, notably the Institute of Marine Research and its Coastal Zone Ecosystem Programme, or the State Pollution Control Authority and its Norwegian Coastal Monitoring Programme, although the human aspects of the coastal zone are often subordinate to the physical system. In Greenland, integrated coastal zone management (ICZM) is virtually non-existent. However, the level of integration of the biophysical and human realms is probably greater than in other parts of the circum-Arctic, owing to the small size of the communities, the relatively homogeneous socio-economic framework, primarily organized around coastal resources, and the historical perception of the coastal zone as a holistic realm. A changing political and legal framework combined with greater interaction with aboriginal organizations from neighbouring countries could form the basis for future joint activities in the field of coastal monitoring, in particular in relation to its traditional knowledge dimension.

Coastal area management in the Arctic has historically not been embedded into regional frameworks, national borders often being hermetic to foreign insight, both for economic and sovereignty reasons. Integrated integrated coastal monitoring efforts at regional scale do not (yet) exist in the Arctic, but strong signs of cross-border environmental policy integration may lay the groundwork for future regional ICZM systems. The Norwegian and Russian co-operation for management of fish stocks in the Barents Sea and the North Atlantic Marine Mammal Commission, for example, have paved the way for what could be wider and more advanced co-management in the Arctic. The indigenous peoples' organizations of the North will likely play a prominent role in developing a regional understanding of coastal issues and in organizing coastal monitoring, making use and leading integration of traditional knowledge and western-type science. National borders are a reality, but the promising signs of integration of the Inuit nation across four different countries could show the lead for a greater level of integration.

At the international level, ICZM and coastal monitoring are directed and framed by a long series of UN agreements, by international organizations, as well as by a series of bottom-up research initiatives, the latter having recently been catalyzed in the Arctic during the IPY (2007-2008). Biophysical monitoring and coastal process studies are, for instance promoted and coordinated by the Arctic Coastal Dynamics (ACD project (Couture and Overduin, 2008), an international bottom-up initiative that initiated the Arctic Circumpolar Coastal Observatory Network (ACCOnet). ACCOnet is intended to encompass both the biophysical and socio-economical dimensions of changes in the coastal zone and to study those at 'observatory' sites spread along the Arctic coast. Although the ACCOnet network is not fully in place, many of the sites are based on ACD key sites where observations and monitoring have been ongoing for a number of years or decades. Some sites are actual physical observatories, but in many cases, they represent observation programs that are maintained by the dedication of individual researchers. These initiatives have gained international recognition through the sponsorship of international organizations, but remained largely unconnected to global coastal initiatives.

At the global scale, coastal monitoring and coastal studies are covered by three main entities: Land-Ocean Interactions in the Coastal Zone (LOICZ), a core project of the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP); the Coastal Global Terrestrial Observing System (C-GTOS) (Fig. 37); and the upcoming coastal module of the Global Ocean Observing System (GOOS). Implementation strategies for the coastal modules of these programmes detail the most important data parameters needed by

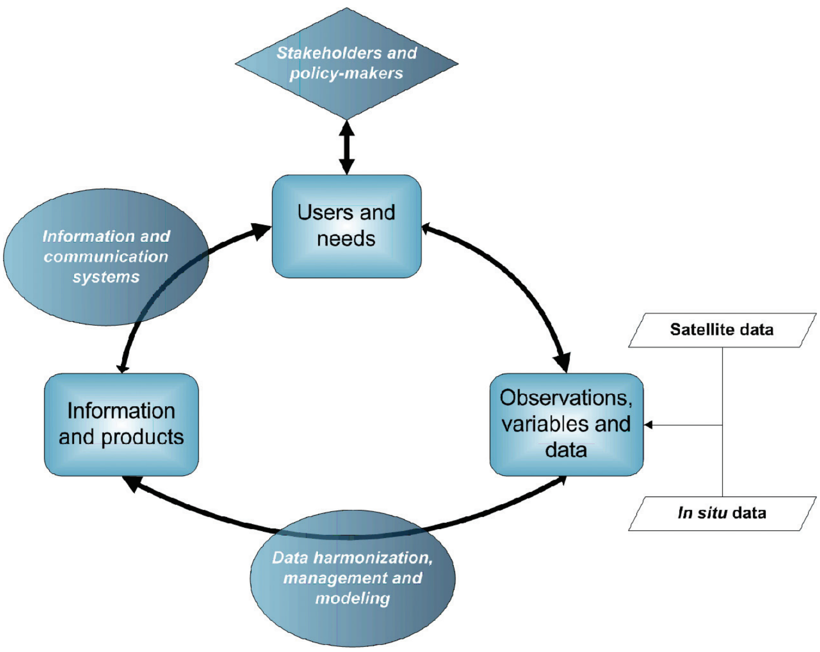

Figure 37. The structure of the Coastal Global Terrestrial Observing System (C-GTOS) includes observations, variables and data, which are transformed into information and products to provide for users and their needs. In turn, users and their needs provide feedback influencing the further development of observations, variables and data. Source: Christian et al. (2005)

users, as well as recommendations on the desired temporal and spatial resolutions and measurement accuracies (UNESCO, 2005, 2006; Christian et al., 2005). Examples include geophysical data such as surface temperature, wind speed and direction, waves, and sea level, as well as biological or biochemical data such as particulate and dissolved matter, nutrients, and contaminants. An additional requirement is the mapping of physical parameters such as topography, bathymetry, or shoreline position, and ecological parameters such as habitat.

The coastal module of GOOS is a long-term, very large-scale initiative which aims at coordinating coastal observing efforts under the auspices of the Intergovernmental Oceanographic Commission (IOC), World Meteorological Organization (WMO), United Nations Environment Program (UNEP), International Council for Science (ICSU), Food and Agriculture Organization (FAO), and IGBP, feeding global observing efforts such as the Global Earth Observation System of Systems (GEOSS). In particular, it proposes to improve the capacity to detect and predict the effects of global climate change on coastal ecosystems, by providing a rationalized framework for the current cluster of national, regional and international observing efforts. By comparison, LOICZ focuses on specific research issues and brings researchers together to solve these issues, which may or may not deal specifically with ICZM and coastal monitoring. Both the coastal module of GOOS and LOICZ plan to rely heavily on regional coastal ocean observing systems (RCOOSs) that would be coordinated in a Global Coastal Network (GCN). Although LOICZ has acknowledged Arctic-focused bottom-up initiatives such as ACD as part of its effort, ties to the coastal module of GOOS and C-GTOS are weak and need to be strengthened. In parallel, the Arctic science community, under the auspices of the Arctic Council and with the impetus from IASC and AMAP has been working on a strategy to develop current observing efforts in the Arctic into an Arctic Observing Forum (AOF) (SAON, 2009). It is obvious that the confluence of these initiatives calls for the establishment of a strong Arctic coastal observing component, fitted into both the upcoming coastal module of GOOS and the AOF. The integrated approach that prevails in networks such as ACCOnet should form the basis for a regional integrated coastal observing system in the Arctic, one that is connected to global initiatives.

3.2.4 Modelling and projecting Arctic coastal change

The overarching goal of modelling efforts is to help understand the dynamics and complex interactions of natural, coupled air-land-sea systems, where possible including biophysical and social systems. Models allow for tracking of the uncertainties of projections or simulations within a geographical context. In this review, the focus is on coastal integrated biophysical and social systems. With appropriate validation in the field, models can be used to test our understanding of processes. In the event that models achieve a certain level of understood quantification, then they can be used to create prognoses of future system states under assumptions pertaining to given scenarios. These may include development scenarios leading to projections of climate or sea level, which in turn could be used to drive other coastal models of change, at various scales from regional studies to the community level.

Change projection

As modelling and prognosis are broad terms (with application in a number of research fields), it is appropriate to first define these terms.

