

Ocean acidification and warming in the Norwegian and Barents Seas: impacts on marine ecosystems and human uses

stakeholder consultation report

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Preface

Climate change and ocean acidification are predicted to impact marine ecosystems and influence food webs, biodiversity and living marine resources, and therefore affect human societies. Within the research project BIOACID (Biological Impacts of Ocean Acidification, phase 2, www.bioacid.de), we brought together people with an interest in the marine ecosystems of the Norwegian Sea and Barents Sea, a region where ocean physics models project an early impact of ocean acidification and warming.

This report synthesizes the results from personal interviews with science experts and stakeholders conducted in Norway in the course of 2013, and from a stakeholder workshop in Bergen/Norway in October 2013. Participants included fishermen and representatives from fishing associations and aquaculture companies, environmental organisations, tourism businesses (hotels/camps, sport fishing, whale watching) and governmental agencies. We asked them about their knowledge about climate change in the ocean, presented the current state of scientific knowledge about possible ecological effects and economic consequences of ocean acidification and warming (OAW), and explained possible research approaches.

In our work, we strive to identify the ecosystem services relevant to society and integrate stakeholders into socio-economic projections and the search for adaptation strategies. A participatory modelling approach is used: communicating with stakeholders and experts and presenting integrated data in a simplified form, visualizing the connections in the ecosystem and to society, and communicating and discussing impacts of climate change and ocean acidification to stakeholders and the public.

The objective of this first phase of stakeholder integration was to identify questions and concerns of stakeholders, determine the relevant ecosystem services potentially affected by ocean acidification

and warming in dialogue with them, and to construct a model structure to explain the linkages between OAW and identified ecosystem services based on the stakeholders' input.

The target questions were:

- How might the marine ecosystems of the Norwegian Sea and the Barents Sea be impacted by warming, acidification and other climate change phenomena?
- How do these impacts interact with the pressure from human use and the extraction of resources?
- How will human societies and economies be affected by these changes in the ecosystems? Whose interests will be touched?
- Which topics are stakeholders interested in? How much does science know? Which questions should be addressed, what factors should be included in research programs?

1. Introduction: climate change, ocean acidification and impacts on marine ecosystems

Human societies depend on the oceans in many ways, but our understanding of their internal processes and their susceptibility to global change are incomplete. The oceans are substantial drivers of our climate but are also affected by climate change. Increasing levels of CO₂ and other greenhouse gases in the atmosphere are changing the earth's climate system, leading to a global warming that will also impact the oceans (IPCC, 2013).

Observations and models agree in a general increase of temperatures in all oceanic regions, but with strong variability between regions (Stocker et al., 2013). Driven by the rise in temperatures, the global ocean system will undergo complex changes in a variety of factors. Increasing temperatures lead to changes in evaporation and sea level rise, melting of sea ice, deoxygenation, and changes in salinity, global ocean currents and the vertical temperature profile. These changes will have profound impacts on the productivity and distribution of marine life (Brander, 2012). Thus, to achieve a sustainable management and use of the oceans under the conditions of climate change is one of the great challenges of our time (European Marine Board, 2013).

Increased atmospheric CO₂ levels also cause a direct chemical interaction with the surface ocean, which is named ocean acidification (OA). First widely discussed after a comprehensive study of the Royal Society in 2005 (The Royal Society, 2005), the problem has been increasingly recognized in the last years and is more and more incorporated into the global climate change debate (CBD Secretariat, 2009, IPCC, 2013). The United Nations Environmental Programme sees ocean acidification as a serious threat to marine biodiversity. In June 2012, the UN Conference on Sustainable Development (Rio+20) recognized ocean acidification as a threat

to economically and ecologically important ecosystems and human wellbeing.

Ocean acidification is caused when an increased amount of atmospheric CO₂ dissolves into the ocean and lowers the pH value, making the water more acidic. As a direct chemical interaction of the atmosphere with the marine environment, it is simpler to predict than climate change effects in general. Since the beginning of the industrial revolution, the increase in atmospheric CO₂ from 280 to 400ppm has led to a drop of the average pH of ocean surface waters by about 0.1 units, from 8.2 to 8.1 (IPCC, 2013). This corresponds to a 26% increase in acidity, an acidification at a faster rate than at any time in the last 300 million years of earth history (IGBP et al., 2013).

The further progression of ocean acidification in the next decades will depend on the amount of CO₂ emissions. In a business-as-usual scenario, oceans are projected to reach an average CO₂ of 7.75 until the end of the century (Bopp et al., 2013). Even if emissions are strongly reduced as in the most optimistic IPCC scenario, oceans will reach an average pH of 8.05. In any case, these values will be subject to strong regional variation, and will be influenced by factors like changes in ocean currents, vertical layering and ice melting.

The impacts of ocean acidification are expected to be different depending on oceanic region and characteristics of the ecosystems. Colder surface waters in high latitudes are expected to be the first impacted areas, because cold water takes up more CO₂ and ice melting increases the problem, causing changes in currents and stratification (CBD Secretariat, 2009; IGBP et al., 2013). For the Arctic ocean, acidification is a major concern, with the highest pH changes expected until the end of the

century and Arctic waters to become corrosive to some shell-producing organisms in the near future (AMAP, 2013). Economically important impacts are also expected to appear in upwelling regions, where a combination of acidification, temperature and hypoxia will act (IGBP et al., 2013). The Norwegian and Barents Seas share characteristics with both aforementioned regions, and can be expected to be impacted by a combination of the influences of continental upwelling along the Norwegian coast, and the influence of changes in arctic and subarctic waters.

Various impacts of ocean acidification on marine organisms and ecosystems have been found, but there are still many scientific uncertainties (Gattuso & Hansson, 2011). Known possible impacts include problems for shell-building organisms, probably leading to negative impacts on mollusks (snails, shellfish), starfish and sea urchins, in corals, and in calcifying microalgae (coccolithophores). Furthermore, early life stages of fish, squid and other animals may be impacted, as changes in larval development and fertilization, behavioral and perception changes are documented. The general impact on phytoplankton, and thus primary production in the ocean is still largely unclear (Wittmann & Pörtner, 2013, Gattuso & Hansson, 2011).

