VULNERABLE OR RESILIENT? A MULTI-SCALE ASSESSMENT OF CLIMATE IMPACTS AND VULNERABILITY IN NORWAY

KAREN O'BRIEN [1], LINDA SYGNA [1] and JAN ERIK HAUGEN [2]

[1] *CICERO, University of Oslo, P.O. Box 1129. Blindern, 0318 Oslo, Norway*
E-mail: karen.obrien@cicero.uio.no
[2] *The Norwegian Meteorological Institute, P.O. Box 43, Blindern, 0313 Oslo, Norway*

Abstract. This paper explores the issue of climate vulnerability in Norway, an affluent country that is generally considered to be resilient to the impacts of climate change. In presenting a multi-scale assessment of climate change impacts and vulnerability in Norway, we show that the concept of vulnerability depends on the scale of analysis. Both exposure and the distribution of climate sensitive sectors vary greatly across scale. So do the underlying social and economic conditions that influence adaptive capacity. These findings question the common notion that climate change may be beneficial for Norway, and that the country can readily adapt to climate change. As scale differences are brought into consideration, vulnerability emerges within some regions, localities, and social groups. To cope with actual and potential changes in climate and climate variability, it will be necessary to acknowledge climate vulnerabilities at the regional and local levels, and to address them accordingly. This multi-scale assessment of impacts and vulnerability in Norway reinforces the importance of scale in global change research.

1. Introduction

For a country that prides itself in the belief that there is no such thing as bad weather – only bad clothing, the prospect of climate change is not very intimidating to Norwegians. In fact, in contrast to the many countries that are considered 'particularly vulnerable' to climate change, Norway may serve as an example of a 'particularly resilient' country when it comes to climate change impacts. With a per capita income of USD $34,530, Norway ranks among the wealthiest countries in the world (World Bank, 2002a). Adaptation costs can potentially be underwritten by investments based on large oil revenues, for although Norway produced only 3.6% of total world oil and natural gas in 1997, it is the second largest exporter of oil in the world. Extreme weather conditions are familiar to Norwegians, and a national disaster relief fund has been in place since 1962 to address climate-related damages. All in all, the prospect of a warmer climate is generally welcomed in a country where annual average temperatures vary from a mild 7 °C on the west coast to a frigid –3 °C in the northern inland areas.

However, complacency about climate change and its anticipated impacts erodes when one moves down in scale, from national to regional and local levels. Aggregated statistics and generalizations about 'Norway' lose their relevance as climate

Climatic Change **00:** 1–33, 2003.

change manifests itself differently across regions, sectors, and social groups. Changes in temperature, precipitation, and other climate parameters will vary across Norway, resulting in differential exposure and uneven consequences. Even if exposure were consistent across Norway, some regions, sectors, or social groups are more socially vulnerable to climate change than others. For example, communities that rely heavily on economic activities based on natural resources that are sensitive to climate and climate variability (e.g., winter tourism) are likely to be disproportionately vulnerable to climate change.

Although long-term adaptation to climate change is likely, there is a need to identify the most vulnerable sectors, regions, or communities, and to assess adaptive capacity within each of these. This is particularly important because the socio-economic conditions that shape vulnerability and adaptive capacity are likely to change along with the climate. Indeed, Norway's oil-based economy currently sustains a large public sector in many municipalities, providing employment opportunities for many Norwegians outside of climate-sensitive sectors; a reduction in oil income may limit any expansion of the public sector, which in turn may increase vulnerability to climate impacts in some communities.

In this paper, we provide a multi-scale assessment of climate change impacts and vulnerability in Norway, exemplifying how the concept of vulnerability depends on the scale of analysis. We first discuss the concept of vulnerability within the climate change literature, including the related concepts of exposure, sensitivity, adaptive capacity, resilience, and robustness. To illustrate differential exposure to climate change within Norway, we present scenarios at national, regional, and local scales,* and discuss the anticipated impacts on climate-sensitive sectors. We then consider vulnerability, which is shaped not only by exposure, but by the underlying social and economic conditions that influence adaptive capacity. A national-level assessment suggests that climate change may be beneficial for Norway. However, when social and economic differences within Norway are taken into consideration, then vulnerability emerges within some regions, localities, and social groups.

This multi-scale assessment of impacts and vulnerability in Norway reinforces the importance of scale in global change research. (Wilbanks and Kates, 1999). This is not to say that one scale of analysis is superior to another. In fact, most resource management systems are multiscale (see Berkes, 2002), thus a multi-scale analyses may provide greater insights into vulnerability and adaptation. In any case, impact and vulnerability assessments are carried out for different reasons. The understanding of aggregate impacts and vulnerability provided by national and

* By national level assessments, we refer to impact and vulnerability assessments that focus on impacts for a particular country, such as Norway. Although these assessments may be international or multinational in scope, the general unit of analysis is the country. Regional and local assessments refer to those studies that distinguish differential impacts within a country. A national-level assessment thus differs from a country study, which usually focuses on regional, sectoral, and local-level impacts and vulnerabilities.

global level assessments can be useful for international comparisons, as well as for identifying the relative importance of impacts and potential adaptations within particular sectors. At the regional and local scales, impact and vulnerability assessments can begin to uncover the complexity of vulnerability, addressing the questions not only of 'whether', but of 'where, how, and why'.

As we demonstrate with the example of Norway, it is important that the scale of analysis be congruent with the purpose of the assessment, and that conclusions from one scale are not erroneously applied to other scales, leading to misunderstandings of cause and effect (Wilbanks and Kates, 1999; Gibson et al., 2000). In the big picture, Norway may indeed be considered resilient to climate change. However, to cope with actual and potential changes in climate and climate variability, it will be necessary for policy makers, sectoral associations, and local institutions to acknowledge climate vulnerabilities at the regional and local levels (that is, within Norway), and to address them accordingly. The relevance of scale in vulnerability assessments is important not only to Norway, but to all countries that consider themselves as either resilient or vulnerable to climate change.

2. Vulnerability versus Resilience

Much of the climate impacts literature focuses on vulnerability and the related concepts of exposure, sensitivity, adaptability, robustness, and resilience (Watson et al., 1996; McCarthy et al., 2001). These characteristics are used to describe how particular 'exposure units' respond to climate change (Parry and Carter, 1998). The exposure units in impact assessments are often geographic regions, countries, sectors, ecosystems, and less frequently, social groups.

Vulnerability describes the extent to which a system is susceptible to sustaining damage from climate change (Schneider and Sarukhan et al., 2001). It can be considered a dynamic state or condition that is influenced by both biophysical and socioeconomic conditions (Dow, 1992; Bohle et al., 1994; Liverman, 2001, Kasperson et al., 2001). Although many conceptualizations of vulnerability have emerged from the natural hazards and food security literature, within the climate change literature it is generally considered to be a function of exposure, sensitivity, and adaptive capacity (Schneider et al., 2001). These concepts are described in Table I.

There are three features of vulnerability that are important to recognize. First, vulnerability is inherently a differential concept, because risks or changes and the ability to cope with them vary across physical space, as well as among and within social groups. Second, vulnerability is scale-dependent. That is, it varies depending on the unit of analysis, from 'country' to 'region', 'community', or 'social group'. Although a country may not be considered vulnerable to environmental change, there are likely to be regions or groups within that country that are indeed vulner-

Table I
Factors influencing climate vulnerability. (Source: Smit et al., 2000; McCarthy et al., 2001)

- *Exposure* – the degree of climate stress upon a particular unit of analysis. Climate stress can refer to long-term changes in climate conditions or to changes in climate variability and the magnitude and frequency of extreme events.
- *Sensitivity* – the degree to which a system will respond, either positively or negatively, to a change in climate. Climate sensitivity can be considered a precondition for vulnerability: the more sensitive an exposure unit is to climate change, the greater are the potential impacts, and hence the more vulnerable.
- *Adaptability* – the capacity of a system to adjust in response to actual or expected climate stimuli, their effects, or impacts. The latest IPCC report (McCarthy et al., 2001, p. 8) identifies adaptive capacity as 'a function of wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities'.

able. Finally, vulnerability is dynamic, and may change over time as underlying structures and conditions change.

Resilience is often considered to be the opposite of vulnerability. In the climate change literature, resilience refers to a tendency to withstand, recover from, or adjust easily to misfortune or change (Smit et al., 2000). The term has been traditionally used as a measure of the functioning and control of ecological systems (Carpenter et al., 2001). More recently, however, it has become part of discussions concerning nature-society interactions and global change (Folke et al., 2002). Adger et al. (2002, p. 359) define social resilience as 'the ability of communities to absorb external changes and stresses while maintaining the sustainability of their livelihoods'. Whereas resilience refers to the ability to recover from stresses, robustness is a characteristic associated with strength or vigorous health, and it describes the degree to which a system is not susceptible to damages from external stresses in the first place (Smit et al., 2000).

Vulnerability and resilience are somewhat generic concepts, and the underlying or driving factors often overlap to make distinctions between the two unclear. When exposure, sensitivity, and adaptive capacity are added to the discussion, it becomes difficult and confusing to distinguish whether or how one concept influences or interacts with the others. Does vulnerability influence adaptive capacity, or does adaptive capacity determine vulnerability? Does decreasing sensitivity enhance adaptive capacity? Does reduced vulnerability always lead to increased resilience? It is important to emphasize that all of these concepts describe relative rather than absolute states that are dynamic over time, and thus difficult to measure or quantify.

We find it useful to conceptualize vulnerability and resilience as representing different states along a multidimensional continuum which spans from vulnerable to resilient, including flexible axes that characterize the biophysical properties of a system; that is, sensitivity and robustness. Each exposure unit is situated along this continuum, with its location determined by a myriad of factors related to both social and biophysical conditions. If the sensitivity or robustness of a system or unit changes (for example, as the result of technological changes or when a threshold is surpassed), then the unit may move towards the vulnerable or resilient end of the continuum. It is important to note that high sensitivity does not invariably contribute to high vulnerability (for example, it can be beneficial when exposure to climate change improves productivity). At the same time, for any given level or type of exposure (which can change as the result of climate mitigation policies), changes in adaptive capacity can also move a system or exposure unit from vulnerable to resilient, or vice versa.

The position on the continuum is tied to the scale of analysis. For example, national-level assessments may place a country on the resilient end of the continuum, but regional- or local-level analyses might shift some areas towards the vulnerable end, i.e., relatively less resilient. The factors or driving forces that shape vulnerability and resilience will also change with the scale of analysis, reflecting differences in both spatial scale and the relative factors that are considered important to vulnerability within the context of the assessment. For instance, at the national level, resilience may be shaped by the macro economic situation, exemplified by indicators such as GDP or employment diversity. At the local level, resilience may be tied more closely to entitlements such as crop insurance, savings, and so on.