A prognosis is a forecast of the likely outcome of a scenario or situation. The word prognosis has secondary meanings dealing with implications of projected outcomes. Often a prognosis is defined in qualitative terms. In dealing with the Arctic coastal zone, prognosis refers to projecting plausible futures. These futures may involve changes (inter alia) in:

- sea level
- sea-ice conditions
- coastal permafrost stability
- precipitation (magnitude and intensity)
- river discharge (timing and magnitude)
- coastal topography and landscape transformation
- biodiversity in coastal ecosystems
- coastal hazards
- constraints on subsistence activities
- impacts on cultural resources
- constraints on community, industrial, or other infrastructure.

A model is a simplified description (often mathematical) of a system to assist in quantitative calculations or predictions. Often models are used to quantify a prognosis or scenario. Because of their mathematical framework, models can be used to help understand the sensitivity of a process or system to changing boundary conditions. Advanced models are used to deal with non-linear behaviour of systems, including situational thresholds.

Prognosis and modelling applied to the Arctic coastal zone

Prognosis and modelling are important tools for working in data-poor regions as they can be used to test our understanding of processes through validation experiments and to help understand uncertainties in complex systems. The Arctic tends to be data-poor due to issues of accessibility, sampling density, limited long time series, and representation. In addition not all of the forcing functions that drive systems (human, physical, and biological drivers) are well constrained. Arctic processes often remain not fully understood – either we are missing information or we lack adequate understanding of the physical, ecological and socio-economic processes. Additionally we do not fully understand all the various nonlinearities in the system. Examples of coastal modelling in the Arctic range from process-specific analytical models (e.g. Hoque and Pollard, 2008, 2009) to community- or site-specific coastal erosion modelling (e.g. Peckham et al., 2002) to broader projections of climate implications for sediment supply or erosion rates (e.g. Syvitski, 2002, Syvitski et al., 2003, 2005). Examples of qualitative modelling for the development of adaptation policy include Brunner et al. (2004) and Lynch and Brunner (2007).

We recognize three types of models of importance to studies of the Arctic coastal zone based on the nature of the problem or process.

- **Physical system models:** These models are often targeted to specific components of the overall physical system such as ocean circulation, meteorology, climate dynamics and climate forecasting, hydrology, sediment transport, coastal morphodynamics, wave dynamics, tidal modelling, storm surge dynamics, permafrost dynamics, sea-ice and iceberg drift, and tidewater glacier dynamics.
- **Coastal ecosystems models:** These are largely driven by the physical and biological

environment and dynamics. They represent various levels of sophistication and dynamics; from simple box models to those that integrate more fully the dynamics that define the system. These models include those related to productivity, nutrient dynamics, light, water and temperature regime, snow cover, sea ice movement and trophic dynamics and interspecific competition.

- **Socio-economic models:** These may involve renewable or non-renewable resources, tourism, community development, coastal infrastructure and pollution, among a host other human issues.

Model scenarios for the Arctic coastal zone involve analysis of expected changes in the following components:

- climate,
- other aspects of the physical environment,
- social and economic conditions,
- ecosystems, and
- governance.

Risk assessment is predicated on the notion of humans being risk averse. Thus scientists must better understand the uncertainties associated with models (in data, forcing, physics, and representation). Model validation is imperative for proper risk assessment. Models can be validated with field data by using a hindcast methodology with re-analysis, but the short record lengths often associated with Arctic systems remain a systemic problem for validating Arctic models. Many Arctic coastal zone models are on the scale of human engineering, in other words on the time scale of years. These models differ from longer-term morphodynamic models that track changes in topography and bathymetry through decades and in some cases centuries. A worry in employing morphodynamic models is whether the science is in place to discern processes that operate with gradualism, versus those that employ different dynamics on either side of some well understood threshold condition. Four dimensional (4D) data assimilation schemes offer methods (inversion algorithms, conditional simulations) to improve our ability to incorporate large-scale observations with limited ground observations and model simulations.

It is unclear how the Arctic coastal research community should proceed with respect to prognosis and modelling at the village or hamlet scale? Often coastal zone models are used to understand the generic state of the Arctic environment; they do not necessarily address the needs of the indigenous peoples, nor are they able to easily incorporate oral-based indigenous knowledge (traditional knowledge). Coastal management models at the scale of individual communities can be applied on a case-by-case basis with good two-way communication, education and outreach. As noted earlier, Huntington et al. (2007a) described the application in the context of five community studies of dynamic simulation models in the context of five community studies. These models incorporated vegetation change, caribou migration and energetics, and household economies to feed various sub-models.

Constraints and future directions for modelling the Arctic coastal zone

An Arctic coastal zone model survey is required before we can effectively identify model gaps. A modelling framework system for the Arctic coastal zone is not yet implemented. Model integration is thus at a very early stage. More effort is required on error propagation analysis and an understanding of model uncertainty.

Better understanding of the surface heat budget throughout the Arctic, a gap identified by Barry et al. (1993), remains a priority. This is important for most ocean-ice-climate modelling efforts as well as for many ecosystem dynamic models. Relative sea-level projections remain poor for the Arctic coastal zone, although some progress is being made.

No long-term coastal morphodynamic models have been identified that are applicable to the Arctic coastal zone, e.g. taking permafrost or other ice-sediment interactions into account, although some efforts have been made to incorporate thermal processes in physical dynamics models (e.g. Kobayashi et al., 1999) and longer-term modelling has been undertaken using hybrid models (e.g. Leont'yev, 2003, 2004)

Very limited long-term (and even medium-term) data are available for validating many of the existing physical models. Because the Arctic is entering a new state with limited summer sea ice, wave measurements of the past may be of limited use for the validation of wave forecast models. Furthermore, the present limited network of observation stations is inadequate for data assimilation schemes. This is a recognized need and formed part of the drive for a sustained Arctic observing network following on the International Polar Year (see Chapter 4).

Over the past few years, an international consortium led by the USA has developed a science plan for a 'community' integrated 'Arctic System Model', designed as a tool to synthesize models and observations for understanding the Arctic as a system. (Roberts et al., 2010a). Although clearly driven by the physical science community, this initiative aims to promote progressively more integrated approaches to modelling physical,

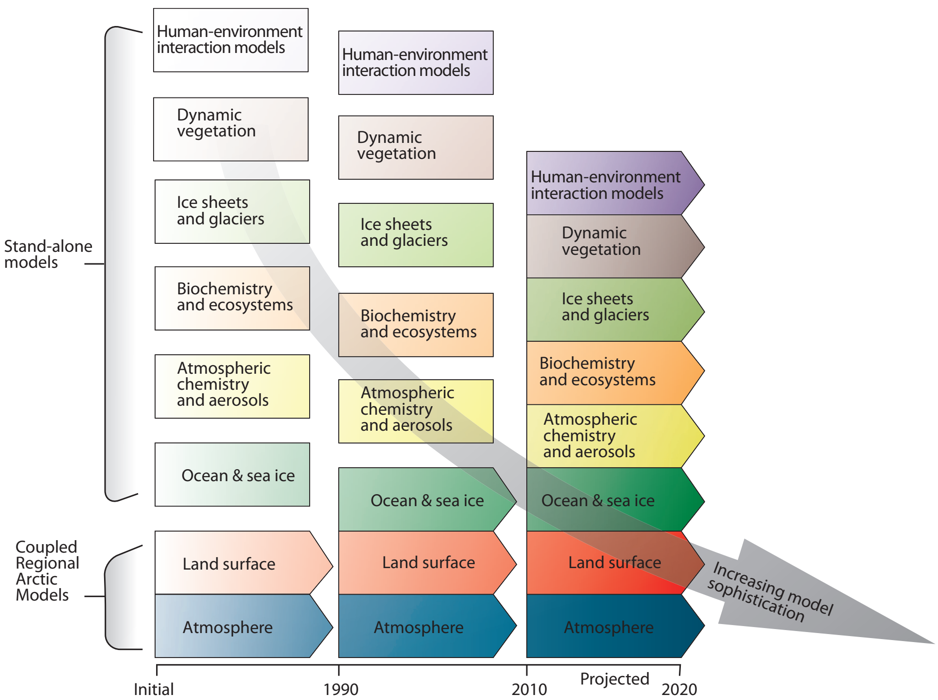

Figure 38. Model integration architecture for a community integrated Arctic System Model. (from Roberts et al., 2010a)

biological, and socio-economic aspects of climate-driven change and adaptation in the Arctic (Fig.38). Coastal erosion, coastal habitats and coastal communities are all seen as components of this system. While it is unclear to what extent this initiative will result in effective models of socio-ecological adjustments in the coastal zone, some progress has been made in the development of agent-based models of community response (Berman et al., 2004), which indicate a potential for integrated modelling.