Over the last ten years, these questions have attracted considerable attention from the scientific community and have been the focus of collaborative and multidisciplinary research programs in Europe (e.g. EPOCA, BIOACID, UKOA, MedSeA). The effects of ocean acidification are being researched with a variety of approaches, including controlled aquarium experiments under increased CO₂ levels with individual organisms, where physiological parameters like survival, growth, calcification, respiration, photosynthesis or metabolic activities are measured. Analyses of chemical composition and molecular genetic analyses provide more detailed data, 'mesocosm' experiments host whole ecological communities under near-natural conditions, and CO₂-rich ocean sites serve as 'natural

laboratories' (CBD Secretariat, 2009; Hilmi et al., 2012). Computer models serve to integrate data from this variety of approaches.

It is thus a scientific priority to improve the understanding of the impacts of ocean acidification on marine taxa and underlying processes, and to investigate the roles of adaptation and variability (European Marine Board, 2013). Doing this, it is important to keep in mind that ocean acidification will occur together with other stressors (warming, increased UV radiation, hypoxia, pollution). Therefore, the effects should be considered in relation to other environmental changes in marine ecosystems and biological and chemical feedbacks (The Royal Society, 2005). The health, behaviour and function of individual organisms depends on environmental factors, but also on interactions with other organisms - including humans. Dramatic and unexpected regime shifts in marine systems can be triggered by minor fluctuations. On the other hand, effects are buffered by stress tolerance and adaptation of marine populations, and can also be mitigated by socio-technical adaptation of human societies in the use of marine ecosystems.

2. Ecosystem services & potential impacts

While substantial changes in marine ecosystems in response to rising CO₂ levels are expected within our lifetimes, it remains challenging to predict just how these changes will affect human societies. More work has to be done to achieve reliable, quantitative predictions of the impacts on ecosystem services that are relevant for human societies. Significant knowledge gaps are preventing economists from estimating the potential socio-economic impacts of ocean acidification (Hilmi et al., 2012), and only some partial analyses are available, which carry large uncertainties (Armstrong et al., 2012). Nevertheless, to achieve a sustainable management and use of the oceans under the negative impacts of warming, acidification, and other consequences of human activity (e.g. over-fishing, habitat destruction, pollution, etc.) is one of the great challenges of our time (European Marine Board, 2013).

The concept of 'ecosystem services' can be used to investigate the interactions between the marine ecosystems and human societies. Ecosystem services are "the benefits people obtain from ecosystems" (Millenium Ecosystem Assessment, 2005) and can be more exactly defined as "the ecological components directly consumed or enjoyed to produce human well-being" (Boyd & Banzhaf, 2007). Ecosystem services can be divided into four categories: supporting, provisioning, regulating and cultural services (Millenium Ecosystem Assessment, 2005). This concept can provide a theoretical basis for the economic quantification of services of nature used by mankind (TEEB 2010). But as benefits are subjective properties, the first step is to ask which ecosystem services are relevant to the stakeholders in the investigated region.

In the following paragraphs, we will discuss the relevant marine ecosystem services in our focus region, as identified by the stakeholders and by the scientific literature, and how they are potentially affected by ocean acidification and climate change

in general. We will give an introduction about the current state of scientific knowledge on each service or aspect and present the views and opinions of the stakeholders that participated in our project.

2.1 Fisheries

Background: Fisheries are an important provisioning service of marine ecosystems, as they provide food to humanity and employment for coastal regions (World Ocean Review, 2013). In 2010, fisheries reached an economic value of USD 217.5 billion and provided livelihoods to 10–12% of the world's population, whereby 90% of fishers work in small-scale fisheries (FAO, 2012). While world fisheries yields have been stagnating since 1988, this is compensated for by the growth in aquaculture, which has reached half of the total production. Today, 30% of world fish stocks are over-exploited and a further 57% are fully exploited (FAO, 2012). Recognizing this problem and aiming to make fisheries management more sustainable, the European Union has recently reformed its Common Fisheries Policy towards a more ecosystem-based and precautionary approach (European Commission, 2013).

Climate change puts additional pressure on fisheries management (FAO, 2012). The impacts of climate change and ocean acidification on fish species and their prey organisms affect the stability of commercial fish stocks and are among the key research questions for the future of fisheries (European Marine Board, 2013). Impacts of ocean warming on fish stocks are visible already, as many stocks have shifted range visibly in the last decades, especially those at the edges of their species distribution range (Poloczanska et al., 2013). As species are moving towards the poles, temperate areas will continue to receive new species, tropical

areas will have less species, and some polar species might disappear altogether. Fish body size decreases with increasing temperature, so average fish size is expected to decrease by 14-24% (Cheung et al., 2012).

The impact of ocean acidification on fish stocks is still unclear, since comprehensive research programs do not exist yet (AMAP, 2013), but it is expected to differ between world ocean regions. Shellfish and crustaceans represent a significant part of world aquaculture and fisheries yields and may be severely impacted, e.g. by acidification in coastal waters. An early estimate of the impact of ocean acidification on marine fisheries values it at US\$ 10 billion per year (Kite-Powell, 2009). Fish stocks in Arctic regions with simpler food webs and influenced by ice melt, as well as shallower continental shelf fish stocks are speculated to be impacted more or earlier than other regions (AMAP, 2013). Fisheries in the North Atlantic are expected to be impacted by more-than-average ocean warming and acidification, causing issues of fishing industry adaptation and relocation (Hilmi et al., 2013). While some studies have hypothesized an overall slightly positive effect for Norway (Armstrong et al., 2012), others predict a significant reduction for the whole Northeast Atlantic (Cheung et al., 2011).