Conclusions derived from impact and vulnerability assessments are valid for the scale of the assessment, and should not be generalized to other scales (Wilbanks and Kates, 1999). Ignoring the scale-dependency of results can be problematic in terms of understanding and addressing climate change, particularly if conclusions are derived from coarse scale assessments. In this case, winners and losers at the local level are likely to be obscured, and an incomplete understanding of vulnerability will result (O'Brien and Leichenko, 2003). Yet it is first and foremost at the local level where the consequences of climate change will be felt (Adger, 2001). Although national or international policies may facilitate or constrain adaptation, most adaptive responses will be made at this level by resource managers, municipal planners, and individuals.

Furthermore, conclusions regarding resilience or vulnerability based on aggregated level assessments may hamper mitigation or adaptation policies. Generalizations about benefits or 'winning' may generate complacency about the impacts of climate change and diminish the resolve to address climate change in a country like Norway, whose economic performance is tightly linked to fossil fuels (Caplan et al., 1999). In contrast, generalizations about 'losing' may foster a sense of helplessness or victimization that is unwarranted when regional or local level analyses are considered (O'Brien and Leichenko, 2003). Such defeatism may make it difficult to exploit benefits or identify opportunities for adaptations. To successfully address climate change, there is a need to consider vulnerability at multiple scales, and assess both mitigation and adaptation options and strategies at each scale.

3. National Level Assessment

At first glance, Norway, a country with 4.5 million people spread over 323,758 km^2, can be considered relatively robust to climate change. Norway's coastal geomorphology is relatively steep, with low-lying land limited to parts of the southern coast. In addition, isostatic land uplift is still taking place after the last glaciation in eastern parts of Norway (Holtedahl, 1960). Consequently, most of Norway's extensive coast is not considered vulnerable to sea level rise (Aunan and Romstad, 2003). Furthermore, Norway's architecture and infrastructure are generally designed to tolerate extreme weather conditions. While some standards and regulations will clearly have to be altered to accommodate changing patterns of precipitation, wind, temperature and extreme events, Norway's building industry is at the forefront in terms of developing climate adaptation strategies (Lisø et al., 2002).

In addition, Norway has a 'climate culture', where people are accustomed to harsh or bad weather. Norway's mainland and islands extend from 57°57′ to 71°11′ degrees N. latitude. Its climate varies from one region to another, with different types of extremes prevalent in different parts of the country. Nearly one-third of the country is located north of the Arctic Circle, experiencing frigid or cool weather throughout the year. The coastal climate is characterized by mild winters and cool summers, with frequent precipitation throughout much of the year. The interior of the country has colder winters, warmer summers, and less precipitation. Norwegians pride themselves on being robust in terms of climate and climate extremes, and have adopted many coping strategies, including weather-tolerant clothing. Furthermore, many Norwegians travel to warm locations for vacation one or more times per year, a trend that is facilitated by strong economic growth and affluence. The warmer temperatures expected to result from climate change seem to be viewed positively by many Norwegians, particularly those who equate them with longer and warmer summers.

Although Norway can be considered robust to climate change relative to many other countries, its economy can nevertheless be considered sensitive to climate change. Norway has a very open economy, where exports and imports of goods and services represented the equivalent of 46 per cent and 30 per cent of GDP, respectively, in 2001 (Statistics Norway, 2001b). With a comparative advantage in natural resources, Norway's income is strongly influenced by environmental conditions and international markets. On the export side, the oil and gas sector is by far the most important, accounting for 46% (NOK 306 billion) of total export earnings in 2000 (Statistics Norway, 2001b). Fisheries and aquaculture follows with a share of 4.5% (Forsberg and Kaise, 2000). The marine sectors are expected to increase dramatically in the coming decades, eventually replacing oil as a primary source of export earnings.

Norway's sensitivity to climate change applies to current socioeconomic conditions. What the future holds in terms of both sensitivity and vulnerability is, however, highly dependent on future economic, political, demographic and social processes. Changes in the age distribution of the population and the prospects of reduced petroleum incomes constitute the main political and economic challenges in the years ahead. Norway's population is expected to continue to grow slowly, increasing by two to three per cent every five years the next decades (Statistics Norway, 1999). Within a projected population of 4.8–5.8 million in 2031, older people will constitute a larger share than today, and estimates show that retirement and disability payments will increase from 8 percent of GDP in 2001 to 16 per cent in 2030 (The Royal Norwegian Ministry of Foreign Affairs, 2002). Similar increases in national income are not expected. On the contrary, state income from the petroleum industry is expected to drop from 10 per cent of GDP to 2 per cent over the same time span (The Royal Norwegian Ministry of Foreign Affairs, 2002). Whether the government's Petroleum Fund* will be able to buffer the budgetary deficits is questionable, and highly dependent on developments within the mainland economy. Only small distortions in the mainland economy, which currently accounts for about four-fifths of the total output of Norway's economy, can be enough to erode the buffering capacity of the Petroleum Fund (The Royal Norwegian Ministry of Foreign Affairs, 2002).

Projections of GDP and employment by sector (up to 2030) indicate that the importance of offshore oil-related activities will decline in importance, as will primary sector activities within the mainland economy (Table II). Meanwhile, both the service sector and the public sector are expected to grow. Norway's economy in 2030 is likely to rely more on mainland activities, where the service sector will be more important than the commodity sector.

Future social and economic development is likely to take place within the context of changing climate conditions throughout Europe, including a warmer and wetter climate in Norway. Results from climate scenarios based on the most relevant global circulation models (GCMs) show a general warming in Europe throughout the year, with decadal temperature variations stronger in Scandinavia compared to the global mean. The models also show increased winter precipitation in northern Europe and drier winter conditions in southern regions (Hulme and Carter, 2000). Both Raisanen (2001) and Christensen et al. (2001) found a general increase in precipitation for the Nordic region; the latter study reported a tendency towards generally wetter autumns (15% increase). However, at the regional scale, there is larger scatter among GCM results.

* The Norwegian Government Petroleum Fund was established in 1990 by the Parliament. The fund is intended to serve as a tool in the management of fiscal policy, by making the spending of petroleum income more visible (Ministry of Finance, 2002).

Table II
Gross domestic product and employment by sector (percent). (Source: NOU, 1996)

Sector	Share of GDP (%)			Share of employment (%)		
	1992	2010	2030	1992	2010	2030
Extraction of crude petroleum and natural gas	12.9	9.1	3.0	1.0	0.6	0.3
Ocean transport and oil drilling	2.4	2.8	2.4	3.1	2.5	2.4
Primary industries	2.6	2.0	1.1	7.5	4.5	1.8
Manufacturing and mining	11.5	11.2	8.7	15.0	14.6	10.3
Electricity and gas supply	2.8	3.3	3.4	1.0	1.0	1.0
Construction	3.6	3.7	3.8	5.9	6.4	6.2
Service industries [a]	40.0	41.0	46.1	39.8	42.7	45.0
Public sector	16.4	17.0	21.0	26.7	27.7	33.0
Miscellaneous	7.8	9.9	10.5	0	0	0
All	100.0	100	100	100	100	100
Summary of main trends:						
Industry (offshore and mainland)	75.8	73.1	68.5	73.3	72.3	67.0
Industry (mainland)	60.5	61.2	63.1	69.3	69.2	64.2
Service industies [a]	40.0	41.0	46.1	39.8	42.7	45.0
Public sector	16.4	17.0	21.0	26.7	27.7	33.0

[a] Includes wholesale and retail trade, hotels and restaurants, communication and transport (except ocean transport), bank and insurance, dwelling service and other private services.

The projected regional warming from 1990 to 2050 over Norway is 0.1 to 0.5 °C/decade (Benestad, 2002). The increase is expected to be largest during winter and smallest during spring and summer. At latitudes closer to the Arctic region, the increase is even higher due to a reduction of the snow and ice cover (Hulme and Carter, 2000). In terms of precipitation, an analysis based on 13 GCM models showed an increase of annual precipitation in Norway of about 35–55 mm/year from 1961–1990 to 2010–2039 (Benestad, 2000).

Uncertainty regarding the positive temperature and precipitation trends can be attributed to variations in future greenhouse gas emissions, natural climate variability, and differences in the response of the climate system in individual GCMs. With resolutions often on the order of 300 km $\times$ 300 km, coarse-resolution models also lack topographic detail for the Scandinavian Peninsula. Adding to the uncertainty, a significant amount of the rainfall over Scandinavia can be associated with the North Atlantic Oscillation (NAO) Index. However, there is little consensus within multimodel ensembles as to how the NAO is affected by global warming (Benestad, 2002). Moreover, the climate conditions in Norway are highly dependent on the heat transported by the North Atlantic Ocean Current (NAC). One important premise for this heat transport is the North Atlantic Deep Water (NADW), an ocean current that 'pulls' the Gulf Stream northwards. During the past several decades, a significant reduction in this deep-water formation has been observed (Houghton et al., 2001). It is thus possible that a weakening of the ocean current may result in new periods of climatic instability in Norway and other areas, and possibly a negative feedback in terms of temperature changes (Davies et al., 2001; Vellinga and Wood, 2002).

The scenarios of climate change presented above are likely to affect the performance of Norway's economy, either positively or negatively. However, in this case, the high sensitivity of the Norwegian economy does not necessarily contribute to high vulnerability. Indeed, for an economy that is based heavily on natural resources or industries dependent upon natural resources, warmer and wetter conditions may in fact present benefits and opportunities. National-level impact assessments based on scenarios generated by coarse-resolution models generally conclude that Norway may be a winner under climate change (Parry, 2000; Fischer et al., 2001).

Norway's energy sector is likely to receive economic benefits from increased precipitation under climate change. Almost all electricity production in Norway is based on hydropower. Norwegian electricity production is estimated to increase by almost 4% under scenarios of future climate change, largely because of changes in runoff (Sælthun et al., 1998).* This change may seem marginal, but in terms of production value it translates to an annual increase of approximately NOK 1.4 billion. For comparison, the value of hydroelectricity production was NOK 36.3 billion in year 2000 (Statistics Norway, 2001). At the same time, a temperature increase of 2.1 °C by 2060 is expected to result in a 5% decrease in electricity demand, mainly through reductions in household heating (Sælthun et al., 1998). Increased energy demand due to increased use of air conditioning during summer is assumed to be marginal, as the warming is expected to be larger during winter compared to summer.

Norway's fishery and aquaculture sectors are also expected to benefit from climate change (Norwegian Ministry of Environment, 1991). These sectors are currently experiencing tremendous growth, with the value of products expected to increase from NOK 35 billion in 2000 to NOK 150 billion by 2020 (ECON, 2000).** Climate change is expected to impact freshwater and marine environments strongly (IPCC). Studies indicate that the stock of some fish species in Norway may increase by as much as 40% (Norwegian Directorate for Nature Management, 1990). Warmer ocean temperatures may also lead to the introduction of new fish

* Assuming an annual mean temperature increase of 0.30–0.45 °C/decade and annual precipitation increases of 1.5–2.0% over the next 30 years, compared to the baseline 1961–90.

** These estimates do not include the impacts of climate change.

species from the south. The expected warming of mid-to high latitude waters will also result in a lengthening of the growing season for cultured fish and shell fish. This in turn will be beneficial to the growth rate and the feed conversion efficiency (Lehtonen, 1996). Increased water temperatures could also lead to a northward expansion of the area suitable for aquaculture production.