Integrative Approaches to Change Projection

Both the Arctic Climate Impact Assessment (ACIA, 2005) and the Arctic Human Development Report (AHDR, 2004) focussed on an understanding of change based on existing data but with a more multidisciplinary than integrated perspective. Several more recent initiatives (e.g. the Millennium Ecosystem Assessment and the UNEP Global Environmental Outlook), aiming to provide integrated assessments of change combine several frameworks and tools (see Fig. B3 in Box, Section 3.1.2).

Recognizing the complex role humans play in coastal change, the LOICZ Science Plan and Implementation Strategy (Kremer et al., 2005) framing the second decade of the global LOICZ project, identified the need to expand research that contextualizes biogeochemical and physical processes with social, political and economic aspects. The goal is to elucidate human activity as an agent of change and reflect society's response to change, which influences resilience of coastal systems in a social-ecological context (Folke, 2007). Initial results from the EU project ELME (Langmead and McQuatters-Golop, 2007), linking lifestyles and the environmental state of marine and coastal ecosystems, underline the key role social choice plays in determining the quality, institutional aspects and robustness of political and management response to pressures and environmental change. Social choice prioritizes between value systems (e.g., consumerism vs. community values) and levels of governance (interdependence vs. autonomy). Resulting scenarios provide narratives for the anthropogenic footprint and likely consequences for coastal resources including 'winning' and 'losing' species

Figure 39. Hunter at the floe edge in the Canadian Arctic.
Source: James Ford, ArcticNet

in the coastal marine ecosystem. Such ecosystem shifts have implications for goods and services and feed back into human livelihood, health and cultural stability. The German research project "Coastal Futures" (Kannen and Burkhard, 2009) also explores scenarios, but the focus was to sketch the likely consequences of developing new forms of sea use in the German North Sea. Coastal Futures aims to apply integrative approaches to analyze coastal, offshore, and ocean changes. These approaches may also support spatial planning in coastal land and sea areas. They incorporate natural and social science expertise to ensure a unified systems description. Differing methods are applied to assess ecological risks (and opportunities) on the one hand and economic opportunities (and risks) on the other. Nevertheless, both types of analysis are needed when it comes to evaluating changes within resource and area use. While this project lies outside the Arctic, similar approaches could be adopted and adapted to Arctic settings.

Another integrative approach is the use of dynamic simulation models, which aim to offer integrated perspectives of future scenario outcomes based on a variety of ecological, economic and social indicators. User interactions and stochastically-driven processes in the model provide elements of contingency so that the alternative "futures" are not simply mechanically-determined forecasts. Huntington et al. (2007a) describe an approach for the application of a dynamic simulation model based on detailed statistical analysis of vegetation change, caribou energetics and migration, and northern household economies, which informed the various sub-models.

Approaches from the field of ecological economics aim to integrate different forms of information through a quantitative assessment of the value of coastal resources and ecosystems in monetary terms. Wilson et al., 2006 in reviewing earlier estimates (Costanza et al., 1997) indicate that total global coastal ecosystem goods and services of coastal wetlands may equal more than 40% of the whole global value, though deriving from only 8% of the world's surface. Similar assessments specifically for Arctic coasts are missing. However, many of the non-use values, which in reality have a substantial share, are neglected in such assessments. Given the high importance of non-use values (including religious and inspirational values) to indigenous communities in the Arctic, one may question whether such a highly rational quantitative approach is at all appropriate (Fig. 39). Nevertheless, recognising and mapping (in a qualitative way) the non-use value of Arctic coasts is a way to link traditional knowledge with scientific knowledge, thereby bridging both knowledge systems.

3.3 Vulnerability, Adaptation, Adaptive Capacity and Resilience

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Key Findings

- Increasingly governments, communities, and industry stakeholders are exploring ways to reduce the negative impacts of climate change and take advantage of new opportunities through adaptation.
- Many Arctic coastal communities are experiencing vulnerabilities to decreased or less reliable sea ice, greater wave energy, rising sea levels, changes in winds and storm patterns, storm-surge flooding or coastal erosion, with impacts on travel (on ice or water), subsistence hunting, cultural resources (e.g. archaeological remains, burial sites) and housing and infrastructure in communities.
- In some places, this has necessitated community relocation, which in some cases increased vulnerability.
- In places, coastal erosion is threatening critical infrastructure or contaminated sites, with potential for spreading of pollutants.
- There has been great progress in recent years in the understanding of exposures and identification of elements of adaptive capacity that may enhance resilience, but other challenges including social, technical, financial, and institutional barriers may be inhibiting successful adaptation.
- There is a wide range of adaptive capacity among coastal communities of the circumpolar Arctic. A community with a greater resource base, including physical resources, financial capacity, knowledge (of all kinds), and social cohesion, is in a better position to successfully adapt than one that lacks resources and options.
- Arctic indigenous peoples are traditionally resilient. This has allowed them to adapt to a harsh climate and changing environmental conditions over multi-century time-scales.
- With a faster pace of change and numerous compounding challenges, the indigenous peoples of the Arctic are generally less resilient today, although developments in regional governance and cultural initiatives, as well as growing familiarity with climate change, may be improving the situation to some extent.
- Quantitative scientific research concerning past, present, and future environmental changes and impacts is a key component informing policy and decision-making.
- Adaptation strategies perceived as imposed from outside will not be incorporated into the community's reservoir of mechanisms for coping with change, will not form a component of its adaptive capacity, and will thus not contribute to its resilience and ultimate sustainability.

Numerous changes in the northern coastal environment, combined with marked social, economic, and political change are already evident and challenging the validity of traditional knowledge, the viability of current economic activities (including traditional harvesting), and the social cohesion, capacity, and resilience of Arctic coastal communities. The range of choices, feasibility of responses, exposure and adaptive capacity of communities vary over a wide spectrum, but studies over the past decade have focused on a broad-based understanding of the physical and ecological changes occurring or likely to occur under projected climate changes and how these will affect communities and residents. Among the promising outcomes of increased awareness has been the development of community-based monitoring and adaptation initiatives, as discussed in the previous section. However the scale of potential impacts on Arctic communities and existing social, cultural, economic, demographic and governance constraints pose massive challenges.

3.3.1 Vulnerability and adaptation

Increasingly governments, communities, and industry stakeholders are exploring ways to reduce the negative impacts of climate change and take advantage of new opportunities through adaptation (Kelman and van Dam, 2008; ACIA, 2005; Séguin, 2008; Lemmen et al., 2008). Effective adaptation requires an understanding of vulnerability at present and in the future under various scenarios of climate-change and adaptive capacity to address potential exposure and sensitivity and thereby to limit or minimize negative impacts.

Vulnerability is the degree to which a person, community, or sector is adversely affected by change and/or to variability in climate and other drivers (see Smit et al., 1999; Kelly and Adger, 2000; Gunderson and Holling, 2002; Adger et al., 2007; Hyndman et al., 2008). Vulnerability is the combined function of exposure and sensitivity. The frequency of occurrence (exposure) is not the only factor influencing vulnerability. If the effects of the change are too great, any sector may be vulnerable. Communities or sectors that have fewer resources to cope are more vulnerable than those with greater resources, even if the degree of exposure is less. The necessary resources, collectively contributing to adaptive capacity, include money, expertise, trained emergency response personnel, medical facilities, previous experience, social networks (local people helping each other), and assistance from other communities, ranging from adjacent communities to national governments to world-wide appeals for aid.