In Norway, the fisheries sector plays a key economic and social role with a production of 2.3 million tons and 12.800 employees in 2011. The country is the world's second-largest seafood exporter by value of almost 1 billion USD, with the European Union as the largest market (FAO, 2013). The capture fishery can be divided between industrial offshore vessels and small-scale coastal fishery. Main capture species are cod, herring, capelin, mackerel, saithe and other whitefish. Fisheries are highly regulated and well-managed, and management agreements are reached between politics, fishing associations and scientific advisors (FAO, 2013). Most stocks are managed sustainably and Norway has stock management agreements with Russia for the

Barents Sea and with the European Union, and has been active against illegal, unreported and unregulated fishing (FAO, 2012).

Statements on fisheries management

Overall, stakeholders from the fisheries sector were content with the state of the fish stocks and their economic situation. The interchange of information in fisheries management between fishers, scientists, administration and policymakers was generally regarded as good. Nevertheless, more multi-species and ecosystem-based management of fisheries were wished by participants from the fisheries sector, and more reliable forecasts of catch quota over a period of several years would be highly valuable to increase planning efficiency in vessel and processing capacities.

From a management perspective, range shifts of economically important stocks were seen as a challenge, leading to higher fuel costs and other technical as well as quota distribution problems. Range shifts across legal borders would create additional challenges because they might lead to international disputes. The recent cases of mackerel and herring were given as an example, where shifts of the stocks in the North Atlantic have led to unsolved disputes about the allocation of catch quota between the EU and Norway on one side and Iceland and the Faroe Islands on the other.

As possible adaptations to environmental change from the management side were mentioned a) quota adjustments, b) fishing gear improvements, and c) areas closed for certain types of fishing, e.g. bottom trawling. Fishing gear and method would have to be adapted to size of the target fish and stock occurrence. It was also pointed out that evaluation of management options should not be political and should leave choices open to decision makers. In the past, fisheries productivity had been increased by reducing the number of fishers. It was noted that fishing effort was determined by target species de-

mand, which was also influenced by the amount used as feed for aquaculture. General fisheries moratoria were perceived as a danger for fish markets.

Statements on stock range shifts

Many stakeholders reported the observation of northwards stock range shifts in recent years, especially for cod and mackerel stocks. These stocks seemed to be shifting further to the Northeast into Finnmark and were becoming available to the local fishers there. It was pointed out that the appearance in new areas might also be caused by a range expansion caused by a large stock, which was suspected for mackerel. Sardines were reported as newly immigrated species into Norwegian waters.

Changes of timing and location of spawning of important commercial fish stocks were reported for the last years, e.g. a later spawning of capelin. The Northeast Arctic cod stock was reported to spawn increasingly further north of the area off Lofoten. One prominent concern was the consequence of the cod spawning area moving even further north-east, which would influence the stock and its potential for exploitation. It was detailed that in the Northeast Arctic cod stock, smaller juvenile cods presently dominated the East Barents Sea and were fished by Russian vessels, while bigger adult cods lived in the Western part and were fished by Norwegian vessels. Thus, a moving cod stock might lead to problems for Russian vessels if these were not prepared for the increase in size. From the Russian side, a range shift into the eastern Barents Sea and the Russian territory was also seen as a potentially new situation for management.

Spawning grounds of highly migratory stocks, e.g. herring, were described as very inconsistent, and therefore the attempt to predict herring migrations or distribution shifts was seen as useless. In herring stocks, fishers in Norway had historically experienced strong stock fluctuations, abrupt collapse

and recovery, which had also contributed to the development of the management agreements established today.

A prediction of stock range shifts was generally valued as very helpful for planning in the fisheries sector. Fishers were interested if future changes could be expected to be abrupt, like in the past for herring stocks, or if there would be time to adapt to changes. Although most stocks were regarded as being in a good state, for some this was realized as a problem, as market prices of some commercial species, e.g. cod, were very low due to high supply.

Statements on ecological interactions and model detail

From a management perspective, the two main factors of interest to be represented in ecosystem-based models were recruitment stability and distribution of stocks. Also, change of spawning areas, possible abrupt changes or collapses in stocks, as well as capacity for adaptation to climate change were seen as relevant. Furthermore, changes in growth rate and size distribution of fish individuals would be interesting parameters from a management perspective.

Implications of food web interactions were a regular concern for fishers. Connections between the states of mackerel, capelin, herring and cod stocks were mentioned. The large mackerel stocks along the Norwegian coast were also a reason for concern, because of food competition and juvenile predation of more valuable species. Workshop participants advised to make use of the high amount of information available about food web connections in the Norwegian and Barents Seas to improve models and increase the knowledge about changes in the system. Models would be more credible if more of these food web interactions were incorporated. On the other hand, management representatives pointed out that complexity should not be overdone, projections should be sufficiently reli-

able for commercially relevant species but many other food web elements could probably be left out. In this context, the impact on the food web from high amounts of small fish being fished out for aquaculture feed was an additional interest.

A major concern about ocean acidification was the impact on fish recruitment. It was pointed out that present models only consider adult stock dynamics and earlier life stages are described by recruitment, but potential effects on larval growth and mortality would be a topic of high interest. Another topic of concern was primary production and whether it will remain sufficient to support fish stocks under climate change. Change of productivity and pelagic fish stocks in the Arctic Ocean under increasing ice melt was a further concern. There was interest in the effect of ocean acidification on the food of commercial fish species, e.g. copepods and pteropods, and possible changes in the ecological coupling to plankton production in spawning grounds.

Statements on socio-economic factors

A number of socio-economic connections became apparent in the fisheries sector. It was pointed out that social factors influence the adaptive capacity of fisheries towards changes in fish stocks. Historically, there had been a drastic reduction in workers from 120,000 in the 1940's down to 12,000 today. If harvests cannot be increased further, productivity will have to be increased further to keep the income stable. The impacts on employment could be mitigated only as long as there are other economic sectors that absorb the work force.

It was noted that the fuel use of trawl fisheries is considerable and that the fishing fleet accounts for 5-7% of Norwegian CO₂ emissions. There was seen potential for improving the carbon footprint of the fishing fleet.