Northern agriculture is frequently cited as a winner under climate change (Haglerød, 1990; Parry, 2000; Fischer et al., 2001; McCarthy, 2001). Warmer and wetter conditions are likely to lead to a longer growing season, higher agricultural crop yields, an expansion of the area suitable for crop cultivation, and the potential for introduction of new crops (Haglerød, 1990; Harrison and Butterfield, 1999; Skaugen, 2002b). A recent study by IIASA calculated the increase in cereal production in Norway to exceed 50%, compared to average production in 1992–1993, assuming one crop per year with a high level of inputs on land that is currently under cultivation (Fischer et al., 2001). The increases are assumed to be even greater if multi-cropping and irrigation is included (Fischer et al., 2001). Similar effects are also projected for seed crops, such as soybean and sunflower, maize and potato (see McCarthy et al., 2001, p. 668). Climate change may thus be considered a boon to Norwegian agriculture and the 60,300 farms that employ about 3% of the total working population (Norwegian Ministry of Agriculture, 1998).

Approximately 37% of Norway's land area (12 million hectares) is presently covered by forests. Although only about 0.25% of the total workforce is employed directly in this sector, forestry and forestry-related industries are Norway's third largest export industry (Statistics Norway 2000). Studies indicate that areas of land available for forest production in Norway may increase by 30% under climate change (Norwegian Ministry of Environment, 1991). In fact, the current northward expansion of the boreal forest and increase in biomass is likely to continue under warmer conditions (Holten et al., 1993; Parry, 2000). Increased production of species with a high market value may increase the profitability of the forestry sector (Norwegian Ministry of Environment, 1991).

The promising outlook for Norway under climate change is, of course, limited by the assumptions and factors included (or not included) in the studies. In agriculture, the quantity and quality of yields may be influenced by increased incidents of pests and diseases, and by soil erosion and nutrient deficiencies resulting from climate change (Haglerød, 1990; Hessen and Wright, 1993). Furthermore, the calculations by Fischer et al. (2001) assume optimal adaptations of crop calendars, as well as switching of crop types. These adaptations may or may not be optimal in the context of structural changes in Norway's agricultural sector. For example, the number of farms is expected to decrease by up to 50% over the next thirty years (Nersten, 2001), and subsidies to farmers may be reduced (Søyland, 2002). Economic and institutional changes, such as membership in the European Union, are also likely to have significant consequences for Norwegian agriculture, changing the context within which farmers operate.

Likewise, forest production may be constrained by increased winds, a lack of winter snow cover, and spring frosts (Parry, 2000). Studies have shown that the distribution of some of the traditional forest species, such as Norway spruce, may be reduced due to increased competition (Holten, 1993). For hydropower, increased precipitation and runoff can potentially benefit production, but at the same time runoff may increase the magnitude of floods (Sælthun et al., 1998). Within fisheries, the positive effects of warming, such as longer growing seasons and faster growth rates, may be offset by changes in environmental conditions, availability of forage, migration routes, and frequency of diseases and predator-prey interactions (Loeng, 1995; Eide and Heen, 2001). Increased frequency and intensity of disease outbreaks as a result of warmer waters is also of great concern for the aquaculture sector, together with the threat of more incidences of algal blooms (Kent and Poppe, 1998). Any increases in the intensity and frequency of extreme climatic events will potentially have negative impacts on aquaculture production and result in substantial damages to infrastructure (McLean and Tsyban, 2001).

Climate change may have some other negative consequences for Norway. Approximately NOK 4 billion is used each year to repair damages to buildings, of which more than three-quarters are related to water and dampness (Ingvaldsen, 1994). As Lisø et al. (2003) point out, both the functionality of the existing built environment and the design of future buildings are likely to be altered by the impacts of climate change, depending on the design, construction, use, and location of buildings and building clusters. The demand for cost efficiency in the construction industry has in some cases contributed to the reduced robustness of Norwegian buildings, at the same time that changing preferences for both housing types and locations have led to an increase in high-risk constructions (Lisø et al., 2003). Projected changes in wind, temperature and precipitation will enhance vulnerability in this sector further. The transportation sector, which plays a critical role in linking producers and markets, is also considered vulnerable to changes in climate, particularly potential changes in extreme events (Parry, 2000; Engebretsen and Hagen, 2001). Avalanches, landslides, floods and other disasters triggered by meteorological events affect the transportation sector's efficiency, reliability, and security.

In the case of negative impacts, it is generally assumed that Norwegian society is well prepared to adapt to both gradual and abrupt changes in climate. Norway ranks highly in all of the characteristics associated with a high adaptive capacity, such as wealth, technology, education, information skills, infrastructure, and so on. In terms of wealth, Norway maintains one of the highest per capita incomes in the world (World Bank, 2002a). Income distribution in Norway is also considered to be among the most equitable in the world; the GINI index* in 1997 was 0.261 (Sta-

* The Gini index is a measure of how much the distribution of income among individuals or households within an economy deviates from an completely equal distribution. Thus a Gini index of zero represents complete equality, while an index of 100 implies complete inequality (World Bank, 2001).

tistics Norway, 2000). Economic growth averaged 3.6% annually over the period between 1990 and 2000 (World Bank, 2002b). Norway also exhibits high levels of technological development, with particularly high rankings in terms of digital and communication infrastructure. According to the UNDP Human Development Index for 2002 (UNDP, 2002), Norway ranks first in the world in terms of human development.

Thus at the national level, Norway is either considered a winner under climate change, or is at least considered to have a high capacity to adapt to climate change. However, the optimistic picture of climate change for Norway is tempered by the uncertainties associated with impacts, particularly the complex interactions within and between different ecosystems and sectors. More important, impacts and vulnerability to climate change differ across spatial scales. The magnitude and possibly the rate of climate change will vary across Norway, and the impacts of these changes will be experienced differently both across and within regions. Despite relatively high levels of equality in Norway, there are regional and local differences in factors that influence vulnerability, including regional employment structure and demographic composition. In the following section, the impacts of climate change are considered from a regional perspective, along with the implications for vulnerability.

4. Regional Level Assessment

Coarse-resolution climate scenarios do not fully capture regional differences in exposure to climate change for a country such as Norway, with its extensive mountains and long coastline. Compared to the coarse-resolution scenarios for Norway discussed above, dynamically downscaled scenarios project different scenarios of climate change for roughly three regions of Norway. These scenarios have been developed under the RegClim project (Regional Climate Development under Global Warming) using the HIRHAM regional climate model (Iversen, 1997, Haugen et al., 1999, Bjørge et al., 2000). The main focus of RegClim is Northern Europe and adjacent sea areas. In contrast to global climate models, where a coupled ocean-atmosphere system simulates climate over hundreds of years with a relative course spatial resolution, a regional climate model covers only a certain part of the atmosphere, but with a much more detailed description of features such as the orography and land surface types. A regional climate simulation typically covers certain time-slices from a global experiment (20-year periods in the case of RegClim), thus it may be viewed as a local adaptation of global results.

The RegClim model has a 0.5 degree resolution, such that each grid point represents an average value over an area of 55×55 km^2. The increased resolution of the model gives a much better representation of the Scandinavian mountains, which is essential for the local simulation of variables such as precipitation amounts, temperature variations, or modified wind due to flow over and around mountainous areas. The higher resolution also makes it possible to simulate the strength of low-pressure systems more correctly, in particular heavy precipitation events with strong winds. By running the regional HIRHAM model with forcing from the Max-Planck Institute global ECHAM4 model over several years, then computing the probability distribution of some of the model output variables (e.g. mean sea level pressure, temperature, wind, precipitation amounts, snowfall, etc.), a regional climatology was obtained. The distribution was calculated for a scenario climate that includes the effect of increased greenhouse gases in the radiation scheme of the model.*

It should be noted that the resulting estimates are based on one particular scenario and that the relative short time series are more prone to sample fluctuations. Benestad (2002) presented results from empirical downscaling of multimodel global ensembles and Christensen et al. (2001) analyzed the results from dynamical downscaling of three different scenarios (ECHAM4 GSDIO, ECHAM4 GHG and HadCM2 GHG), including the RegClim model results. All three models simulated a substantial and statistically significant warming, where the spread among the ensemble (∼1 °C) was smaller than the mean climate change (1.5 °C in the summer and 2.5 °C in the winter) over the Scandinavian area. The mean precipitation increase was about 15% during the autumn and 5–10% for the remainder of the year.

The regional temperature, precipitation, and wind speed changes are summarized in Table III. The RegClim results estimate a 0.24 °C/decade increase in annually averaged temperature. The warming is stronger in the northern areas (0.3 °C/decade) compared to southwestern Norway (0.2 °C/decade) and tends to be somewhat stronger inland than along the coast. The heating rate during the winter months (0.3 °C/decade) is nearly doubled compared to summer months; that is, the strongest heating is found to occur in northern parts of the country during the winter months (0.4 °C/decade). Figure 1 displays the distribution of temperature increases for the winter months (December–February) over the period from 1980–1999 to 2030–2049.

According to the RegClim results shown in Table III, which again are based on only one scenario, precipitation may potentially increase in all regions by an average of about 10%. The largest increase is found in the southwestern region (13%), and along the western coast further north. These areas are already highly exposed to precipitation when weather systems from the west reach the steep coast, and this orographic precipitation is further strengthened in a future warmer climate. The greatest percentage increase will occur during the period from late summer to early winter. In fact, precipitation is estimated to increase by almost 25% during the

* On a global scale, the temperature increase in the chosen simulation over the next 50 years is in the lower end of intervals stated in the newer IPCC reports, when comparing available global model simulations. On a national scale, the additional effect of increased greenhouse gases are for some parameters and some seasons rather small, compared with the natural variations of the atmospheric circulation patterns.

Table III

Absolute change in temperature (°C/decade) and relative change in precipitation and wind-speed (%) between 1980–99 and 2030–49. The results are from dynamical downscaling [with the HIRHAM regional climate model] of the ECHAM4/OPYC3 global scenario from the Max-Planck Institute, Germany, assuming a 1% increase in CO_2 concentrations per year after 1990

		Temperature change (°C/decade)	Precipitation change (percent)	Windspeed change (percent)
All	Whole year	0.24	9.33	1.89
	Spring	0.22	0.01	0.86
	Summer	0.17	9.79	0.02
	Autumn	0.28	16.70	4.25
	Winter	0.31	8.69	1.91
Northern Norway	Whole year	0.31	7.36	2.17
	Spring	0.28	5.08	1.38
	Summer	0.23	2.09	–1.06
	Autumn	0.33	17.16	3.57
	Winter	0.40	3.87	3.64
Southwestern Norway	Whole year	0.20	13.32	2.11
	Spring	0.19	1.19	1.11
	Summer	0.13	18.75	1.83
	Autumn	0.22	23.60	5.44
	Winter	0.24	8.21	0.20
Southeastern Norway	Whole year	0.21	4.16	1.13
	Spring	0.19	–4.39	–0.34
	Summer	0.13	1.71	–0.02
	Autumn	0.26	5.92	4.28
	Winter	0.26	13.91	0.45

autumn in southwestern Norway. By contrast, the change is almost neutral in the spring, and on the leeward side of the mountains the tendency is slightly negative. An analysis of the frequency distribution of precipitation in terms of mm/day shows a tendency towards more events with heavy precipitation. An example of this from the regional climate model is shown in Figure 2, which displays the increase in number of days during the autumn with precipitation exceeding 20 mm/day.*

* Although 20 mm/day is not considered extreme precipitation in this area based on the observed record, it was chosen to include a significant number of cases as simulated in the regional climate model.