Adaptive capacity refers to the ability to cope with or adapt to a change (see Smit et al, 1999; DesJarlais et al, 2004; Ford and Smit, 2004; Adger et al, 2005, 2007; Armitage, 2005; Kofinas, 2005; Anisimov et al, 2007; Vincent, 2007; Agrawal, 2008; Armitage et al, 2009; Armitage and Plummer, 2010; Ford et al, 2010). For natural terrestrial and marine ecosystems, adaptive capacity and vulnerability to change are directly related: an ecosystem which has a relatively greater capacity to evolve is also relatively less vulnerable. Most natural systems have moderate to high exposure to climate change impacts, in a multidecadal time frame. Ecosystems have evolved in response to the changing climate since deglaciation. In many cases a sudden shift in climate conditions will impact them adversely (e.g. Bean and Henry, 2001; Jacobs et al., 2006; Prowse et al., 2009; Tarnocai, 2009). Differences in lifespan and size of individual organisms influence the degree to which each species is exposed, as well as the immediacy of the reaction to changed conditions. Insect species respond more rapidly to climate variation

Community Adaptation and Vulnerability in Arctic Regions (CAVIAR)

J. West and G.K. Hovelsrud

The Arctic is experiencing rapid changes in environmental, societal and economic conditions. The particular conditions to which communities are sensitive are not well documented, nor have the conditions that might facilitate or constrain their adaptive capacity in the face of interacting climate and socioeconomic changes been substantiated. Insights into the particular vulnerabilities of Arctic communities have not been compared across the Arctic countries, nor are these studies well connected to policy development. CAVIAR (Community adaptation and vulnerability in Arctic Regions), a circum-Arctic research consortium and endorsed IPY cluster involving all eight Arctic nations, and 26 case sites, was designed to meet these research gaps, using a research strategy to develop a theoretical framework for community vulnerability assessment, refined a common methodology, established procedures for case studies, developed a process to compare and integrate results, and ensured direct application of research to policy (Smit et al., 2008; Hovelsrud et al., 2010). Research conducted under the CAVIAR Norway-Russia contribution identified past, current and future exposure-sensitivities and adaptation strategies in nine communities/regions, assessed community vulnerability and adaptation, determined the extent to which available meteorological data series could provide a meaningful description of local conditions that influence the sensitivity in selected communities, given downscaled climate projections with sufficient spatial resolution for vulnerability assessment.

One finding that emerged from CAVIAR research in Lebesby, Northern Norway was the existence of cross-scale adaptation challenges facing the coastal fisheries sector. While fisheries actors there are aware of, experience, and describe a number of connections between climate variability and coastal fishing activities, they do not characterize their livelihoods as being particularly vulnerable to climate change. Nonetheless, they identified a range of social factors that shape the flexibility of coastal fishing activities and livelihoods that constitute important aspects of adaptive capacity. Adaptation challenges identified through the fieldwork fell into a four "adaptation arenas": local perceptions of vulnerability and resilience to climate change; social and economic viability of the municipality; national fisheries management and regulations; and markets and the economy of coastal fishing. These arenas involve different geographic and temporal scales, creating specific barriers and opportunities for local adaptation (West and Hovelsrud, 2010).

A project of the International Polar Year 2007- 2010, the CAVIAR consortium was co-led by Grete K. Hovelsrud at the Center for International Climate and Environmental Research -Oslo (CICERO), Oslo, Norway, and Barry Smit, University of Guelph, Canada.

Coastal fishers hard at work in Lebesby, Finnmark County, Northern Norway. Photo: Jennifer West, ©CICERO

Nunavut Climate Change Partnership

Beate Bowron, Lee Ann Pugh, David Mate

This unique partnership included the Government of Nunavut (GN), the Earth Sciences Sector of Natural Resources Canada (NRCan), the Canadian Institute of Planners (CIP), and Indian and Northern Affairs Canada (INAC). The overarching goal of this multi-disciplinary climate-change adaptation program was to enable Nunavut communities (all but one of which are coastal) to incorporate climate-change adaptation measures into all aspects of their planning processes. All of the partners coordinated their respective areas of work (science, planning, community engagement, etc), so that the proverbial total was truly greater than the sum of its individual parts.

The project focused on three themes:

1. To create locally and regionally targeted scientific information for climate-change adaptation planning and to integrate this information into decision-making processes.
2. To build capacity for climate-change adaptation planning within the GN and Nunavut communities.
3. To develop tools to collect, publish, share and communicate climate-change adaptation knowledge across Nunavut and beyond.

Between 2006 and 2011, the following individual projects were completed:

- Prioritization of climate-change issues based on workshops held as part of the development of the Nunavut Climate Change Adaptation Plan (www.planningforclimatechange.ca);
- Climate change adaptation plans in the communities of Clyde River, Hall Beach, Kugluktuk, Cambridge Bay, Whale Cove and Arviat (www.planningforclimatechange.ca); volunteer CIP planning teams and scientists worked with these communities to produce adaptation plans. Aspects of these plans will feed into other planning processes such as community plans, emergency management plans, and infrastructure budgets, among others.
- Climate change adaptation work in the City of Iqaluit (Nunavut's capital) concurrent with the City's review of its Community Land Use Plan. Scientifically this included studies on permafrost and landscape hazards (Allard et al., 2010), coastal flooding and sea-level rise (Hatcher et al., 2010) and water resources (Brière, 2010). Planners from CIP worked with the city to establish a network among people from different levels of government and NGOs working on climate change issues.
- Supporting the establishment of the Ittaq Heritage and Research Centre in Clyde River (www.ittaq.ca).
- Conducting first order assessments of the impact of climate change on freshwater supply in a range of communities across Nunavut using geomatics and remotely sensed information (Brière, 2010). This process and technology was transferred to Nunavut Arctic College and the GN.
- First-order modeling of sea-level rise across Nunavut with an emphasis on the climate change adaptation action plan communities noted above (James et al., 2011).
- A methodology for landscape hazard assessments (combining permafrost and coastal science) in Nunavut with detailed studies conducted in Iqaluit (Allard et al., 2010), Pangnirtung (Leblanc et al., 2010) and Clyde River (Forbes et al., 2007b; Irvine et al., 2009).
- Reconnaissance landscape hazard assessments in collaboration with planners and the communities of Arviat, Whale Cove, Cambridge Bay and Kugluktuk.
- Establishment of a permafrost monitoring network across Nunavut (Ednie and Smith, 2011)
- A case study on how to visualize climate change impacts and adaptation options in Nunavut communities (using Clyde River as the example) by combining science and planning results.
- A Climate Change Adaptation Planning Tool Kit (www.planningforclimatechange.ca);
- A Nunavut Climate Change website (www.climatechangenunavut.ca).

The Nunavut Climate Change Partnership is committed to involving elders, hamlet councils, local stakeholders and the communities at large in all parts of its program. Some of the scientific research involves and trains community residents in data collection and monitoring. Partners are paying particular attention to the integration of old and new scientific knowledge with the traditional knowledge that exists in Nunavut communities. It is expected that this partnership will continue to evolve in the future.

and change, both in terms of survival and migration, than do many large mammals.

Marine ecosystems are also capable of evolving, but the interconnectedness of marine environments is a counterbalancing factor. Seasonal temperature variations in marine waters are less than the variations in air temperature, but many marine species are highly sensitive to temperature changes (e.g. Chabot and Dutil, 1999; Drinkwater, 2005; Dawe et al, 2007; Doniol-Valcroze et al, 2007; Lavers et al, 2008; Regular et al, 2009; Friedlaender et al, 2010). Marine waters are slower to respond to climate changes, and may also take longer to revert to previous conditions.