Differences in estimation of adaptive capacity exist among groups of fishers: while the big offshore

vessels based in West and South Norway can follow their target stocks by longer distances, coastal fishermen in Northern Norway might be left behind, because their smaller boats are not able to follow stocks from the fjords out to the open sea. Yet especially in these regions, fishery is of social importance, since it attenuates socio-economic pressure on the communities and plays an important role for the cultural heritage of traditional Sami culture. External pull for educated workers from the oil industry, livelihoods of fishers, employment alternatives and social structures were mentioned as relevant factors for the stability of Northern communities. Thus, changes in fish stocks could have locally and regionally dramatic impacts on communities, even when overall economic cost was limited.

Stakeholders noted that market demand, multi-species fisheries, by-catches and processing costs were further socio-economic factors which influence the connection between fish stocks and the fisheries sector, and which should be included in a comprehensive model. Also, various connections to aquaculture were mentioned, e.g. smaller capture fish were increasingly used as aquaculture feed, increasing demand and influencing market prices. Although an influence of ocean warming on the placement of aquaculture installations along the Norwegian coast was observed, stakeholders voted for not including aquaculture at this point of the model building process because no detailed information was currently available. The industry might be considered in the future of the project for its socio-economic relevance and connection with other fisheries.

Fishery is considered to play an important role for the food provision for humanity, i.e. it is considered essential for coping with population growth under limited resources. Prices were generally expected to increase in the future, with climate change possibly aggravating the situation. The marine sector would have to deliver a growing share of the world food production, maximize long-term fisheries yield and increase the aquaculture share. The economic

importance of fisheries was expected to increase further in the future after the Norwegian oil peak, and a transition back to a fisheries-based economy would be possible if stocks continued to be managed sustainably.

A topic of pronounced interest for stakeholders from the fisheries sector was the oil exploration

around Lofoten islands, which is feared to lead to pollution of cod spawning areas. A similar concern was the increased granting of mining licenses in the north of Norway. The impacts of pollutants and sediment discharges on fjord ecosystems were regarded as potentially dramatic and the rate of transport out into the open sea as unclear.

2.2 Tourism & recreation (cultural services)

Background: Marine ecosystems provide an array of cultural services that are used either by locals or by domestic and international tourists. Total worldwide revenue from international tourism amounts to USD 1,075 billion and keeps growing in spite of recent economic crises (World Tourism Organization, 2013). Tourism can support sustainable development, but is also one of the most highly climate-sensitive economic sectors (Simpson et al., 2008). It may be indirectly impacted by climate change through changes in water availability, biodiversity loss, reduced aesthetic value of landscapes, sea level rise causing coastal erosion, inundation and damage to infrastructure, and a rise in vector-borne diseases. On the other hand, tourism contributes about 5% of world carbon emissions (Simpson et al., 2008).

The oceans play a substantial role in tourism and recreation. In Europe, recreational saltwater fishing has approximately 8–10 million practitioners and is a considerable industry with socio-economic relevance (FAO, 2012). Recreational fisheries and associated tourism can provide alternative livelihoods for small-scale fishers, but tourism activities are also competing for space with professional fishery in some coastal areas (FAO, 2013).

In Norway, tourism is strongly connected to the coastal regions and the fjords, and fishing is the most well known activity (NMTI, 2012). The tourism industry, including transport, accommodation and

gastronomy services, travel and tour companies, is an important employer especially in Northern Norway, where it provides 18,000 jobs and 6% of total added value (Klima- og Miljødepartementet, 2011). Sea fishing contributes significantly to added value and development in Norwegian coastal communities, creating a value of about € 26 million, with € 12 million just in the North (Klima- og Miljødepartementet, 2011). Apart from sea fishing, activities include whale and seal watching tours, bird watching, kayaking, hiking, camping and other nature-related recreation activities. Whale watching revenue in Norway amounts to €12 million per year and has risen by 18% since 1994 (Greenpeace, n.d.).

While tourism economy can serve as an indirect indicator for recreation value, value for local recreation is more difficult to quantify. Apart from recreation, the coastal marine ecosystems provide aesthetic services, religious and spiritual services, cultural identity, as well as options for education and research. Most of these services are difficult to quantify on a monetary basis, but nevertheless have economic and societal value.

Statements on recreational fishing and other coastal tourism

Stakeholders reported that tourism in Norway was strongly connected to nature experience, and to

the sea and maritime activities as cultural heritages of the Norwegian people. It was stated that a decrease in the experience of 'intact nature' would have a severely negative impact on tourism.

Seabirds, seals and sea lions, and fish were mentioned as elements of the marine ecosystems that play a role in coastal tourism. Drastic drops in many seabird populations in recent years were reported for Northern Norway and Svalbard, which was suspected to be linked to declines in prey fish. The white-tailed eagle was mentioned as an exception and was reported to increasingly hunt for puffins instead of fish.

Stakeholders from the tourism sector confirmed recreational fishing as one of the most popular nature-related activities and an important pillar of Norwegian tourism, practiced from the shore and from small boats in fjords and the coastal areas up to 20-30km from the coast. It was pointed out that non-professional fishing is also officially controlled and monitored in Norway and fish exports are restricted. Among the most popular game fish were halibut, spawning Atlantic cod (skrei), catfish, plaice and saithe. Tourism linked to sports fishing was seen as especially relevant on the Lofoten and Vesterålen islands in Northern Norway, where occurrence of some of the game fish species was reportedly linked to the annual cod spawning migrations in spring, and sport fishing in this area had recently profited from increased numbers of spawning cod along the coast.

It was stated that tourism in Northern Norway was strongly linked to small-scale fishing, as boats, harbors and the connected activities (e.g. production of stockfish) were culturally unique and a strong pull-factor for tourists. Many ship owners used their vessels seasonally for professional fishing as well as for sport fishing or other recreational activities linked to tourism. Thus, it was pointed out that tourism could not simply serve as a substitute for fishing, and the socio-economic connections especially in the northern regions had to be considered. Boat

ownership was also regarded as having a strong cultural significance for people from small coastal communities in the North, many of which were under pressure from modernization, urbanization and demographic ageing.