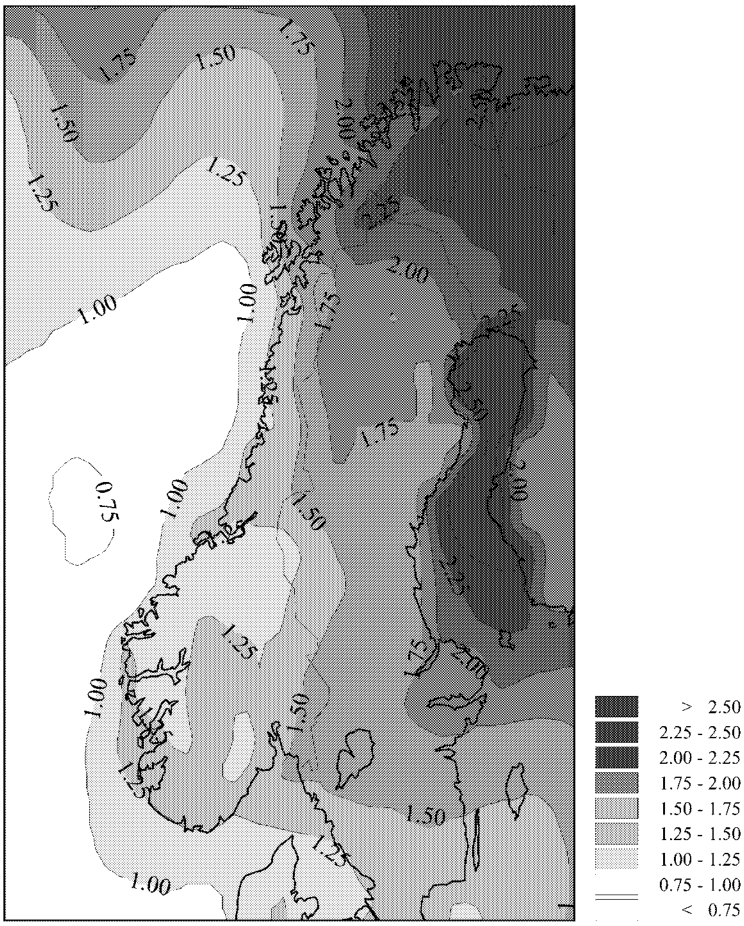

Figure 1. Change in winter temperature (Dec–Feb) over the period from 1980–99 to 2030–49 (Units: °C). The results are from dynamical downscaling [with the HIRHAM regional climate model] of the ECHAM4/OPYC3 global scenario from the Max-Planck Institute, Germany, assuming a 1% increase in CO_2 concentrations per year after 1990.

The results from the RegClim project show that the change in surface wind-speed will be rather small over the next 50 years (see Figure 3). However, significant changes in relation to the natural variability can be found for some areas and for some seasons. Large wind-speeds are connected to the low-pressure systems reaching the Norwegian coast, but the natural variability of the dominant tracks of these systems varies over several decades. The RegClim analysis of wind is for this reason limited by a relatively short time period of data. One particular result is an increased frequency of wind-speed between 10 and 20 m/s along the coast of southwestern Norway. This is in agreement with a theory that a somewhat warmer ocean will result in more frequent and stronger storms, since the potential for release of heat by condensation taking place under developments of

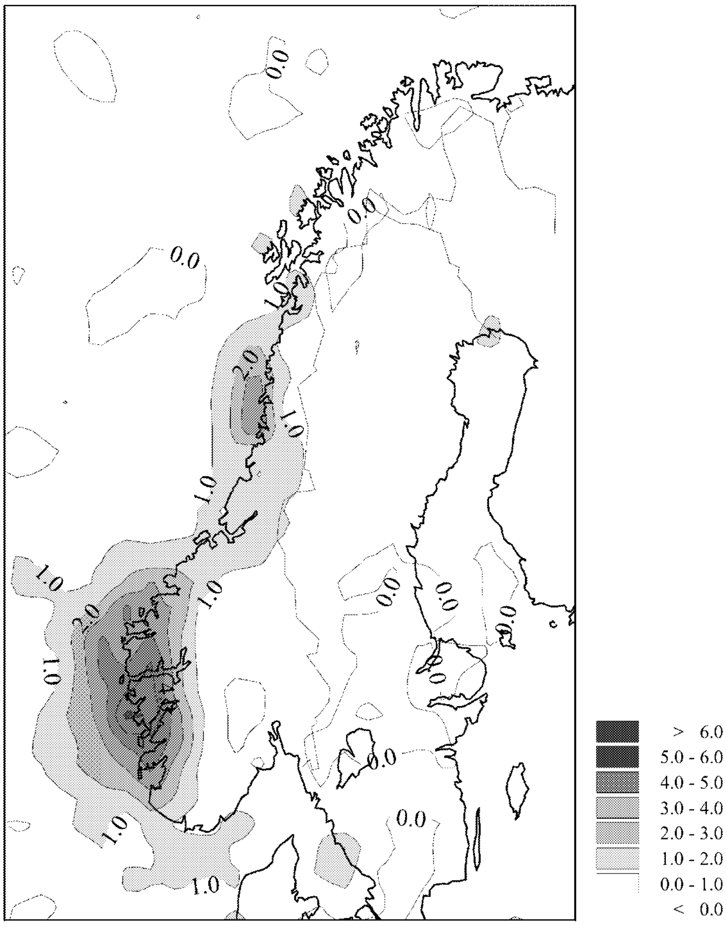

Figure 2. Change in autumn precipitation (Sep–Nov) over the period from 1980–99 to 2030–49. (Units: Number of days with $P > 20$ mm/day). The results are from dynamical downscaling [with the HIRHAM regional climate model] of the ECHAM4/OPYC3 global scenario from the Max-Planck Institute, Germany, assuming a 1% increase in CO_2 concentrations per year after 1990.

low-pressure systems is stronger. However, it should be noted that atmospheric circulation in this scenario is characterized by an intensification of the north-south gradient of mean sea level pressure over Scandinavia, and that other scenarios for circulation patterns with less increase in the windspeed along the western coast of Scandinavia are possible.

The RegClim results indicate that climate change will differ across Norway, both in terms of magnitude and seasonality (see Table III). Nevertheless, results from other scenarios would need to be included to estimate the uncertainty of these changes. The important point is that, regardless of the uncertainty surrounding the numbers, the regionally downscaled results show distinct differences for three gen-

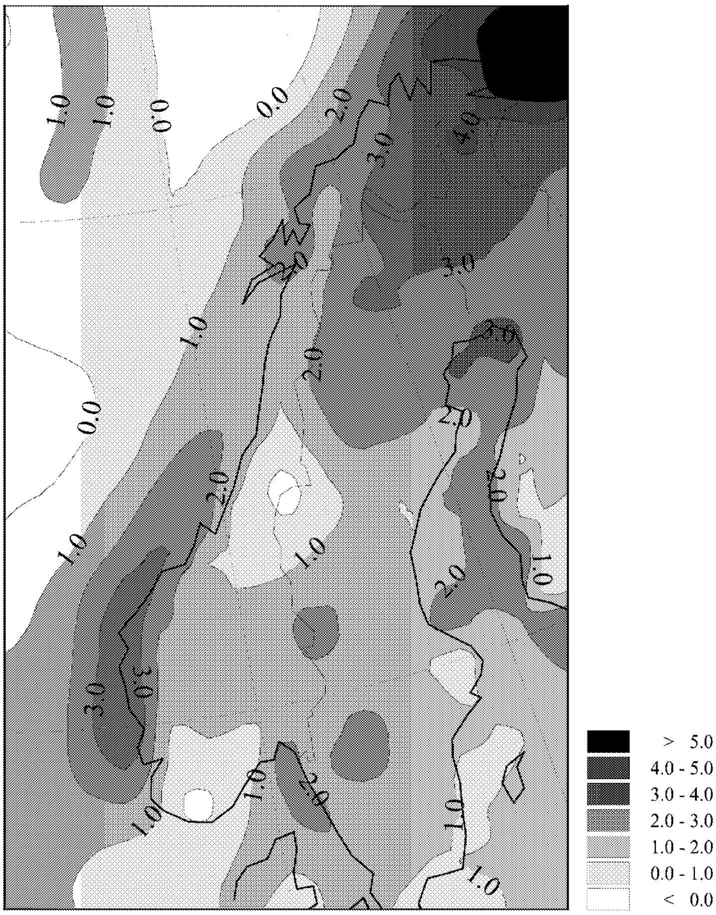

Figure 3. Change in annual mean wind-speed over the period from 1980–99 to 2030–49. (Units: %). The results are from dynamical downscaling [with the HIRHAM regional climate model] of the ECHAM4/OPYC3 global scenario from the Max-Planck Institute, Germany, assuming a 1% increase in CO_2 concentrations per year after 1990.

eral regions of Norway. Exposure to climate change thus shows regional variations across Norway.

The impacts associated with climatic changes will also differ across regions. Economic activities in Norway have strong regional components, and the impacts of climate change (both positive and negative) are likely to be felt more in some regions than in others. During the last century Norway has, as many other western European countries, experienced strong economic growth. This has lead to increased economic well-being among the population and at the same time large structural changes (NOU, 2000). The growth has mainly been generated within the industry and the service sector, promoting centralization, whereas the primary sector has become less important. Currently there are rather clear regional distinctions in employment. Fishing communities are located along the coast, from Rogaland in the south to Finnmark County in the far north. There are, however, strong disparities between the northern and southern regions in terms of employment in fisheries; the northern region is more dependent on fisheries for employment compared to the southern region, where fisheries are characterized by specialized and less labor intensive production systems (Lindkvist, 1996). Forestry is limited to southern Norway, with most production taking place in the interior eastern counties. Although agriculture is practiced throughout the country, it accounts for over 50% of total employment in about one quarter of Norway's 435 municipalities.

As a result of the changing employment opportunities and levels of education there has been a strong tendency towards centralization in recent decades. During the 1980s and 1990s there was a continuous trend of increased populations in urban areas, at the expense of the periphery (Eikeland and Johansen, 2000). At the same time, there was also a significant north-south migration, leaving the northernmost areas even less populated than other regions (Statistics Norway, 1999). These demographic shifts have resulted in a lack of entrepreneurship in some areas, and a mismatch between employment supply and demand, resulting in large structural problems and increased unemployment in many rural areas (Eikeland and Johansen, 2000). In term of living conditions, peripheral areas are worse off in terms of income and wealth compared to more central areas. Among the ten municipalities scoring lowest in a national survey of living conditions, nine are located in Northern Norway (NOU, 2000). In contrast, municipalities in southwestern Norway had the highest scores.