For human-related sectors considered in a climate-change context, adaptive capacity not only involves the potential (or latent) ability, but also the success at mobilization in response (see Scheffer et al., 2002; Etkin et al., 2004; Haque, 2005; Auld et al., 2006; Canadian Council of Professional Engineers, 2008; Hyndman et al., 2008; Reimer and Tachikawa, 2008; Füssel, 2009). In a community or sector, the evaluation of adaptive capacity involves comparison of available resources (financial, technical, and human) with the scope and magnitude of the issue to be addressed. A realistic assessment of adaptive capacity, however, must also consider the practicality, societal attitudes, and political willingness to proceed with the initiative. Climate change and variability will not occur in isolation of other human influences and adaption needs to be undertaken in the context of all other issues facing a community.

3.3.2 Resilience and adaptive capacity in Arctic coastal communities

The magnitudes and frequencies of the stresses imposed by changing and varying climates are important factors affecting Arctic coastal communities (Ford and Smit, 2004; Furgal and Seguin, 2006; Tremblay et al, 2006; Anisimov et al, 2007; DeSantis, 2008; Furgal and Prowse, 2008; Séguin, 2008; Ford et al, 2010). However, the ability of each particular community to respond and successfully adapt also depends upon the prevailing social, economic, and governmental conditions. A community with a greater resource base, including physical resources, financial capacity, knowledge (of all kinds), and social structures and relationships, is in a better position to successfully adapt than one that lacks resources and options. Adaptive capacity is a measure of both the physical stresses and the community resources and resilience.

Resilience is neither a finite nor a perpetually inherent quantity (Gunderson and Holling, 2002; Berkes et al, 2003; Resilience Alliance, 2011). In a community, the degree of resilience is constantly dynamic, in response to all manner of stresses and in a developing or diminishing capacity to cope. As communities are composites of numerous individuals, social and economic sectors, and physical landscapes, community resilience is a composite property.

From an adaptive system perspective, a community may encounter an actual decline in a physical resource dimension of the community (such as a decrease in the availability of a particular species for harvesting), or an apparent decline (such as a perception that changing weather conditions preclude successful application of traditional approaches), or an increase in stress (such as accelerated coastal erosion). Whether those physical stresses translate into increased community vulnerability depends upon the capacity of the community to adapt. A community with strong resilience can respond to the physical stresses through other socio-ecological system dimensions - people, organizations and the relationships that bind them to the land and sea, and to one another.

Adaptive capacity represents the extent to which compensation for changed physical conditions is theoretically possible. If capacity exists but is not utilized, however, the community's resilience will not be enhanced. A resilient community is one that not only has the capacity to respond, but proceeds in an attempt to adapt.

In a broader regional or national context, larger questions of governance, including jurisdiction and authority, characterize discussions of necessarily multi-scalar responses to coastal change (e.g. Kooiman, 1999, 2003). In this section, the focus is on the lived, local change and adaptive experiences of coastal peoples. Local governance and agency is a domain of particular interest in considering the accelerated morphological processes acting on Arctic coasts. In relation to both detailed local assessment of the practicability of any proposed or instituted adaptation measures, and supporting the individual and local agency needed to identify, assess and act on potential environmental stresses and hazards, the day-to-day realities of coastal community dynamics must be understood and respected.

In any assessment of appropriate adaptation measures for a community, quantitative scientific research concerning past, present, and future environmental changes and impacts is a key component informing policy and decision-making. Minimizing the adverse physical effects of changes requires a strong understanding of the physical environment. However, an approach that only considers the physical dynamics to the exclusion of the particular culture of the community, formerly practiced by many physical scientists (see Chester, 1993) will fail to generate adaptation measures that enjoy broad community support. A solution perceived as imposed from outside will not be incorporated into the community's reservoir of mechanisms for coping with change, will not form a component of its adaptive capacity, and will thus not contribute to its resiliency and ultimate sustainability.

Throughout the Arctic, there has been a fundamental change in the ethical stance of outside researchers in relation to the inhabitants in the last decade. A majority of researchers consider a community as a living group of people to be interacted with, rather than as an object of study or a group to be spoken to. The effort to see communities from the perspective of understanding the 'sense of place', cultural and physical, has allowed researchers and community to begin the process of true interaction, including all the key methods of engaging and listening: effective mutual communication, regular information-sharing, continuity of contact (old friendships, rather than passing summer acquaintances), and creative exploration and conceptual experimentation (c.f. Huntington, 1992; Hayward, 2005; Catto and Parewick, 2008).

The politics of knowledge collection, generation, and utilization bear the mark of decolonialization (cf. Sluyter, 2002). Researchers in many jurisdictions not only submit to both licensing and community stakeholder review processes, but strongly support these efforts to assure greater accountability and foster mutually beneficial partnerships.

Integrating coastal science with local decision-making presents 'cross-cultural' challenges in the conventional sense (between parties of different ethnicities or socio-economic backgrounds), and in the equally significant respect of the 'cultures of mind' which are characteristic of individual disciplines. Ongoing inter- or trans-disciplinary conversations entail new levels of effort. These can require researchers to discard habitual practices used for communication with disciplinary colleagues, which in a multi-cultural or multi-disciplinary context may present obstacles to true syntheses of knowledge. Communities contain vital information and energy for adaptation, which is best displayed by encouraging the exercise of community muscles, physical and mental.

Significant attention has been focused on the challenges facing traditional knowledge practitioners in relation to predicting weather, food harvesting, and traveling safely on the land, sea and ice (Berkes, 1999; Berkes et al., 2003; Jolly et al., 2002; Laidler, 2006; Nickels et al., 2006; Ford et al., 2010) as the Arctic environment changes. Issues related to contemporary physical infrastructure planning, design and location have also been examined in relation to communities (e.g. Allard et al, 2004; Catto and Parewick, 2008; Tremblay et al, 2006), industrial, and military developments (e.g. Reschny, 2007). The adoption of more collaborative practices by scientists working in the Arctic reflects the ongoing processes of legitimization of multiple 'ways of knowing' as a basis for arriving at the most comprehensive understanding of all the factors in play in a given community (see Section 3.1).

The impacts of ongoing environmental changes on knowledge and belief systems, language and the material culture of many Arctic populations have thus received substantial recent considerations by researchers. This includes the sociological components of culture, including the analysis of interpersonal relationships, community and societal organizations and practices, and responses to stresses. Adaptive cycling within cultural systems may be readily organized into those day-to-day adjustments made by individuals or communities encountering their environment, through the longer cycles of group and regional organization, to the uppermost levels of worldview binding the entire cultural community together. The explicit interest in the dynamic features of these enmeshed scales offers an organizing principle with which the multiplicity of other factors conditioning communities' experiences of change may be considered. Adaptation must occur throughout the system, with the potential for changes existing within cycles, working their way down or up through various levels (cf. Ostrom, 2008).

The 'local' is arguably the primary scale for considering human adaptation (Holling, 1986; Berkes et al, 2003; Johnson et al, 2003; Ford and Smit, 2004; Adger et al, 2007; Catto and Parewick, 2008; Armitage and Plummer, 2010; Ford et al, 2010). The consequences of coastal erosion, flooding, declining sea ice extent and duration, and permafrost terrain changes are visited upon the peoples preferentially settled there. The relatively recent built environment of many Arctic settlements in North America and Russia offers a starting point for exploring a variety of key adaptation themes. As tangible manifestations of intertwined form and function, they define a major transition and period of cultural adaptation. Traditional forms of indigenous Arctic shelters optimized mobility, minimized baggage, and used local materials to suit the season (snow, ice, skins, turf). The first generation of substitutes (e.g., canvas tarpaulins, tents) mirrored those forms and functions. However, the second generation of shelters, involving rigid construction anchored to terrain with exotic imported materials, represented a break with past experience. The experiential learning of older community members embodied in the traditional forms may not be lost, but neither is it preserved in anything but the most superficial of ways by contemporary Northern housing.