In Troms and Finnmark, many coastal cod stocks in the fjords were considered to be declining or to have collapsed, leading to dramatic consequences for local communities. There were concerns that high mackerel numbers coming into fjords might have negative impacts on cod because of food competition and direct feeding on cod larvae. Seals were also speculated to have an impact on cod populations in the fjords, driving them further into the fjords, but seal hunting was now prohibited.

Concerns were expressed about the fjords in the North being increasingly explored for construction of mineral mines, with new licenses progressively being granted. The pollution from mining waste was a substantial concern for stakeholders from environmental conservation groups. An increasing use of fjords for aquaculture was also reported, causing concerns about influences on fish spawning in fjords through space competition and emissions.

Statements on whale watching

Whale watching was seen as an important tourism and recreation activity in Lofoten, Vesterålen and the Tromsø region. According to stakeholders from the whale watching sector, the patterns of whale migration are variable, but the occurrence of most whale species was linked to the occurrence of their prey. While humpback whales were the most regular sighting, tooth whales like orcas and sperm whales followed the highly migratory herring stocks in their overwintering areas, which varied from year to year. It was added that many whale stocks had a social structure with dominant specimens, which could influence sightings. While minke whales were regarded as uninteresting for whale watching tours, they are commercially fished in Northern Norway

and it was pointed out that the minke population is stable and being sustainably exploited as a resource.

Tour operators described the number of whale sightings as the defining variable for their business, and asked to consider that whales moving out to far from the coast would make it impossible to provide tourist trips. A lack of ecological information about stocks was diagnosed, as only minke whales and to a certain degree sperm and orcas were researched and information about possible impacts of climate change on whale stocks was very scarce. Nevertheless, changes in prey abundance were expected to have drastic impacts. Whales were also mentioned as a generally important part of the marine food webs through their feeding interactions with lower trophic levels and also

through the release of nutrients in the surface water layers. Winter whale watching was said to be closely connected to the overwintering location of herring stocks, but to provide only a small part of the revenue. Summer sightings might be more connected to other factors, for example deep zooplankton distribution. Other ecosystem links to fisheries were mentioned, e.g. sperm whales being increasingly observed to feed on cod, because squid seemed to have declined in the Norwegian Sea.

Concerns about negative impacts on whale stocks and whale watching activities by other human activities were expressed, e.g. by seismic exploration and noise produced by fishing and transport shipping, which is expected to increase under climate change due to the reduction of the Arctic ice cover.

2.3 Carbon uptake & primary production

Background: Carbon absorption is a regulating service of the oceans with great importance for the planet's climate. Atmospheric CO₂ is taken up by the ocean surface, primarily by chemical solution, which depends on temperature. In high latitudes, a high amount of CO₂ is taken up because of low water temperatures, forming water masses that are cold and carbon-rich, which sink to the deep and drive the worldwide ocean circulations. In contrast, the additional CO₂ released by anthropogenic emissions enters the oceans uniformly at the surface and leads to a higher concentration in surface waters. All carbon is temporarily stored for up to 1000 years in the ocean, until it flows back up to the surface in upwelling regions (CBD Secretariat, 2009; IPCC, 2013). More than one quarter of all human CO₂ emissions are taken up by the oceans in this way. Therefore, the oceans represent a huge carbon reservoir and an important buffer against climate change. As ocean acidity increases, its capacity to chemically absorb CO₂ from the atmosphere decreases, reducing the capacity of the oce-

ans to moderate climate change (IGBP et al., 2013). In the future, warming of the North Atlantic, changes of the overturning circulations and an increased stratification will reduce the solubility of CO₂ and is expected to lead to a reduction in carbon uptake (Pérez et al., 2013).

The solubility pump is complemented by the so-called 'biological pump', which converts some of the CO₂ taken up by the ocean into organic matter. By this process, the dissolved inorganic carbon (DIC) in the water is taken up through photosynthesis by marine microalgae (phytoplankton), transformed into phytoplankton biomass and then further transported into the food web. A part of the plankton biomass sinks down into the deep layers of the ocean, where it is recycled by bacteria or, to a small fraction, buried forever in the marine sediments.

Rising water temperatures under climate change may decrease chemical solution of CO₂ in many areas, although reduced ice cover in the Arctic

ocean may lead to higher primary production and biological CO₂ uptake (Manizza et al., 2013). The impact of ocean acidification on primary production is still unclear: While it has been speculated that photosynthesis will be generally positively impacted by a higher amount of CO₂ available, increased stability of depth layers might decrease nutrient input into the light zone at the surface and act negatively on primary production. It is unclear to what extent the different groups of phytoplankton will be negatively affected by increasingly stressful conditions caused by warming and acidification. As two important phytoplankton groups (coccolithophores and foraminiferans) and some of the zooplankton (e.g. pteropods, or sea butterflies) have calcareous shells or structures, it seems probable that they will be negatively impacted by ocean acidification (Kroeker, Kordas, & Crim, 2013). Total export capacity of organic matter could be reduced (Le Quéré & Metzl, 2004).

For Norway, first economic assessments have estimated that negative impacts of ocean acidification on carbon storage may be several orders of magnitude higher than effects on fisheries and aquaculture (Armstrong et al., 2012).

Statements on carbon cycle and emissions

Stakeholders with an environmental conservation background noted that Norway is internationally known to be an environmentally friendly country. Nevertheless, it was stated that Norway exported CO₂ emissions by the export of oil and by the import of goods produced from other countries, distorting the actual carbon budget. Additional com-

penensation came from buying up CO₂ emission certificates. Most stakeholders regarded personal willingness in Norway's society to change behavior and cut CO₂ emissions as rather low. It was stated that due to the very good economic situation in Norway, people tended to be satisfied with the situation, but were ready to accept some additional cost for emission compensation.

Participants from the fisheries sector suggested that reduction of CO₂ emissions from fishing vessels was also a means of reducing impacts of a high CO₂ atmosphere.

Statements on primary production and biological carbon

Stakeholders from the fisheries and conservation fields repeatedly mentioned primary production as an important factor, as its potential changes under climate change would have impacts on the marine food webs and finally change the productivity of fish stocks. It was therefore a prominent concern that primary production would not suffice to support productive fish stocks under climate change and ocean acidification.