It is difficult to predict future regional social and economic developments in Norway, particularly up to 2050, which corresponds to the RegClim scenarios. Several studies have attempted to develop regional scenarios (NOU, 2000; Øverland, 2000; St.meld.nr.34, 2001), but the scenarios are highly dependent on assumptions about Norway's general economic situation and the influence of global economic changes, among other things. In general, the scenarios suggest that many of the present-day driving forces of development will continue to dominate in the future; i.e., increased centralization both within and between regions, further growth within the service sector, and increased importance of transportation infrastructure. For many peripheral areas this means reduced population levels and most likely a decline in the supply of public services such as schools and health care (NOU, 2000). These projections indicate that vulnerability is dynamic, and that any conclusions about regional vulnerability made today may change in response to Norway's regional developments in the next 50 years. In the following we point out some of the regional disparities regarding vulnerability and impacts in Norway.

Northern Norway: According to the RegClim scenarios, temperature increases are likely to be largest in Northern Norway. In addition, the already high natural climate variability in this region will most likely be intensified. What stands out as particularly vulnerable in this region are various species and natural ecosystems (see Directorate for Nature Management, 1990; Holten et al., 1993, Anisimov and

Fitzharris, et al. 2001; Ottersen et al., 2001). Some species are already living on the southernmost border of their habitats, while others require particular environmental conditions, such as winter snow cover. In these areas the natural resource base is vital for both economic and cultural reasons, and changes in climate may have considerable socioeconomic consequences. For example, the reindeer herding conducted by the Lapp people may be in jeopardy under climate change. Increased temperatures followed by changes in vegetation may limit the availability of forage for reindeer, and relatively warm episodes during the winter can result in deep snow with an ice surface that prevents animals from reaching vital forage (Hobbs, 1989; Ottersen et al., 2001). Limited forage could intensify the problem of overgrazing and threaten the livelihoods of the Lapp herders.

Historically, the fishing of Norwegian Arctic Cod and herring has been the basis for economic development in Northern Norway. On the one hand, studies indicate that fish stock recruitment seems to be better in warmer years, as the stocks seems to benefit from increased food availability and more favorable growing conditions (Loeng, 1989; Sakshaug et al., 1994). On the other hand, increased ocean temperature and availability of forage may result in an northwestward movement of cod in the Barents Sea – a situation that will challenge current management regimes (Nakken and Raknes, 1987; Ottersen et al., 1998). A key question is whether climate change will add to the current pressures on regional management regimes in the fishery sector (Eide and Heen, 2001).

Potential scenarios of climate change include the possibility of changing ocean currents. Historical evidence reveals that economically important species in the Barents Sea are highly sensitive to changing ocean currents (Loeng, 2001). The IPCC reports that 'most models show weakening of the Northern Hemisphere Thermohaline Circulation, which contributes to a reduction to the surface warming in the northern North Atlantic' (Houghton et al., 2001, p. 73). Although the weakening will most likely not offset the warming due to increased greenhouse gases in the next century, it is uncertain what the long term effects will be (Houghton et al., 2001). In any case, less stable ocean currents can have dramatic effects on the recruitment and availability of the temperature-sensitive Norwegian Arctic Cod. Northern coastal communities are especially vulnerable to reductions in fishing and fish processing, as these sectors contribute disproportionately to the regional economy (Mariussen and Heen, 1998).

Southwestern Norway: In contrast to fish stocks in northern waters of Norway, the species currently in the North Sea may experience a decrease in recruitment under warmer conditions. The cod stock in the North Sea is found at the southern limit of its thermal range. Observations indicate that the recruitment of these stocks increases during cold periods (Dippner, 1997). In fact, adverse warm conditions together with overfishing may endanger the long term sustainability of cod in the North Sea (O'Brien et al., 2000). As mentioned earlier, the introduction of new species from the south may to some extent counteract this negative trend.

Most of Norway's hydropower resources are found along the southwestern coast of Norway and most of the power plants have excess capacity (Statistics Norway, 2000). Increased precipitation and changes in the seasonal distribution of runoff are estimated to increase hydropower production on the west coast by 6% from 2000 to 2030 (Sælthun et al., 1998). However, hydropower producers in this region also face challenges associated with increased flooding under climate change, such as damage to dams and infrastructure (Sælthun et al., 1998). The timing of floods is likely to shift from spring to winter, if winter temperatures increase and there is less snow accumulation in mountainous inland regions to melt in the spring (Eikenæs, 2000). More incidents of flooding on frozen ground will have large effects on erosion and sediment transport in the area (Norwegian Ministry of Environment, 1991).

In the southwestern region of Norway, increased precipitation may cause problems for the building and insurance industry. A projected precipitation increase of 20% during the fall may result in greater damages to buildings and infrastructure. For some constructions, the duration of rainy periods is likely to be of greater importance than the maximum intensity of precipitation, whereas for other types, the intensity of driving rain (combined rain and wind) may be the most important (Lisø et al., 2002). It is likely that climate change will adversely affect property insurance through increased outpayments.

The health effects of climate change may also be considerable, as exposure to dampness in buildings is correlated with poor health (Bornehag et al., 2001). In some parts of southwestern Norway, wind-speed is projected to increase by a few percent, leading to potentially more intense storm events. Historical evidence indicates that coastal communities are vulnerable to strong winds. The strongest hurricane on record in Norway hit the northwestern coast in 1992, resulting in damages estimated at NOK 2 billion (National Office of Building Technology and Administration, 1993). Future prospects of stronger winds coinciding with greater precipitation will result in more frequent lashing rain. Such conditions will trigger material exhaustion and accumulated damages (Lisø et al., 2002).

Southeastern Norway: Agricultural production in southeastern Norway is characterized by favourable climatic conditions and high quality soil and terrain. Currently almost 80% of the country's cereal production is found in this region. The current trend of regional specialization in agricultural production, including an increase in the area under cereal cultivation in southeastern Norway, will most likely be intensified with higher temperatures. Both national and international assessments indicate that this region will benefit from increased agricultural yields (Haglerød, 1990; Fischer et al., 2001). What might counteract or potentially offset the positive effects is the prospect of increased soil erosion and nutrient leakage due to more frequent and intense episodes of heavy rain. The threat of pests and diseases from the south (due to warmer temperatures) may further offset the positive effects of climate change. Although increased use of fertilizer and pesticides and carefully planned agronomic practices may limit these damages, high input agriculture may have adverse environmental and health consequences (UNEP, 1999).

The flood regimes most common to the southeastern region of Norway are spring floods. Norway's largest river, the Glomma, has historically experienced spring floods which have resulted in devastating damages (NOU, 1996). According to a study by Erichsen and Sælthun (1995), annual mean flood will be reduced by 5% in southeastern Norway as the result of a projected decline in snow accumulation during winter. The return period of extreme floods is not expected to increase as long as there is no seasonal shift towards a fall flood regime (Erichsen and Sælthun, 1995). However, such a shift cannot be ruled out, as fall precipitation is expected to increase in these areas. If there is a shift in flood regimes, the optimal operation of reservoirs will be more difficult as the result of greater uncertainty associated with fall and winter flood regimes (Sælthun et al., 1998).

These regional assessments of climate change impacts suggest that southeastern Norway is likely to emerge as a winner under climate change relative to southwestern and northern Norway, where the results are more mixed. Climate change is likely to adversely affect the Arctic ecosystem of Northern Norway, with potentially negative implications for the people that depend on natural resources for their livelihoods. Nevertheless, northern fish stocks may increase under climate change, offering benefits to the economically important fishery sector. Although increased runoff may boost hydroelectric production in southwestern Norway, an increase in the number of days with heavy precipitation and in some cases stronger winds is likely to have negative repercussions for a number of sectors. These generalizations about regional vulnerability are not based on comprehensive and integrated assessments, therefore they should be considered preliminary conclusions. Nevertheless, they do illustrate that the impacts of climate change will not be evenly distributed across Norway, and that some regions are indeed more vulnerable than others.

5. Local Level Assessment

The same holds true for local level impacts. In a country with an intricate local topography, including an extensive coastline, long fjords, high mountains, and deep valleys, climate change exposure is likely to vary over relatively short distances. Climate change scenarios developed for a 55×55 km^2 grid are unlikely to capture these local variations. Social vulnerability also varies among Norway's 435 municipalities, depending on socioeconomic conditions, access to the transportation network, and other factors. An overview of these conditions is a premise for understanding local and individual vulnerability to climate change. Among other indicators, the share of total employment in primary sector activities by municipality may provide a rough estimate of the geographical distribution of vulnerable communities. Figure 4 shows the relative importance in terms of municipal employment for three climate-sensitive sectors in Norway. From this figure, it can

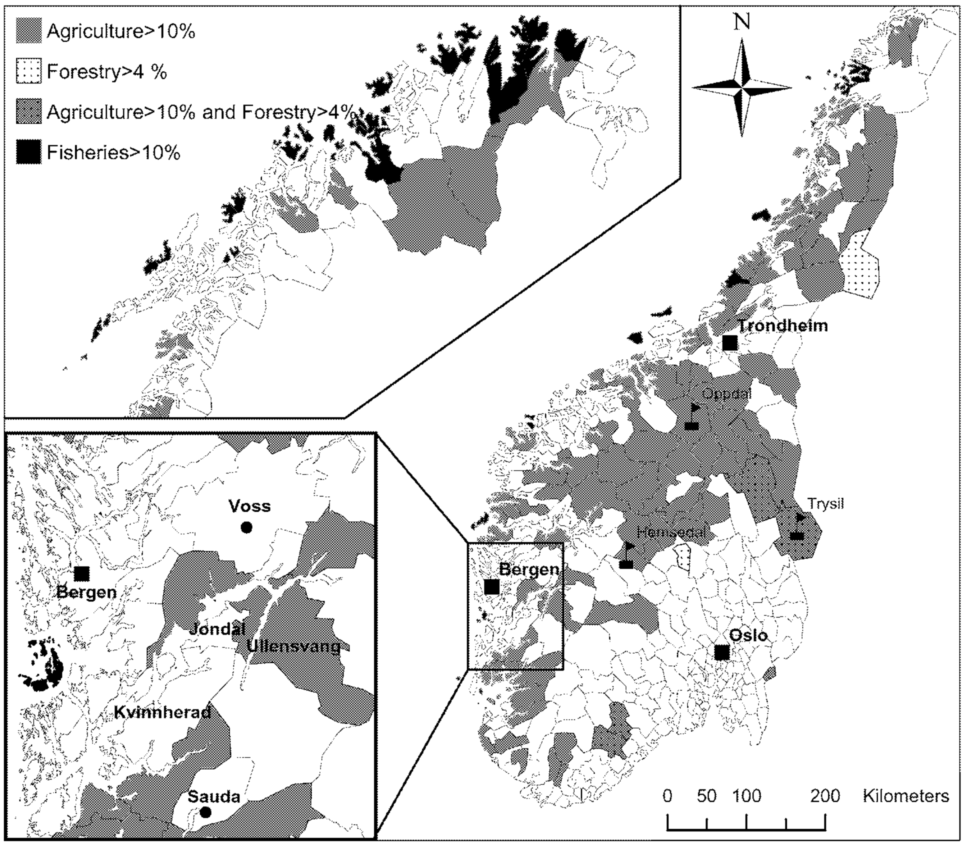

Figure 4. Map showing share of employment within the primary sectors at the municipal level.

be seen that agriculture is a vital source of employment in southern and central Norway; fishing is important along the coast in northern Norway; and forestry is significant in a few municipalities in the southeastern region.