The rapid dissemination of imported forms and their accompanying infrastructure (streets, utilities, commercial and industrial uses) is such that within only a couple of generations, the appearance and nature of Inuit, Inuvialiut, and Aleut cultural landscapes have been radically altered (see e.g. Alunik et al, 2003). To what extent does the 'getting used to' by inhabitants of the appearance of their present community landscape, with its new sense of place, mirror other, less apparent adaptations? In particular, have other colonial institutions of similar vintage been 'adapted by' or 'adapted to' the original culture? What evidence is there of new forms and institutions emerging out of the meeting of any number of formerly distinct cultural traits?

Ongoing transitions on multiple levels in response to multiple stresses produce multiple strains of adaptive cause and effect, co-mingling to produce numerous complex adaptation scenarios. Strain rates vary as well, requiring adaptation efforts that vary in both time and space.

The dynamic interplay of local human dimensions (infrastructure, economy, organizations and governance) with a mutable environment is in evidence across the Arctic. In recent community case studies, documented physical change variables (sea level rise, isostatic movement, erosion rates) were assessed in terms of their relative degree of hazard and compared with community-based interpretive assessments of local economic, institutional and human resource circumstances. A bifurcation of interests into those of locational and relational sustainabilities was apparent. The best-practice 'engineering' of adaptations may then be seen as parallel system lifecycles of design, development, and maintenance interventions. While physical and social science evaluative methods (risk and hazard assessments, resilience assessments, cross-cultural knowledge-sharing and integration of science and decision-making) have moved in the direction of greater cross-over and integration, their outcomes with respect to policy have still tended to decouple. The duality of the physically and socially-constituted realities that condition human response to change are ever present in adaptive strategies: to adapt by changing the physical world at hand or to adapt by changing either the communities' spatial or functional relationship both to and within it.

In professional planning practice, there is another strategic posture that is always considered: the 'do nothing' scenario. Meant with the best of intentions to reinforce the rigorous consideration of every action scenario's merits relative to a baseline value, in the context of climate change, it could also be read as a maladaptive response to overwhelming and unfamiliar stimuli. Perhaps most pronounced in political arenas, the 'do nothing' scenario is regularly played out at the local level. The community-scale 'laboratory' is where the full array of informal adaptation experiments are played out. In concert with local physical hazard evaluations, community resilience assessments (e.g. Catto and Parewick, 2008) reveal significant community adaptation challenges stemming from human resource, organizational and relational factors. This approach leads to a working understanding of the many cross-scale interactions that ongoing physical changes are precipitating in tandem with globalizing economic and social influences on northern populations

Inquiries focusing on community-scale adaptation processes must examine a variety of community systems. In addition to numerous conventional forms of physical infrastructure, communities have 'non-structural' infrastructure – assets of a cultural, organizational or attitudinal nature - which can be more important to maintain. Although the non-structural assets are not physical, they are tangible to those engaged in the community. Absence of non-structural assets is quickly felt in a community, leading to erosion of community spirit, self-confidence, and adaptability, a sharp decline in both theoretical and real adaptive capacity, and a huge loss in resilience. Communities which superficially would appear equally able to cope with a given physical stress (such as a defined rate of coastal erosion) will exhibit very different responses, depending upon the strength of their non-structural institutions.

Restoring, preserving or enhancing these more relational capacities can take many forms. Locally-delivered employment-related training and certification, culturally-based activities or celebrations that aim to bring the community together, and health and wellness programs are critical examples.

In many northern communities, a key factor decreasing resilience is the replacement of the indigenous language with one from outside. Language loss is tied to the failure of inter-generational communication, leading to a collective failure to profit from community memory. Lack of communication between elders and youth occurs, as they literally do not speak the same language. Continuing negative feedback forms a classic 'trap', eventually resulting in reduced adaptive capacity and resilience in the face of physical stresses resulting from climate change. One key adaptation measure is thus to break the trap, by facilitating the transmission of critical community knowledge. Speakers are engaged to deliver a variety of indigenous language learning activities (interventions) in many community schools today. Relational interventions may also entail the development of physical infrastructure: for example, a community centre and gathering place if such a facility is otherwise lacking.

Until systematic training of Arctic residents progresses much further, communities will remain dependent on researchers, practitioners, and professionals and technical staff from outside. Non-resident engineers and planners tend to focus on specific pieces of infrastructure, both as a consequence of their short tenure in the Arctic and their previous disciplinary training. Public works design and management tends to react to rather than anticipate forthcoming changes, and inter-agency conflicts regularly stall responsive efforts.

The problem of attracting and retaining professional and technical staff in many Arctic communities also represents a 'trap'. Constant turnover not only limits the time available for new initiatives and research, but disconnects the revolving staff from the community. As the newly arrived staff members must integrate into a community of a different multi-dimensional culture (disciplinary as well as ethnically and socio-economically), time is required before effective work on adaptation and accentuating resilience can begin. The importance of institutional memory is greatly underappreciated: human resource turn-over interferes with the transmission of 'standard' and acquired operational procedures, leading to an erosion of preventative maintenance and even the loss of key infrastructure.

The Siku-Inuit-Hila Project

S. Gearheard and partners

The *Siku-Inuit-Hila* [Sea Ice-People-Weather] Project looks at the different ways in which the Inuit coastal communities of Barrow (Alaska), Kangiqtugaapik/Clyde River (Nunavut), and Qaanaaq (Greenland), live with and from sea ice. Indigenous experts from each of these areas have teamed up with scientists to examine sea ice and human-sea ice relationships. Despite being separated by vast distances, cultures, and languages, these groups all share knowledge and experience of sea ice. The *Siku-Inuit-Hila* project brings these perspectives together, and combines different community-based and innovative research methods in order to monitor sea ice, gather local and traditional knowledge about sea ice, and enable exchange between the partner communities and scientists (Huntington et al., 2010).

Siku-Inuit-Hila combines three main methods. The first and foremost is the knowledge exchange that happens between the different indigenous experts from participating communities, and between the indigenous experts and scientists. The team travels as a group to each of the communities, studying the sea ice together and learning about life with ice from the hosts in each community (Fig. B4) Travelling long distances together and living, camping, travelling the ice, hunting, talking, and eating together has created very strong bonds between the team members, who have become good friends as well as co-researchers. The sea ice acts as the common denominator for the group and each expert, no matter what their background, language, or particular expertise, is able to relate to the ice, share their unique perspective, and has something to contribute to the collective research. At various times, each team member thus has an opportunity to be a student or a teacher and everyone is able to broaden their understanding of ice in context.

The second method is the quantitative monitoring of sea ice that has been established in each community. Using stationary sea ice monitoring stations set up in the sea ice at freeze up each year (Mahoney and Gearheard, 2008), a local monitor has been trained in each location to measure various sea ice parameters such as ice thickness, snow thickness, and ice temperature, on a weekly basis. These measurements are graphed and combined with local qualitative observations of the sea ice environment and are shared with the local communities and with the project scientists who help further analyze the information for each community and comparatively across communities (e.g. Mahoney et al., 2009). The method has been successful as a community-based sea ice monitoring model and has been adopted in several other communities in Nunavut and Nunavik, Canada.

The last core method in *Siku-Inuit-Hila* is the establishment of sea ice expert working groups in each of the partner communities. These working groups meet on a regular basis (monthly), to discuss various topics such as past and recent sea ice conditions, sea ice travel, and hunting skills, and share stories and advice. The transcripts and minutes from these meetings provide detailed sea ice knowledge and insights into life with ice. The discussions are also a time for local experts to review project materials and analyze project data (e.g. interview material or data collected in the sea ice monitoring program).