It was also suggested that the general structure of marine food webs, and the total biomass held in all trophic levels, further determined the amount of carbon stored in biological organisms. The net carbon effect of climate change on food webs under extraction of biomass by fishing was therefore an interest. Whales, big fish and squid also were noted for their role in carbon cycling, releasing organic matter and nutrients at the surface and in the deep.

2.4 Biodiversity

Background: Biodiversity is not an ecosystem service by itself, but a basic property of all ecosystems. Through the provision of ecosystem services,

biodiversity affects human well-being and forms the basis of human economies (Millenium Ecosystem Assessment, 2005; TEEB, 2010). Loss of biodiver-

sity can be seen as one of the most pressing economic problems of our time, but the lack of appropriate methods for economic valuation of biodiversity has contributed to the degradation of ecosystems and prevented the successful introduction of protective tools (Jones-Walters & Mulder, 2009). Worldwide, biodiversity is threatened by human activities, and marine biodiversity has been declining by 22% since the 1970s (Leadley et al., 2010; WWF, 2012).

Biodiversity is a central attribute for ecosystem resilience and contributes to a variety of services of the marine ecosystem, e.g. food provision, raw materials, climate regulation and biological habitat (Beaumont et al., 2008). Nevertheless, it is difficult to exactly define biodiversity, as it embraces variability of living organisms of any origin, on several biological levels of description, and includes species diversity, genetic diversity and ecosystem diversity (United Nations, 1992; Pearce & Moran, 1994; TEEB, 2010). It is thus extremely difficult to quantify the economic impacts of a loss of biodiversity. Representative data and indicators have to be found for each aspect, which can then form the basis of an objective and quantifiable evaluation. Nevertheless, it is an important concept in addressing the public, describing general properties of changing ecosystems.

Norwegian coastal waters have an overall good state of biodiversity, as measured by the Nature Index of the Norwegian Directorate for Nature Management, but ocean acidification is seen as one of a number of human-caused threats to biological diversity in Norwegian waters (Nybø, Certain, & Skarpaas, 2011). Changes in Arctic Ocean chemistry, influenced by climate change and sea ice melt, are expected to affect populations of calcifying species and impact biodiversity and trophic pathways (CAFF, 2013). Additionally, many polar organisms are highly adapted to their niches and may be highly threatened by change. Shifts in marine plankton community structure in the Arctic Ocean due to ocean warming and acidification are one of

the major tipping points in the earth system, where biodiversity loss can potentially pass an irreversible threshold (Leadley et al., 2010).

Sensitivity to ocean acidification differs among groups of animals, but in many species, reduced growth, increased mortality or impaired reproduction have been reported (Gattuso & Hansson, 2011). Shell-building molluscs (e.g. mussels, scallops, clams, oysters) will be impacted by ocean acidification with very high probability, since their calcium carbonate shells dissolve under a decreased pH. The same seems to be true for echinoderms (starfish, sea urchins, sea cucumbers), which have calcareous skeletons. Both groups play important ecological roles in benthic coastal ecosystems, as food for fish, and some species have a high economic significance for coastal communities in many world regions. Negative impacts on different groups of calcifying plankton organisms, as coccolithophores and foraminifera (phytoplankton) and pteropods (zooplankton) are expected under ocean acidification. The sensitivity of small crustaceans, copepods and krill, which form part of the zooplankton and play an important role in food webs in the Norwegian and Barents Sea, is still unclear, but these groups may be more influenced by temperature than acidification (IGBP et al., 2013; Kroeker et al., 2013; Kroeker et al., 2010; Wittmann & Pörtner, 2013).

Statements on biodiversity and ecosystem resilience

For interview and workshop participants, biodiversity was an important issue; therefore it is included as a separate topic in this report. Although most of the impacted organisms groups are not regularly visible to stakeholders, biodiversity was seen as a 'buffer' for species loss, providing adaptation capacity in marine ecosystems under climate change. In this sense, biodiversity might be treated as an aspect in marine ecosystems that is not directly economically valuable, but informs about the re-

silience of ecosystems. Also, the cultural significance of biodiversity was noted. The stakeholders regarded the value of biodiversity as very difficult to quantify, but welcomed attempts to find indicators for this important property.

Some changes in distribution of species are directly visible for stakeholders and a connection to global change was mentioned frequently. Reported examples include brown seaweed (*Fucus*) along the Northern coasts, birch trees in Finnmark, newly introduced species as Sea bass and Pacific oyster in Oslofjord and Skagerrak. Changes in marine food webs were also suspected to play a role in the declines in seabird populations in Northern Norway and Svalbard.

Biodiversity was seen as important for ecosystem-based management of living resources. Stakeholders from different sectors noted that potential thresholds in the ecosystems have to be observed because they might be indicative of upcoming regime shifts or collapses. In the Arctic Ocean, the

impact of a melting ice cover was perceived as likely having drastic impacts on biodiversity. Primary productivity was expected to change, and some species that live in close association with the sea ice might be threatened. For example, the ecological effects of a disappearance of polar cod in the high northern latitudes might be severe, therefore stakeholders wished to include this question in the investigation.

According to many stakeholders, conservation of biological diversity should be given political priority and has a value that should be included in studies and models. If some groups or species were severely impacted and went extinct, biodiversity would decline. Because of the complexity of marine food webs, questions were posed on how interactions between species would change, what would happen when key species were impacted, and what chain reactions might happen. On the other hand, stakeholders speculated that some impacts might also be buffered in the ecosystem.

2.5 Coral reefs

Background: Ocean acidification is expected to impact tropical coral reefs, which are already under high stress from increasing temperatures and acidification and may be severely impacted within the next decades (IGBP, 2013). Tropical coral reefs provide significant regulating services for coastal protection, cultural services for tourism and recreation, and supporting services as nursery ground for many fish species. In addition to acidification, warming, pollution, sedimentation and destructive fishing practices impact tropical coral reefs. The potential impacts are similar but less investigated for cold-water coral reefs.