To capture local climate characteristics, a so-called empirical downscaling method can be used to generate scenarios of climate change. As an alternative to the dynamical downscaling method used to generate regional scenarios, this method involves downscaling temperature fields from the global model to develop empirical relationships between the conditions of large scale and local climate. The method consists of two steps: (1) Developing statistical relationships between observed local climate elements (e.g., temperature and precipitation) and observed large scale atmospheric fields (e.g., pressure patterns at sea level), and (2) Utilizing these relationships on a large-scale field simulated with global climate models for present-day and scenario periods.

One assumption in empirical downscaling is that statistical relationships are also valid under future conditions. As with dynamical models, a substantial part of historical variations should be explained. This is confirmed in the analyses made within the RegClim project: Both temperature and precipitation in different parts of Norway over the last hundred years can to a large extent be explained by variations in the pressure patterns in Northern Europe (Hanssen-Bauer, 1999). When compared to dynamical downscaling, empirical downscaling results in similar trends during summer and autumn, but in somewhat larger warming trends during winter and spring. This is most pronounced in the lower elevation stations inland, where the heating rate is nearly doubled. It is speculated that this difference is connected to a poor description of the valleys in the regional climate model, which results in a poor description of the storage of cold air masses frequently observed during winters.

Two empirically downscaled climate change scenarios for the southwestern region of Norway are presented in Table IV. The two meter temperature fields from the ECHAM4/OPYC3 integration performed at Max-Planck Institute, Germany, were used as predictors for downscaling of local monthly mean temperature during the period 1870–2050. For precipitation values, two meter temperature and sea level pressure fields were used during the same period. The global experiment included effects of greenhouse gases and tropospheric ozone, as well as direct and indirect effects of sulphur aerosols. The scenarios for Voss and Sauda, located only 60 km apart (see map inset in Figure 4), are notably different. For example, precipitation is projected to increase by 17% in Voss as compared to 11% in Sauda, and the length of the growing season is likely to increase by 27 days in Voss, compared to 19 in Sauda. The differences in exposure to climate change at the local level can be attributed to influences of topography on local climates, and the distance from the coast. Although this particular Max-Planck simulation has been shown to realistically simulate the present climate (Allen et al., 2000), as discussed in the case of the dynamically downscaled results, other scenarios are possible.

Not all municipalities in Norway will be affected equally by climate change. Some are more heavily dependent upon economic activities that are sensitive to climate change. For example, diverse economic activities are represented among neighboring municipalities in western Norway: Kvinnherad holds 11 of the region's 18 fish farming licenses, and earned NOK 121 million from aquaculture in 1999 (Hordaland County, 2000). Climate change may impact aquaculture both positively and negatively, as the growing season may lengthen and growth rates may increase, but disease outbreaks may also increase (McLean and Tsyban, 2001). Ullensvang specializes in fruit production, and with 500,000 trees produces more fruit than any other municipality in Norway (Hordaland County, 2000). The production of apples and pears is highly correlated with temperature; yield increases up to 30 and 50 percent, respectively, are projected under temperature increases of 1 °C (Haglerød, 1991). Jondal is heavily dependent on summer tourism, resulting from its easy access to Norway's third largest glacier, Folgefonn, which is a key summer ski destination. Projected increases in rainfall during summer may be less beneficial, as people tend to prefer indoor activities under such weather conditions.

Table IV

Empirically downscaled climate change scenarios for southwestern Norway. The results are based on empirical downscaling of the ECHAM4/OPYC3 global scenario from the Max-Planck Institute, Germany, assuming a 1 % increase in CO_2 concentrations per year after 1990

Station	Sauda			Voss		
Period	Control (1981–2000)	Scenario (2021–2050)	Change	Control (1981–2000)	Scenario (2021–2050)	Change
Annual Temperature Change (°C)	6.96	8.34	1.38	5.67	7.28	1.61
Length of winter (Tday < 0 °C)	80	58	–22	108	82	–26
1st winter day (Tday < 0 °C)	Dec 8	Dec 19	+11	Nov 21	Dec 3	+12
1st spring day (Tday > 0 °C)	Feb 26	Feb 15	–11	Mar 9	Feb 23	–14
Length of growing season (Tday > 5 °C)	201	220	+19	184	211	+27
Yearly precipitation (mm)	2207	2462	255 (11%)	1260	1473	213 (17%)

In terms of impacts, climate change may benefit some municipalities, while posing challenges for others.

As a social democratic state, Norway maintains a large public sector that depends heavily on the local tax base and state transfers for income (Statistics Norway, 2001). For many peripheral areas in Norway, the public sector has been the main engine of economic development (St.meld.nr. 34, 2001). Recent trends, including economic recession and increased migration, have disproportionately impacted peripheral areas; reduced numbers of inhabitants affect local demand for services and commodities, hence employment. Population declines in turn affect both the local tax income base and state transfers (Eikeland and Johansen, 2000). Despite special transfer arrangements for the most marginalized municipalities, the reduced income base has been shown to have implications for maintenance of pubic services in these areas (Eikeland and Johansen, 2000). Regarding future developments, the trend towards increased demographic centralization may not be counteracted by policy measures that promote regional settlements and economic development in peripheral areas (St.meld.nr. 34, 2001).

From a sectoral perspective, tourism provides an example of an activity that may be significantly affected by local impacts of climate change. A small number of municipalities in Norway derive a substantial proportion of income from seasonal tourism. Municipalities such as Hemsedal, Trysil, and Oppdal (see Figure 4) rely heavily on tourism and tourist-related activities for income and employment. For winter tourism, economic success depends heavily on the amount and timing of snowfall, as well as the reputation for conditions. For example, studies have shown that the skiing industry is particularly vulnerable in the years subsequent to snow deficits, as people tend to adjust their travel behavior based on past snow conditions (Koenig and Abegg, 1997). Many ski resorts are already operating at the margin in terms of profitability, in part attributable to short seasons, and thus they are vulnerable to snow-deficient winters, including warmer temperatures that hamper the production of artificial snow.

Even within local communities, some groups are likely to be disproportionately more vulnerable to climate change than others. An assessment of the social distribution of climate change impacts has not been carried out in Norway. However, warmer winter conditions in the past suggest that the elderly population is particularly vulnerable to increased accidents and bone fractures as winter temperatures rise and fall and create sheets of ice on roads and sidewalks. With respect to human well being, a changing climate may have differential effects on individuals. As one example, Seasonal Affective Disorder (SAD) tends to increase with the reduction of light, which may result from reduced snow cover and increased rainfall (Albert et al., 1991). Assessments of local level impacts and vulnerabilities to past climate anomalies can be considered one way of understanding future vulnerability to climate change (Glantz 1988; Subak et al., 2000).

6. Vulnerable or Resilient? It's a Matter of Scale

Is Norway resilient or vulnerable to climate change? The multi-scale assessment of impacts and vulnerability presented in this paper suggests that there is no simple answer to the question regarding vulnerability and resilience in Norway. The answer depends on the scale of analysis, and the context for the assessment. Within the global context, Norway can be considered resilient to climate change, and it is even possible that it may experience net benefits. However, regional and local level assessments indicate that neither the impacts nor the benefits will be evenly distributed; climate change will pose substantial challenges to some regions and localities, and to some social groups. From these perspectives, Norway is indeed vulnerable to climate change.

The relationship between global environmental change and scale has been recognized in other contexts as well (Gibson et al., 2000; Berkes, 2002; Young, 2002) and in other country studies of climate impacts and vulnerability (Government of Canada, 2001). Canada, for example, also exhibits low vulnerability to the negative impacts of climate variability and change at the national level, while at smaller scales, some regions or sectors may be highly vulnerable (Government of Canada, 2001). In contrast to Norway, Canada has carried out a thorough country study on climate change impacts and adaptation that included six regional assessments, as well as an assessment of cross-cutting issues (Environment Canada, 1998). Regional assessments provide a stronger basis for understanding where, how, and why certain regions or groups are vulnerable to climate change. In Norway, there has until recently been relatively little focus on assessing vulnerability at regional and local levels. It may very well be that the perception that Norway is resilient and adaptable to climate change has generated complacency among policy makers and the general public. However, by extending this assumption about resilience to smaller scales, the diversity of impacts of and potential responses to climate change at regional and municipal levels are disregarded.

Earlier in the paper we presented a conceptual understanding of vulnerability and resilience, whereby the two were considered endpoints on a multidimensional continuum that incorporates notions of sensitivity and robustness. We then demonstrated that the position on the continuum depends on the scale of the analysis: A national level assessment is likely to conclude that Norway lies firmly on the resilient end of the continuum, at least in relation to other countries. Regional and local assessments, however, are likely to shift some parts of Norway towards the vulnerable end of the continuum. Positions along the continuum are, however, not fixed; they can shift as the result of changing socioeconomic conditions, as well as with changes in climate sensitivity and robustness. For example, technological changes may make Norway's building sector less sensitive to moisture damage, whereas climate 'surprises' such as a collapse of the Atlantic Thermohaline Circulation may make some regions of Norway less robust to climate change. Changes in adaptive capacity can also contribute to shifts along the continuum.

The metric along the vulnerability-resilience continuum also changes as the scale of assessment changes. Climate change is unlikely to result in increased mortality, famine, or major disruptions within Norwegian society. Instead, regional and local vulnerability must be considered within the context of economic productivity and sustainability, social and regional equality, maintenance of a decentralized population structure, and continued access to nature and recreation. Vulnerability to climate change is likely to emerge as an issue in Norway if the impacts of climate change challenge policies and ideals that are core to the Norwegian populace and its system of social democracy.

Nevertheless, Norway is considered to be a country that can readily adapt to climate change. A high adaptive capacity, reflected by aggregated statistics and international indicators, should in theory increase Norway's resilience to climate change at multiple scales. However, whether Norway's high adaptive capacity is actually translated into regional and local-level adaptations remains to be seen. At the local level, adaptation is rarely simple and straightforward, and existing institutions may in fact constrain rather than facilitate adaptation. For example, northern communities that are highly dependent on fishing have demonstrated limited capacity to adapt to permanently unfavorable changes in catch, which are probably unrelated to climate change (Mariussen and Heen, 1998). Similarly, local authorities may lack the institutional capacity to control compliance with new building regulations, which are often ignored to maintain competitive prices (Lisø et al., 2003). Understanding vulnerability and adaptive capacity within regions, localities, and social groups can be considered a prerequisite for determining whether Norway is, in fact, highly adaptable to climate change.