Siku-Inuit-Hila reveals the true strengths of bringing together multiple perspectives on sea ice. The local-scale perspective of Inuit hunters and whalers, with their detailed knowledge of sea ice characteristics, dynamics, and changes, complements the larger-scale perspectives provided by some scientific methods such as remote sensing. As a team, the members of *Siku-Inuit-Hila* have also documented in detail what it means to live with sea ice and how sea ice changes are having an impact on local communities in different parts of the Arctic, as well as the broader environment and climate system.

The project ran through 2010 and the team is preparing to publish a book based on their research together. The project was funded by the National Science Foundation, with Dr. Shari Gearheard from the National Snow and Ice Data Center, University of Colorado, as the PI.

3.3.3 Summary discussion

The development of effective adaptation strategies requires an understanding of the vulnerability, sensitivity, and resilience of human-environment systems in a changing Arctic, in terms of who is vulnerable, to what stresses, what are the determinants of vulnerability and resilience, and what are the opportunities for adaptation policy (Ford, 2008b; Ford et al., 2008b, 2009; Furgal and Seguin, 2006; Turner et al., 2003a, 2003b).

Several frameworks and methodologies for vulnerability and resilience assessment have been proposed for application in Arctic contexts (Chapin, 2006, Chapin et al., 2004, Ford and Smit, 2004, Wolfe et al., 2007, Smit et al., 2008, Turner et al., 2003a, Alessa et al., 2008, Berkes et al., 2007, Ford, 2009; Keskitalo, 2008a, 2008b, Huntington et al., 2007a); common to the majority is the integration of insights from human and biophysical sciences with local and traditional knowledge. While there is an important role for expert assessment of hazard exposure and other sources of vulnerability, it is also important to recognize that communities and residents are often best placed to identify sources of vulnerability and to initiate coping strategies that form important components of adaptive capacity. A recent synthesis of case studies exemplifying these principles is the final report of the CAVIAR project (Hovelsrud and Smit, 2010).

Nowhere is the complexity of the climate change governance scenario more apparent than at the intersection of those communities 'on the edge' of land, sea, and cultural experience (Pearce et al., 2010; Loring et al., 2011). Ongoing assessment of adaptation in Arctic coastal community settings speaks to the gamut of traditional, theoretical and applied forms of knowledge in play, as well as the political and ethical dimensions of the transformative process. Adaptation must be understood as both an exercise of memory in relation to past hazards, and as an outcome of an ongoing community-scale 'learning system'. Analyses based on this orientation have become more prevalent in the global climate change domain, but there remain few demonstrably-related initiatives to integrate Arctic-region investments in physical interventions with those of a social orientation. Future efforts need to focus on management in the face of change, building of community adaptive capacity and resilience, and recognition that change to both physical and human systems in the Arctic has become constant.

3.4 Governance and Adaptation

Lead author: Alf Håkon Hoel

Key Findings

- National agencies are the main actors in regional governance. In some areas such as northern Canada, regional (or in this case, territorial) agencies may play an equally important part. At national and international scales, almost all international land boundaries are settled, meaning that national jurisdiction at the coast is generally clear.
- There are enormous differences across the circumpolar Arctic in population size and distribution, economy, culture, institutional framework, and other factors.
- There are few Arctic-specific international regimes: the 1973 Polar Bear Treaty is the only legally binding regime.
- The Arctic Council, based on soft law (1996 Declaration), works primarily through assessment programs and projects to develop consensual knowledge and understanding on the status of the Arctic environment and related issues among the eight Arctic countries.
- Integrated coastal area management and integrated ecosystem-based oceans management are desirable strategies for coastal area governance and may embody a number of best practices which have emerged from recent reviews.
- Conclusions from consideration of integrated ecosystem-based management include the following:
    - Management needs to be flexible;
    - Decision-making must be integrated and science-based;
    - National commitment is required for effective management;
    - Area-based approaches and trans-boundary perspectives are necessary;
    - Stakeholder and Arctic resident participation is a key element;
    - Adaptive management is critical.
- It has been recommended that future research should focus on increasing support, opportunity, and capacity for local decision-making or effective resident input to decisions on broader institutional policies with local impacts.

Governance is a purposeful act to realize some objective of an organization, the efforts of some collective to confront problems or challenges they are facing through collective action. Collective action at all societal levels is complex and difficult (Olson, 1965), and constitutes a core area of study in the social sciences. The concept of 'institution', as social order governing the interaction of people, is central to this tradition (Scott, 2001).

In the realm of environmental studies, broadly speaking, two traditions have emerged in the study of collective action problems in relation to the environment: one considers how remedial *action* can be taken and what policy instruments are available for that (Young and Bjerregaard, 2008); the other takes a more resigned stand and asks how can we *adapt* to the deplorable state of affairs (rather than doing something about it) (Folke et al., 2005).

Either way, key questions in the study of environmental governance include the following:

- nature of the problem at hand (tragedy of the commons, etc)
- nature of institutions and flexibility to modify institutions
- drivers (causal factors) of institutions (knowledge, power, etc)
- institutional performance (effectiveness, justice, etc)
- interactions between institutions

Each of these questions is addressed by substantial and impressive literatures, and the state of knowledge with regard to these issues has been conspicuously improved during the last decade or so.

Figure 40. States, organizations, and strategic issues in the Arctic.
Source: People across Borders

3.4.1 Dimensions and scales of governance

The dimensions of governance involve:

- What is governed: what are the attributes of the governance problem? What is the societal sector in question –economic, social, military? Is it a local problem (e.g. pollution) or the ramifications of global change (climate)?
- Who is governing? Is the collective action confronted locally, at a regional or national level, or even at an international or global level? Or are we facing nested governance systems where international rules define national obligations and where implementation has local effects?
- How does governance occur? What are the rules of the game? Who can participate and how? What are the types of policy instruments that are in use: economic incentives, rules, information? At what level of governance does government occur? Are there interactions between the various levels of governance?

The question of institutional performance is particularly acute, as this addresses the issue of whether the collective action undertaken to confront challenges (that is, governance) actually works.

3.4.2 Arctic challenges and current institutions for governance

Many of the major challenges facing the Arctic today are of global origin (Fig. 40). Climate change, global overfishing, the drive to develop petroleum reserves in remote areas, the search for marine genetic resources – all of these are global phenomena with Arctic manifestations, also in the coastal zone where people live and work.

The institutional responses to these challenges are in many cases global, rather than Arctic. There is a global climate regime, a global Convention on the Law of the Sea, and these regimes set the standard that governments are expected to conform to when confronting these challenges. In particular when it comes to the oceans, the Law of the Sea Convention, which is a broad framework for the governance of all aspects of use of the world's ocean, settles questions of who can decide what where and who owns what.

There are few Arctic-specific international regimes: the 1973 Polar Bear Treaty is the only legally binding regime. The Arctic Council (see Section 2.3), based on soft law (1996 Declaration), fundamentally works through assessment programs and projects to develop consensual knowledge and understanding on the status of the Arctic environment and related issues issues. The Arctic Council consists of eight Arctic countries, six Permanent Participants (organizations representing indigenous peoples), and a number of observer countries and organizations.

The Arctic Council is a 'high level forum', under which the actual work is carried out in a number of working groups operating under the oversight of Senior Arctic Officials representing the foreign ministers of the eight Arctic countries:

- The Arctic Monitoring and Assessment Programme (AMAP)
- The Conservation of Arctic Flora and Fauna (CAFF)
- Emergency Preparedness, Prevention and Response (EPPR)
- Protection of the Arctic Marine Environment (PAME)
- The Sustainable Development Working Group (SDWG)
- The Arctic Contaminants Assessment Program (ACAP)

The Arctic Council has a central secretariat in Tromsø, Norway, and each of the working groups has a secretariat located in one of the Arctic countries. Altogether 15-20 people staff the Arctic Council secretariats. In addition, the chairmanship, which rotates among members on a bi-annual basis, has 2-3 persons working continuously on Arctic Council business.