In Norway, the largest cold-water coral reefs in the world exist. It is estimated that 70% of cold-water corals will be exposed to corrosive acidic waters by

2100, and some populations will experience corrosive conditions as early as 2020 (CBD Secretariat, 2009). This leads to reduced calcification and increased dissolution rate of the dead skeletons which form the base of reefs (Maier, Hegeman, & Weinbauer, 2009; Roberts, 2006).

Overall, the ecological significance of cold-water coral environments is not well understood yet, but ocean acidification is threatening these sensitive ecosystems before their biological diversity and significance has been fully explored (The Royal Society, 2005). Ocean acidification is expected to have potentially catastrophic consequences in these deep sea ecosystems, acting together with deep-water warming and deoxygenation (European Marine Board, 2013).

Deep sea ecosystems provide a variety of supporting ecosystem services, but many gaps exist in their monetary and non-monetary valuation (Armstrong et al., 2012). They serve as a habitat for some demersal fish species and as spawning and feeding ground for others, so their loss is expected to have consequences for food webs (Turley et al., 2007; IGBP et al., 2013). They also play a significant role for local biodiversity and coastal carbon cycling (The Hermione project, 2012). Furthermore, they have an existence value and provide cultural services for education and research.

Statements on deep-water coral reefs

Workshop participants stated that ecological connections of deep-water coral reefs with other marine ecosystems are still unclear and seem to be only remotely connected to the priority issues in the present study. Their cultural significance was estimated as limited, and they lacked relevance for tourism. The significance of deep-water coral reefs as a protection against erosion of the continental slope was also seen as unclear.

Participants therefore voted not to consider the impacts of ocean acidification on deep-water coral reefs at this stage. Instead, they pointed out that deep-water coral reefs along the Norwegian coast had been closed areas for bottom trawling fishery since 1988, and suggested that the reefs should remain under a special protection status, adopting a precautionary approach because of their rareness. Therefore, deep-water coral reefs will not be further considered in this study at this point, which may change when indications for important ecological connections to model elements become substantiated.

3. Outlook

3.1 Developing a social-ecological model with stakeholder participation

To investigate how marine ecosystems and coastal communities will be affected by climate change, multi-disciplinary research is needed that takes into account environmental, economic and social factors (European Marine Board, 2013). Ecosystem-based marine resource management can benefit from stakeholder participation, considering both scientific and traditional knowledge, and taking a systemic approach that considers all relevant ecological, social, economic and governance elements (FAO 2012). It appears necessary to assess the biological and socio-economic risks from ocean acidification, but it remains challenging to quantify how marine ecosystems and fisheries will change and how societies will adapt to the changes brought by ocean acidification (Hilmi et al., 2012; IGBP, 2013).

In recent years, the Norwegian Ministry for the Environment has developed integrated ecosystem-based management plans, covering the Norwegian Sea as well as the Barents Sea and the marine area off Lofoten (Klima- og Miljødepartementet, 2007; 2009; 2011). These plans aim to manage activities in those areas within a single context and use ecological principles to assess the various activities and the potential for future development. To understand the behavior of these marine systems and enable long-term management, it will be essential to adequately integrate climate change effects (Hoel & Olsen, 2012). The concept of ecological resilience under climate change for the Norwegian and Barents Seas is also being integrated into the work of environmental organizations, e.g. WWF Norway (Boisen & Jensen, 2013).

The links between elements of the ecosystem and the socio-economic system identified by our stake-

holder consultation are being incorporated into a model of the combined social-ecological system that aims to explain mechanisms and uncertainties, identify critical parameters and investigate the system's resilience towards ocean acidification and warming.

General remarks on the model

General remarks from stakeholders for the project's modeling activities included that although management plans for the areas in question have been developed, no valid indicators for the vulnerability of species under climate change are included. Also, stakeholders demanded that the model should have a clear regional scope and a clear temporal horizon. The model should consider the background of natural variability, of seasonal and inter-annual fluctuations, and enable comparisons with the situation in historical warm periods. It should carefully consider natural causes apart from human-induced changes. The validity range of the model and the uncertainty would be of the highest interest in the end.

Stakeholders demanded that model complexity should not be too high and the representation of the marine food web should be limited to species absolutely necessary. On the other hand, elements that are left out should be named and reasons given for their exclusion. Of high interest to the participants was to what degree the structure of the ecosystem would be able to buffer impacts on its services. Natural variability and long-term adaptation of populations should be investigated experimentally and these factors should be considered in projections. Economic connections between fisheries sectors could remain simple at this point and be based on information about fish stocks and yields, i.e. stakeholders did not see the need to incorporate market mechanisms.

3.2 Conclusions

Our stakeholder consultation has produced a multifaceted overview and yielded detailed insights on the connections and interactions in the investigated social-ecological system. All stakeholder commentaries towards the model structure and components will be taken seriously in the currently ensuing modeling process. However, it will probably not be possible to incorporate all elements that were mentioned.

Statements from the stakeholders have also helped to identify relevant and potentially affected ecosystem services as well as possibilities for adaptation.

These results will be used to investigate system resilience and explore possible futures and adaptation strategies. Into the model structure, indicators for the selected ecosystem services will be incorporated. Focusing on physical components and structures of the ecosystem allows a direct measurement, ideally in standardized biophysical units, and avoids double counting.

Nevertheless, many ecosystem services are difficult to quantify. Not all benefits may be captured, e.g. potential benefits from biodiversity. Furthermore, not all ecosystem services can be evaluated on a monetary basis. For an economic assessment, also non-market valuation methods will be used. Stakeholders are the beneficiaries of an ecosystem's services, and therefore will form the basis for this valuation.

Appendix

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List of contributors

Note: Statements of participants represent their personal opinions and not necessarily their institution's official view. Names of participants are not given for privacy reasons.

