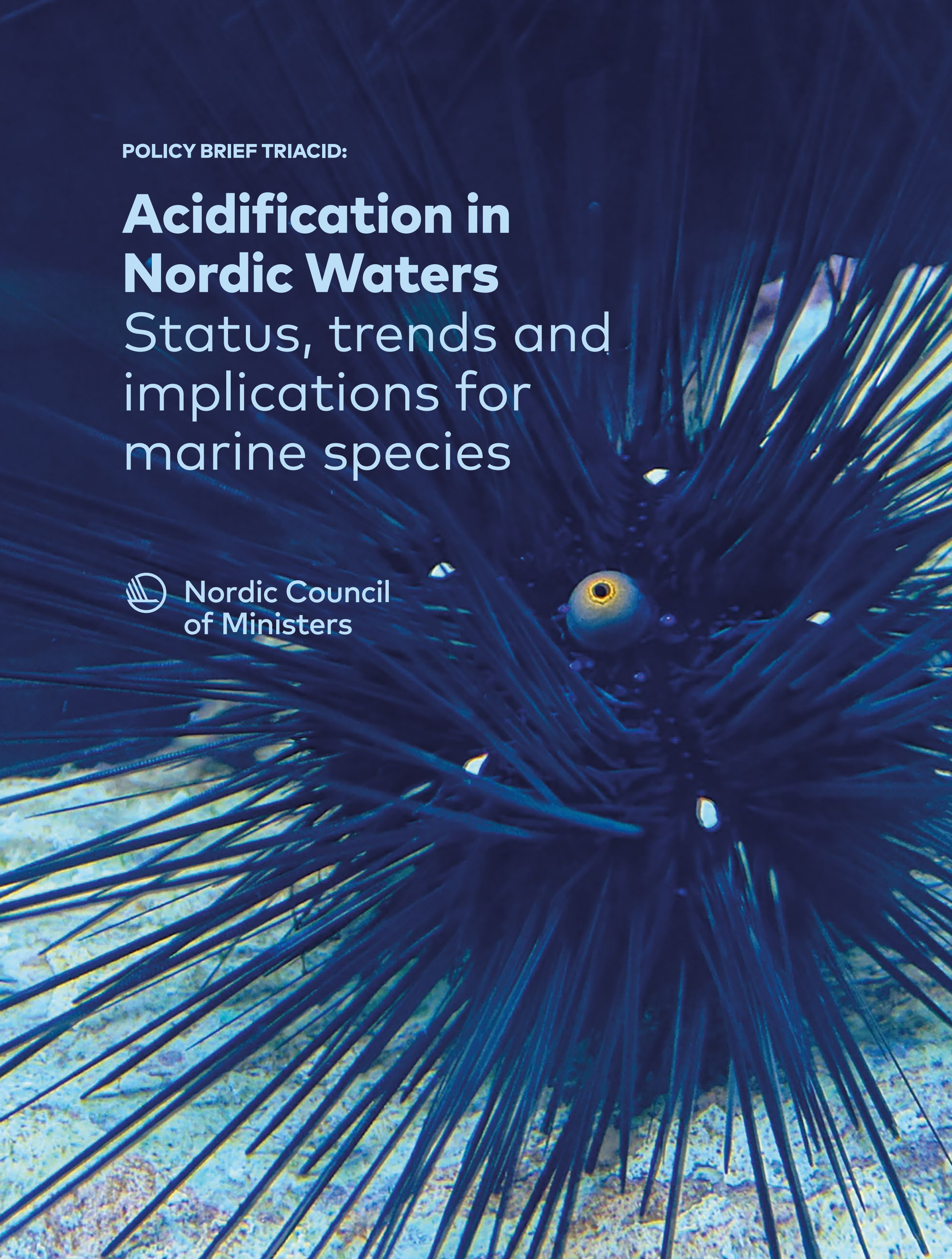
POLICY BRIEF TRIACID:

Acidification in Nordic Waters
Status, trends and implications for marine species



Nordic Council of Ministers

POLICY BRIEF TRIACID: Acidification in Nordic Waters
Status, trends and implications for marine species