The consequences of climate change for Norway are will be determined by factors that influence vulnerability at different scales. Global scale changes are thus also likely to influence Norway's vulnerability or resilience. Exposure to continued processes of economic globalization may, for example, lead to new patterns of climate vulnerability (O'Brien and Leichenko, 2000). Climate impacts elsewhere in the world, both in developing and industrialized regions, may also affect Norway, through strongly internationalized industries, such as oil, shipping, and fisheries; through the international investment portfolio of Norway's Government Petroleum Fund; and through trade, travel, political instability, and movements of people. More than merely a residual of climate impacts and adaptations, climate vulnerability is a dynamic outcome of both environmental and social processes occurring at multiple scales. Differences in climate change exposure, coupled to differences in biophysical and social conditions and trends, call for closer attention to the issue of scale in global change research.

Acknowledgements

Funding for this research was provided by the Norwegian Research Council, under project number 138908/700 (Socioeconomic Impacts of Climate Change in Norway: A Regional Assessment) and 138908/700 (Socio-economic Impacts of Climate Change in Norway: A Pilot Study). We would like to thank two anonymous reviewers for useful comments on an earlier manuscript, and Knut H. Alfsen, Lynn Nygaard, and colleagues at CICERO for helpful suggestions. We would also like to thank Inger Hanssen-Bauer for providing the empirical downscaling results, as well as Baard Romstad and Jane Brattland for help with the figures..

References

Adger, W. N.: 2001, 'Scales of Governance and Environmental Justice for Adaptation and Mitigation of Climate Change', *Journal of International Development* **13**, 921–931.

Adger, W. N., Kelly, P. M., Winkels, A., Quang Huy, L., and Locke, C.: 2002, 'Migration, Remittances, Livelihood Trajectories, and Social Resilience', *Ambio* **31**, 358–366.

Albert P. S., Rosen L. N., Alexander J. R., and Rosenthal, N. E.: 1991, 'Effects of Daily Variations in Weather and Sleep on Patients with Seasonal Affective Disorder', *Psychiatry Research* **36**, 51–63.

Allen, M. R., Scott, P. A., Mitchell, J. F. B., Schnur, R., and Delworth, T. L.: 2000, 'Quantifying the Uncertainty in Forecasts of Anthropogenic Climate Change', *Nature* **407**, 617–620.

Anisimov, O. and Fitzharris, B. et al.: 2001, 'Polar Regions (Arctic and Antarctic)', Chapter 16, in McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 801–841.

Aunan, K. and Romstad, B.: 2003, 'Strong Coasts, Vulnerable communities: Potential Implications of Accelerated Sea-Level Rise for Norway', *J. Coastal Res.*, forthcoming.

Bakkehøi, S.: 1979, *Extreme Weather Events that Results in Avalanches*, Report from Norwegian Geotechnical Institute, Oslo, Norway (in Norwegian).

Benestad, R.: 2000, 'Sprikende Modeller', *Cicerone* **6**, 29–31 (in Norwegian).

Benestad, R.: 2002, 'Empirically Downscaled Temperature Scenarios for Northern Europe Based on a Multi-Model Ensemble', *Clim. Res.* **21**, 105–125.

Berkes, F.: 2002, 'Cross-Scale Institutional Linkages: Perspectives from the Bottom Up', in Ostrom, E., Dietz, T., Dolsak, N., Stern, P. C., Stonich, S., and Weber, E. U. (eds), *The Drama of the Commons*, National Academy Press, Washington, D.C., pp. 293–321.

Bjørge, D., Haugen, J. E., and Nordeng, T. E.: 2000, *Future Climate in Norway. Dynamical Downscaling Experiments within the RegClim Project*, DNMI Res. Rep. 103, Available from Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway.

Bogstad, B. and Gjøsæter, H.: 1994, 'A Method of Estimating the Consumption of Capelin by Cod in the Barents Sea', *ICES J. Mar. Sci.* **51**, 273–280.

Bohle, H. G., Downing, T. E., and Watts, M. J.: 1994, 'Climate Change and Social Vulnerability', *Global Environ. Change* **4**, 37–48.

Bornehag, C. G. et al.: 2001, 'Dampness in Buildings and Health. Nordic Interdisciplinary Review of the Scientific Evidence on Associations between Exposure to "Dampness" in Buildings and Health Effects (NORDDAMP)', *Indoor Air* **11**, 72–86.

Braathen, G. O. (ed.): 1990, *The Greenhouse Effect and Climate Development*, Contribution to the Norwegian Intergovernmental Climate Change Assessment, Norwegian Institute for Air Research, OR 21/90.

Caplan, A. J., Ellis, C., and Silva, E. C. D.: 1999, 'Winners and Losers in a World with Global Warming: Noncooperation, Altruism, and Social Welfare', *J. Environ. Econ. Manage.* **37**, 256–271.

Carpenter, S., Walker, B., Anderies, J. M., and Abel, N.: 2001, 'From Metaphor to Measurement: Resilience of What to What?' *Ecosystems* **4**, 765–781.

Christensen, J. H. et al.: 2001, 'A Synthesis of Regional Climate Change Simulations – A Scandinavian Perspective', *Geophys. Res. Lett.* **28**, 1003–1006.

Davies, R., Cartwright, J., Pike, J., and Line, C.: 2001, 'Early Oligocene Initiation of North Atlantic Deep Water Formation', *Nature* **410**, 917–920.

Dickson, R. R. and Turrell, W. R.: 1999, 'The NAO: The Dominant Atmospheric Process Affecting Oceanic Variability in Home, Middle and Distant Waters of European Atlantic Salmon', in Mills, D. (ed.), *The Ocean Life of Atlantic Salmon*, Blackwell Science Ltd., Oxford, U.K., pp. 92–115.

Dippner, J. W.: 1997, 'Recruitment Success of Different Fish Stocks in the North Sea in Relation to Climate Variability', *Deutche Hydrographische Zeitschrift* **49**, 277–293.

Dow, K.: 1992, 'Exploring Differences in our Common Future(s): The Meaning of Vulnerability to Global Environmental Change', *Geoforum* **23**, 417–436.

ECON: 2000, *The Marine Fairytale. Part I: The Road to the Vision*, Center for Economic Analysis, Oslo, Norway.

Eide, A. and Heen, K.: 2001, 'Economic Impacts of Global Warming: A Study of the Fishing Industry in Northern Norway', *Fisheries Research* **1275**, 1–14.

Eikeland, S. and Johansen, S.: 2000, *Regional Development in the 1990s. Review of Classical Analysis*, Project Report 2000: 15, Norwegian Institute for Urban and Regional Research, Oslo (in Norwegian).

Environment Canada: 1998, *The Canada Country Study: Climate Impacts and Adaptation*, Available online at: http://www.ec.gc.ca/climate/ccs/ccs_e.htm.

Fischer, G., Shah, M., Velthuizen, H., and Nachtergaele, F. O.: 2001, *Global Agro-Ecological Assessment for Agriculture in the 21st Century*, International Institute for Applied Systems and Analysis (IIASA), Luxemburg, Austria.

Folke, C., Carpenter, S., Elmquist, T., Gunderson, L., Holling, C. S., and Walker, B.: 2002, 'Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations', *Ambio* **31**, 437–440.

Forsberg, E.-M. and Kaiser, M.: 2000, *Norwegian Fisheries Towards 2020 – Values and Strategies*, National Committee for Research Ethics in Natural Sciences and Technology (NENT), Oslo, Norway.

Gibson, C. C., Ostrom, E., and T. K. Ahn: 2000, 'The Concept of Scale and the Human Dimensions of Global Change: A Survey', *Ecological Economics* **32**, 217–239.

Glantz, M. H.: 1988, *Societal Responses to Regional Climate Change: Forecasting by Analogy*, Westview Press, Boulder.

Government of Canada: 2001, *Canada's Third National Report on Climate Change*, Available online at: http://www.climatechange.gc.ca/english/3nr/ 3NR_Published_ Version_EN.pdf

Haglerød, A. (ed.): 1990, *Consequences of Increased Emissions of Climate Gases for Agricultural Production*, Report C-005–90, Norwegian Agricultural Economics Research Institute, Oslo, Norway (in Norwegian).

Hanssen-Bauer, I.: 1999, *Temperature and Precipitation Variations in Norway 1900–1994 and their Links to Atmospheric Circulation*, RegClim General Technical Report No. 3 1999, pp. 47–54.

Hanssen-Bauer, I., Tveito, O. E., and Førland, E. J.: 2000, *Temperature Scenarios for Norway, Empirical Downscaling from the ECHAM4/OPYC3 GSDIO Integration*, DNMI Report No. 24/00 Klima.

Hanssen-Bauer, I., Tveito, O. E., and Førland, E. J.: 2001, *Precipitation Scenarios for Norway: Empirical Downscaling from the ECHAM4/OPYC3 GSDIO Integration*, DNMI Report No. 10/01 Klima.

Haugen, J. E., Bjørge, D., and Nordeng, T. E.: 1999, *A 20-Year Climate Change Experiment with HIRHAM, Using MPI Boundary Data*, RegClim Techn. Rep. No. 3, 37–43, Available from NILU, P.O. Box 100, N-2007 Kjeller, Norway.

Hessen, D. O. and Wright, R. F.: 1993, 'Climatic Effects on Fresh Water: Nutrient Loading Eutrophication and Acidification', in Holten, J. I., Paulsen, G., and Oechel, W. C., (eds.), *Impacts of Climate Change on Natural Ecosystems, with Emphasis on Boreal and Arctic/Alpine Areas*, Norwegian Institute for Nature Research and the Directorate for Nature Management, Trondheim, Norway, pp. 154–168.

Holtedahl, O.: 1960, 'General Remarks on Chronology, Ice-recession, and Shoreline Displacement', in Holtedahl, O. (ed.), *Geology of Norway*, Norwegian Geotechnical Institute, Oslo, 540 pp.

Holten, J. I.: 1993, 'Potential Effects of Climate Change on Distribution of Plant Species, with Emphasis on Norway', in Holten, J. I., Paulsen, G., and Oechel, W. C., (eds.), *Impacts of Climate Change on Natural Ecosystems, with Emphasis on Boreal and Arctic/Alpine Areas*, Norwegian Institute for Nature Research and the Directorate for Nature Management, Trondheim, Norway, pp. 84–104.

Holten, J. I., Paulsen, G., and Oechel, W. C.: 1993, *Impacts of Climate Change on Natural Ecosystems, with Emphasis on Boreal and Arctic/Alpine Areas*, Norwegian Institute for Nature Research and the Directorate for Nature Management, Trondheim, Norway.

Hordaland County: 2000, *County Statistics: Hordaland 2000*, Bergen, Norway (in Norwegian).

Houghton, J. T. Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., and Johnson, C. A.: 2001, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Hulme, M. and Carter, T.: 2000, 'Changing Climate of Europe', in Parry, M. (ed.), *Assessment of the Potential Effects and Adaptations for Climate Change in Europe*, Jackson Environment Institute, University of East Anglia, U.K., pp. 47–84.