#	Institution/company	City/county	Participant's background or focus area	Field
1	-	Bergen	Journalist	fisheries
2	-	Tromsø	Fisherman	fisheries
3	Abornes sea fishing	Troms	Sport fishing tours, fishery	tourism, fisheries
4	Akvaplan NIVA	Tromsø	Aquaculture and innovation	aquaculture, research
5	Aqua Lofoten Coast Adventure	Nordland	Tours, fishing, diving	tourism
6	Arctic Management and Assessment Programme (AMAP)	Oslo	Env. monitoring and assessment	intergov. agency
7	Association of Arctic Expedition Cruise Operators (AECO)	Netherlands	Arctic tourism	tourism
8	Bivdi - Sami Fishers' and Hunters' Association	Finnmark	Environmental conservation	env. NGO
9	CICERO (Center for International Climate and Environmental Research)	Nordland	Socio-economic impacts of climate change	research
10	Coastal Sami Resource Centre (Sjøsamisk kompetansesenter)	Finnmark	environmental and cultural conservation	env. NGO
11	Fiskarlaget Nord	Tromsø	Fisheries Management	fisheries
12	Fiskeridirektoratet (Directorate of Fisheries)	Bergen	Fisheries Management	governm. agency
13	Fram Centre	Tromsø	Fish research, aquaculture	research
14	Hvalsafari Andenes	Nordland	Whale watching	tourism
15	Ice Fish AS	Tromsø	Fish trade	fisheries
16	Institute of Marine Research (IMR), Bergen	Bergen	Oceanography and climate	research
17	Institute of Marine Research (IMR), Tromsø	Tromsø	Fisheries, food webs	research
18	KARAT Fisheries Holding, Russia	Murmansk	International affairs	fisheries
19	Lofoten Fishing AS	Nordland	Fishing	tourism
20	MAREFA (Marine Research and Education Fund of Andenes)	Nordland	Whale research	research, tourism
21	Maribell Sjøbuer AS	Troms	Sport fishing, tourism	tourism

22	Miljødirektoratet (Norwegian Environment Agency)	Trondheim	Natural resource use and conservation	governm. agency
23	NCE Tourism Fjord Norway	Bergen	Tourism association	tourism
24	Nergård AS	Tromsø	Fishery and fish processing	fisheries
25	NIVA (Norwegian Institute of Water Research)	Oslo	Marine chemistry and monitoring	research
26	Norges Fiskarlag (The Norwegian Fishermen's Association)	Trondheim	Fishery	fisheries
27	Norges Naturvernforbund (Friends of the Earth Norway)	Oslo	Marine Ecosystems	env. NGO
28	Norsk Institutt for kulturminneforskning (NiKU)	Tromsø	Sami cultural studies	research
29	Norsk Sildesalgslag (Norwegian Fishermen's Sales Organisation for Pelagic Fish)	Bergen	Sales Director	fisheries
30	Norwegian Seafood Federation (FHL)	Bergen	Marine environmental issues	aquaculture
31	Rådgivende Biologer AS	Bergen	Environmental assessment	env. counselling
32	University of Bergen	Bergen	Fish stock dynamics	research
33	WWF Norway	Oslo	Fisheries and Marine Conservation, Socio-Economy	env. NGO

Stakeholder interview questionnaire

Note: The questionnaire was adjusted to stakeholder backgrounds and not all questions were posed to every stakeholder. Interviews were qualitative and flexible follow-up questions were used to further investigate topics of interest.

I. General situation

1. Are you satisfied with how your yields or gains have developed in the last years? Why / why not?
2. What are your biggest concerns about the future development of your business?
3. Which parts of the marine ecosystems are important for you? Which parts do you use?
4. Have you observed changes in the ecosystem in the last years/decades? Which changes?
5. What are your biggest concerns about the future development of the ecosystems?
6. Are you concerned about the effects of climate change on marine ecosystems? Do you think the observed changes may be connected to climate?

II. Climate change & ocean acidification

1. What impacts of climate change are you most concerned about?
2. Which society groups or users of ecosystems do you expect to be first or most strongly impacted?
3. Have you heard about ocean acidification? What?
4. How do you think climate change and ocean acidification could impact marine ecosystems?
5. What consequences might that have for you or your work?
6. How could you / your company react in order to mitigate consequences?

III. Science communication

1. Do science and politics support you / cooperate with you sufficiently?
2. What information do you need from science to plan ahead in the face of possible changes?
3. How should uncertainty of scientific statements be communicated?

IV. Climate change & society

1. What might be the main impacts of climate change on Norwegian societies? Which economic consequences have to be considered?
2. Which might be options for the society to adapt to climate change?
3. What obstacles exist for adaptation strategies?
4. How is the public perception of threat from climate change?
5. How high is the willingness to change one's behavior or pay costs for the prevention of climate change consequences?

V. Management options

1. Which adaptation strategies / regulation measures (examples) decided by politics would you accept? Which not?
2. What factors and whose interests are relevant in decisions about adaptation strategies?
3. Which social or cultural backgrounds influence the acceptance of adaptation strategies?
4. Which other (national/international) dependencies have to be considered when developing strategies or making decisions?

Workshop agenda

Impacts of ocean warming and acidification on the marine ecosystems and their human uses: Stakeholder workshop within the Bioacid 2 project

17th October 2013, Institute of Marine Research (IMR), Bergen/Norway
Hosts: Stefan Koenigstein, Stefan Goessling-Reisemann (University of Bremen)

Part 1: State of scientific knowledge about potential impacts of ocean warming and acidification

- Welcome, BIOACID project concept, and introduction of participants
- scientific background and project presentation
 - o state of scientific knowledge about ocean warming and acidification, connection to climate change, discussion
 - o socio-economic impacts, modeling approaches, discussion
- Guided discussion of important ecosystem services and relevant impacts of climate change
 - o concept of ecosystem services, selected services, discussion

Part 2: Discussion of stakeholder opinions and model structure

- Presentation of the basic model structure
 - o discussion of model structure, 1) ecological, 2) socio-economical
- Final discussion (summary and discussion of results)
- other missing elements, general concerns
- conclusion, outlook and farewell (invitation to further participation)

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Statements about probabilities of future changes are not standardized in this report, and may reflect the personal views of the authors of the cited references, the interviewed experts or the report's authors.

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