The Arctic Council makes decisions by way of ministerial declarations which are adopted at ministerial meetings every second year. In between the ministerials, the Senior Arctic Officials (SAOs) of the Arctic countries run the business through two annual SAO meetings, providing the day-to-day directions for the working groups.

The Arctic Council has three functions: First, it examines the status of scientific knowledge in selected issue areas, and produces assessments of our current understanding of important issues like climate change in the Arctic, oil and gas development, shipping, pollution, quality of life and living conditions in the Arctic. This brings about a critical factor for political action: agreed knowledge. Second, in doing so, agency officials, scientists, and other actors from the Arctic countries and others establish a joint frame of reference for understanding various challenges facing the region and how they can be resolved. And thirdly, this in combination with the development of guidelines in various issue areas (for example offshore oil and gas development) enhances the capacity of countries to act in relation to management of the Arctic environment and other aspects.

Countries are the major actors in the governance of the region. All land boundaries and a majority of ocean boundaries are settled. In the coastal zone proper, the international dimension of governance manifests itself through the obligations that countries have to implement various principles and standards for environmental quality and performance. In Europe, this derives first of all from EU regulations, but also from global treaties, such as the Kyoto Protocol, the implementation of which has implications for economic activities in the coastal zone (e.g. shipping).

3.4.3 Best practices

In the Norwegian Chairmanship of the Arctic Council (2006-2009), a project was initiated to examine how the various Arctic countries have approached the need for ecosystem-based oceans management. The project was carried out by a project group working under the Sustainable Development Working Group (SDWG) and the Protection of the Arctic Marine Environment (PAME) Working Group of the Arctic Council. The project resulted in a report (Hoel, 2009) containing national case studies of Arctic ecosystem-based oceans management, as well as a set of "Best Practices" for ecosystem-based oceans management in the Arctic. The Best Practices were endorsed by the Arctic Council ministerial meeting in April 2009.

The report *Best Practices in Ecosystems Based Oceans Management in the Arctic* contains some *core elements*, as well as a set of *conclusions*. The Core Elements, which are aspects of ecosystem-based oceans management found in most countries, include the following:

- The geographical scope of ecosystems defined by ecological criteria.
- The development of scientific understanding of systems and of the relationship

between human actions and changes in other system components.
- The application of the best available scientific and other knowledge to understand ecosystem interactions and manage human activities accordingly.
- An integrated and multidisciplinary approach to management that takes into account the entire ecosystem, including humans.
- Area-based management and use of scientific and other information on ecosystem changes to continually adapt management of human activities.
- The assessment of cumulative impacts of different sectors on the ecosystem, instead of single species, sectoral approaches.
- A comprehensive framework with explicit conservation standards, targets and indicators in order to facilitate responses to changes in the ecosystem
- Trans-boundary arrangements for resolution and handling of trans-boundary ecosystems and issues.

The *Conclusions* were arrived at by reviewing the practices countries have established in developing and implementing ecosystem-based oceans management, and identifying elements that had been found useful in one or more contexts.

1. **Flexible application of effective ecosystem-based oceans management**
    - Differences in circumstances and contexts have to be taken into consideration as ecosystem-based oceans management is context sensitive. There is not one single method for ecosystem-based management. A number of different practices and understandings of the concept appear to work.
    - Ecosystem-based management is a work in progress and should be considered a process rather than an end-state.
    - Rule-based relationships between countries in oceans affairs, based on applicable international law and agreements, have to be promoted.
    - Recognition of humans as an ecosystem component, and increased consideration of social effects when food security and poverty alleviation are issues of concern.
    - Management must be based on best available science. Open lines of communication between managers, resource users, and the general public are necessary to foster mutual understanding and recognition of shared interests.
    - Biodiversity conservation strengthens the structure and functions of ecosystems, thus ensuring the long term delivery of ecosystem services.

2. **Decision-making must be integrated and science based**
    - Increased communication and exchanges among both states and sectors are also key components of successful ecosystem-based management. A great deal of scientific knowledge already exists. However, much of this information needs to be better synthesized and communicated to a variety of audiences. Cooperation in science and exchange of relevant information within and between countries is important for understanding the cumulative impacts to the coastal marine environment. Another challenge is to address what information exists and what information still needs to be gathered. Knowledge gaps can be closed through development/identification of key ecosystem indicators and comprehensive modelling, mapping, monitoring, and analysis.
    - Various forms of scientific, traditional, and management knowledge need to be integrated to improve ecosystem-based management. Potential advantages of

integrating various forms of knowledge include decision-making that is better informed, more flexible, and incorporates traditional ecological knowledge.
- A multi-sector approach lies at the core of the ecosystem approach as it contributes to a common understanding of challenges in oceans management and thereby an increased trust between authorities with different sector responsibilities/interests. Ecosystem-based management calls for coordination and shared responsibility between all levels of government and cooperation across sectors, with respect to monitoring, mapping and research. The challenge of monitoring, however, is both a scientific challenge and a policy issue. Monitoring programs can provide the ongoing basis for management, but require a long-term commitment of resources. Secondly, a multi-sector approach depends on providing opportunity for stakeholder comments on how a specific sector is to be managed or how to assess the impact of that sector in relation to the ecosystem. This is a difficult process, requiring care and time.

3. **National commitment is required for effective management**
    - National commitment to conservation and sustainable use of ocean resources is necessary. A 'road map', management plan or national action plan for addressing priorities in coastal and oceans management is developed in many of the Arctic countries.
    - An integrated organizational structure (framework) to support the coordination of a holistic approach to the implementation of ecosystem-based management (EBM) at the national level through inter-agency cooperation seems to be effective. In this respect, harmonization of domestic laws governing use of coastal and ocean resources with EBM principles, as well as with regional and international management efforts may be appropriate. This requires legislation and enforceable policy tools to provide government strategic directions and overall framework for EBM implementation.

4. **Area-based approaches and trans-boundary perspectives are necessary**
    - Area-based management approaches are central to ecosystem-based management. The identification of management units within ecosystems should be based on ecological criteria. Management measures should reflect the status of areas and take into account the human element.
    - Ecosystem-based management requires specific geographical units at various scales.
    - Issues of scale can be addressed viewing ecosystems as nested systems.
    - The identification and protection (including through protected areas and networks) of key areas, species, and features that play a significant role within the marine ecosystem help management set priorities and ensure ecosystem structure and function are maintained (see Box in Section 2.2.).
    - Increased international cooperation in shared ecosystems could be addressed through existing regional management bodies and, as necessary, new collaborative efforts focused on individual ecosystems.
    - Effective area-based approaches include mechanisms for addressing effects of land-based activities and atmospheric deposition on ocean ecosystems.

5. **Stakeholder and Arctic resident participation is a key element**
    - Stakeholder and Arctic resident consultation, co-management or decision-

making are important to build understanding and foster development of knowledge.
- Stakeholder participation can be encouraged by providing for public participation in a manner that enables stakeholders and members of the public who lack the capacity to prepare for/attend numerous meetings to make their voices heard in a meaningful fashion.
- Stakeholders can be engaged to develop and strengthen cooperative processes to sustain ecosystem structure and function.
- Effective stakeholder participation can encourage and achieve compliance with necessary conservation measures through education and enforcement.

6. Adaptive management is critical

- Effective management requires adaptive management strategies that reflect changing circumstances. This is especially important in view of the accelerating effects of climate change on marine and coastal ecosystems.
- Implementation of ecosystem-based management should be approached incrementally.
- Conservation objectives and targets, benchmarks and action thresholds should be set for the measurement of achievement of ecosystem health.
- Flexible mechanisms should be used for implementing ecosystem-based management
- While the best practices in Hoel (2009) were developed with oceans rather than coasts in mind, most nevertheless are applicable to and useful for coastal-zone management.