Ingvaldsen, T.: 1994, *Building Damage in Norway*, NBI Project Report 163, Norwegian Building Research Insitute, Oslo (in Norwegian).

Iversen, T., Førland, E. J., Røed, L. P., and Stordal, F.: 1997, *RegClim – Regional Climate Development under Global Warming*, Project Description, Available from NILU, P.O. Box 100, N-2007 Kjeller, Norway.

Kasperson, R. E., Kasperson, J. X., and Dow. K.: 2001, 'Vulnerability, Equity, and Global Environmental Change', in Kasperson, J. X. and Kasperson, R. E. (eds.), *Global Environmental Risk*, United Nations University Press/Earthscan, London, pp. 247–272.

Kent, M. L and Poppe, T. T.: *Diseases of Seawater Netpen-Reared Salmonid Fishes*, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada.

Koenig, U. and Abegg, B.: 1997, 'Impacts of Climate Change on Winter Tourism in the Swiss Alps', *Journal of Sustainable Tourism* **5**, 46–58.

Lehtonen, H.: 1996, 'Potential Effects of Global Warming on Northern European Freshwater Fish and Fisheries', *Fisheries Management and Ecology* **3**, 59–71.

Lindkvist, K. B.: 1996, 'Norwegian Fisheries and the Basis of Regional Development', *Norwegian J. of Geography* **50**, 171–186.

Lisø, K. R. et al.: 2002, *Climate 2000 – Building Constructions in a more Severe Climate – Programme 2000–2005*, Programme Description, Norwegian Building Research Institute, Oslo, Available online at: www.byggforsk.no/prosjekter/klima2000/english).

Liverman, D. M.: 2001, 'Vulnerability to Global Environmental Change', in Kasperson J. X. and Kasperson, R. E. (eds.), *Global Environmental Risk*, United Nations University Press/Earthscan, London, 201–216.

Loeng, H.: 2001, 'Possible Climate Impacts on Marine Ecosystems', in *Report from the Arctic Climate Impact Assessment Modeling and Scenarios Workshop*, January 29–31, 2001, Stockholm, Sweden.

Loeng, H., Bjørke, H., and Ottersen, G.: 1995, 'Larval Fish Growth in the Barents Sea', in Beamish, R. J. (ed.), *Climate Change and Northern Fish Populations*, Canadian Special Publication of Fisheries and Aquatic Sciences, National Research Council of Canada, Ottawa, **121**, pp. 691–698.

Mariussen, Å. and Heen, K.: 1998, 'Dependency, Uncertainty and Climate Change: The Case of Fishing', in *Barents Sea Impact Study (BASIS)*, Proceedings from the First International BASIS Research Conference St. Petersburg, Russia, February 22–25, 1998.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D.J., and White, K. S. (eds.): 2001, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

McLean, R. F. and Tsyban, A.: 2001, 'Coastal Zones and Marine Ecosystems', in McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White K. S. (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 343–379.

Nakken, O. and Raknes, A.: 1987, 'The Distribution and Growth of Northeast Arctic Cod in Relation to Bottom Temperatures in the Barents Sea, 1978–1984', *Fish Res.* **5**, 243–252.

National Office of Building Technology and Administration: 1993, *The 1992 Hurricane: Damages on Buildings. Lesson Learned – Measures*, National Office of Building Technology and Administration, Oslo, Norway (in Norwegian).

Nersten N. K. (red.): 2001, *Vision of Norwegian Agriculture – Current and Future Trends 2001*, Norwegian Agricultural Economics Research Institute, Oslo (in Norwegian).

Norwegian Directorate for Nature Management: 1990, *Climate Change and Natural Resource Management*, DN-Report 1990 - 1, Norwegian Directorate for Nature Management, Trondheim, Norway (in Norwegian).

Norwegian Ministry of Agriculture: 1998, *A Dozen Facts about Norwegian Agriculture and Agricultural Management*, Available online at: http://odin.dep.no/archive/ldbilder/ 01/02/etdus052.pdf.

Norwegian Ministry of Environment: 1991, *The Greenhouse Effect, Impacts and Mitigation*, Report from the Interdepartmental Climate Group, Oslo, Norway (in Norwegian).

Norwegian Ministry of Finance: 2002, *Information about the Kingdom of Norway and the Norwegian Economy*, Ministry of Finance, Available online at: http://odin.dep.no/archive/ finvedlegg/ 01/07/Netut020.doc.

Norwegian Ministry of Foreign Affairs: 2002, *National Strategy for Sustainable Development*, Oslo.

NOU: 1996a, *Measures against Flood*, Ministry of Petroleum and Energy (in Norwegian), Available online at: http://odin.dep.no/oed/norsk/publ/utredninger/NOU/038005-020004/index-inn001-b-n-a.html.

NOU: 1996b, *Competition, Competence and Environment*, Norwegian Ministry of Petroleum and Energy, Oslo (in Norwegian).

NOU: 2000, *A Strategy for Employment and Formation of Values*, Norwegian Ministry of Finance (in Norwegian), Available online at: http://odin.dep.no/fin/norsk/publ/utredninger/NOU/006001-020007/index-dok000-b-n-a.html

O'Brien, C. M., Fox, C. J., Planque, B., and Casey, J.: 2000, 'Fisheries: Climate Variability and North Sea Cod', *Nature* **404**, 142.

O'Brien, K. L. and Leichenko, R. M.: 2000, 'Double Exposure: Assessing the Impacts of Climate Change within the Context of Economic Globalization', *Global Environ. Change* **10**, 221–232.

O'Brien, K. and Leichenko, R.: 2002, 'Winners and Losers in the Context of Global Change: Perspectives and Implications for Research and Policy', *Annals of the Association of American Geographers* **93**, 99–113.

Ottersen, G., Michalsen, K., and Nakken, O.: 1998, 'Ambient Temperature and Distribution of Northeast Arctic Cod', *ICES J Mar Sci.* **55**, 67–85.

Ottersen, G., Planque, B., Belgrano, A., Post, E., Reid, P. C., and Stenseth, N. C.: 2001, 'Ecological Effects of the North Atlantic Oscillation', *Oecologia* **128**, 1–14.

Øverland, E. F.: (2000), *Norge 2030 – 5 Scenarier om Offentlig Sektors Framtid*, Cappelen Akademisk Forlag, Oslo.

Parry, M. L. (ed.): 2000, *Assessment of the Potential Effects and Adaptations for Climate Change in Europe*, Jackson Environment Institute, University of East Anglia, U.K.

Parry, M. and Carter, T.: 1998, *Climate Impact and Adaptation Assessment*, Earthscan Publications, Ltd., London.

Raisanen, J.: 2001, 'CO_2-Induced Climate Change in CMIP2 experiments: Quantification of Agreement and Role of Internal Variability', *J. Climate* **14**, 2088–2104.

Sakshaug, E., Bjørge, A., Gulliksen, B., Loeng, H., and Mehlum, F.: 1994, 'Structure, Biomass Distribution, and Energetics of the Pelagic Ecosystem in the Barents Sea: A Synopsis', *Polar Biology* **14**, 405–411.

Sælthun, N. R. Aittoniemi, P., Bergström, S., Einarsson, K., Jóhannesson, T., Lindström, G., Ohlsson, P.-E., Thomsen, T., Vehviläinen, B., and Aamodt, K. O.: 1998, *Climate Change Impacts on Runoff and Hydropower in the Nordic Countries*, Final Report from the Project Climate Change and Energy Production, TemaNord 1998: 552, 170 pp.

Schneider, S. and Sarukhan, J. et al.: 2001, 'Overview of Impacts, Adaptation, and Vulnerability to Climate Change', Chapter 1 in McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J,. and White, K. S. (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 75–103.

Skaugen, T. E., Tveito O. E., and Førland, E. J.: 2002a, *Heating Degree-Days: Present Conditions and Scenario for the Period 2021–2050*, DNMI Report No. 1/02 KLIMA, Norwegian Meteorological Institute, Oslo.

Skaugen, T. E., Tveito, O. E., and Førland, E. J., 2002b, *Growing Degree-Days -Present Conditions and Scenario for the Period 2021–2050*, DNMI Report No.2/02 KLIMA.

Smit, B., Burton, I., Klein, R. J. T., and Wandel, J.: 2000, 'An Anatomy of Adaptation to Climate Change and Variability', *Clim. Change* **45**, 223–251.

Smithers, J. and Smit, B.: 1997, 'Human Adaptation to Climatic Variability and Change', *Global Environmental Change* **7**, 129–146.

Statistics Norway: 1999, Population Projections: National and Regional Scenarios, 1999–2050 (in Norwegian), Available online at: http://www.ssb.no/emner/02/03/folkfram/main.html.

Statistics Norway: 2000, *Natural Resources and the Environment 2000*, Oslo, Norway.

Statistics Norway: 2001, *Statistics Yearbook*, Oslo, Norway.

St.meld.nr.34: 2001, District- and Regional Politics, Norwegian Ministry of Local Government and Regional Development (in Norwegian), Available online at: http://odin.dep.no/krd/norsk/publ/stmeld/016001-040006/index-dok000-b-n-a.html

Subak, S., Palutikof, J. P., Agnew, M. D., Watson, S. J., Bentham, C. G., Cannell, M. G. R., Hulme, M., McNally, S., Thornes, J. E., Waughray D., and Woods, J. C.: 2000, 'The Impact of the Anomalous Weather of 1995 on the U.K. Economy', *Clim. Change* **44**, 1–26.

Søyland V. (red.): 2002, FOLA 2002: *Landbrukspolitikk – forenkling og målretting*, NILF-Report 2002–1, Norwegian Agricultural Economics Research Institute, Oslo.

UNDP: 2002, *Human Development Report 2002*, United Nations Development Programme, Oxford University Press, Oxford, U.K.

UNEP: 1999, *GEO-2000: UNEP's Millennium Report on the Environment*, Earthscan Publications, Ltd., London.

Vellinga, M. and Wood, R. A.: 2002, 'Global Climatic Impacts of a Collapse of the Atlantic Thermohaline Circulation', *Clim. Change* **54**, 251–267.

Watson, R. T., Zinyowera, M. C., Moss, R. H., and Dokken, D. J.: 1996, *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific – Technical Analyses*, Cambridge University Press, Cambridge.

World Bank: 2002a, *Global Development Finance & World Development Indicators Central*, Available online at: http://www.worldbank.org/data/wdi2002/tables/table1-1.pdf.

World Bank: 2002b, *Global Development Finance & World Development Indicators Central*, Available online at: http://www.worldbank.org/data/wdi2002/tables/table4–1.pdf.

Young, O. R.: 2002, 'Institutional Interplay: The Environmental Consequences of Cross-Scale Interactions', in Ostrom, E., Dietz, T., Dolsak, N., Stern, P. C., Stonich, S., and Weber, E. U. (eds.), *The Drama of the Commons*, National Academy Press, Washington, D.C., pp. 263–292.

(Received 11 February 2002; in revised form 9 June 2003)