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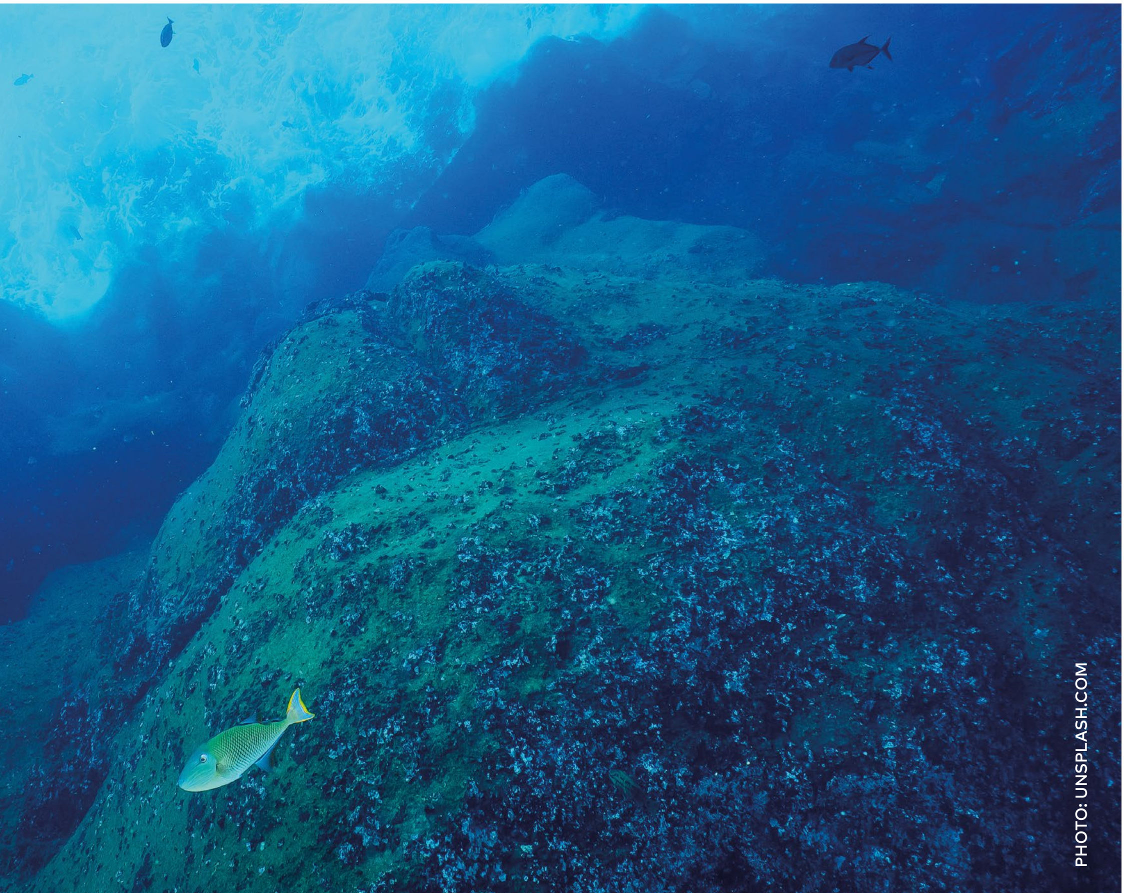
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INTRODUCTION

Recent studies on marine life show that the anthropogenic increase in atmospheric CO_2 concentration can have negative impacts on growth and survival of groups of marine life such as corals and other calcifying organisms.

Increased CO_2 concentration in the atmosphere, and hence in the oceans, lead to decreasing pH or increasing acidification, a process known as ocean acidification (OA). During the last century, the CO_2 concentration in the atmosphere has risen from around 280 ppm to 400 ppm; this has led to a pH decrease in the oceans of 0.1. OA currently takes place at a rate corresponding to approximately -0.02 pH unit per decade and an increase in CO_2 at around 2 ppm per year. The projections for atmospheric CO_2 concentration is an increase to around 1000 ppm at the end of the century, which will lower pH in the oceans by 0.3-0.4. Although this may appear relatively small, a decrease in pH of 0.1 corresponds to an increase in acidity ("free" protons) of 25%, and 0.3-0.4 corresponds to an increase of 200-250%.

Coastal systems experience changes in pH over time exceeding those of the ocean by several orders of magnitude, but the field is poorly studied, and the spatial variation is large. The Baltic Sea is no exception to this. pH changes in the Baltic Sea are tightly coupled to nutrient input, alkalinity (AT) of freshwater sources in addition to increased CO_2 levels and warming. Acidification trends vary substantially among coastal systems and time of year, but have been reported up to 10 times faster than OA.

The TRIACID project has mapped acidification trends in the Baltic Sea during the past 40 years, in different regions, and identified areas with a general lack of data. The project has described spatial variation and trends in pH status, and the main drivers of changing pH have been identified. Given the spatial variation, the data gaps, and all the different drivers a detailed projection of the development is complicated but since we expect increasing CO_2 concentration in the atmosphere, rising temperatures and decreasing nutrient input, the acidification trend will continue or accelerate in most of the region.

KEY FINDINGS

- A decrease in pH has been observed in Nordic marine waters, in some regions at rates substantially higher than in the oceans.
- Data gaps prevent assessment of development in the OA for many coastal areas.
- For estuarine and coastal areas, catchment land use influences the chemical composition of freshwater inputs, which play a significant role in regulating coastal acidification.
- In shallow coastal areas, land-based inputs of organic matter, AT and nutrients are main drivers for seasonal and interannual variability.
- Eutrophication (nutrient enrichment) and oligotrophication (nutrient reductions) have been the primary driver for observed pH trends in most of the Baltic Sea.
- Assessment of acidification trends for coastal and estuarine waters requires additional parameters to determine main drivers of pH and AT change relative to the ocean.

RECOMMENDATIONS FOR POLICY MAKERS

- For future predictions and a broader understanding of drivers of OA, it is recommended to expand marine monitoring programs with measurements of the carbonate system. A more comprehensive knowledge will strengthen the political basis for decision-making.

- Currently, there is no coordinated effort for acidification monitoring in the coastal/shelf zone, as for the open ocean. Improved data coverage on temporal and spatial scales in the coastal areas in the Nordic countries is required to assess acidification trends, their causes and consequences.

- The use of existing platforms and monitoring activities supplemented with sensors on moorings can improve the coverage considerably.

- Upgrading monitoring efforts in areas that are expected to be particularly vulnerable to acidification and constitute important biological hot spots such as spawning grounds and deep-water coral reefs.

STATUS AND DEVELOPMENT

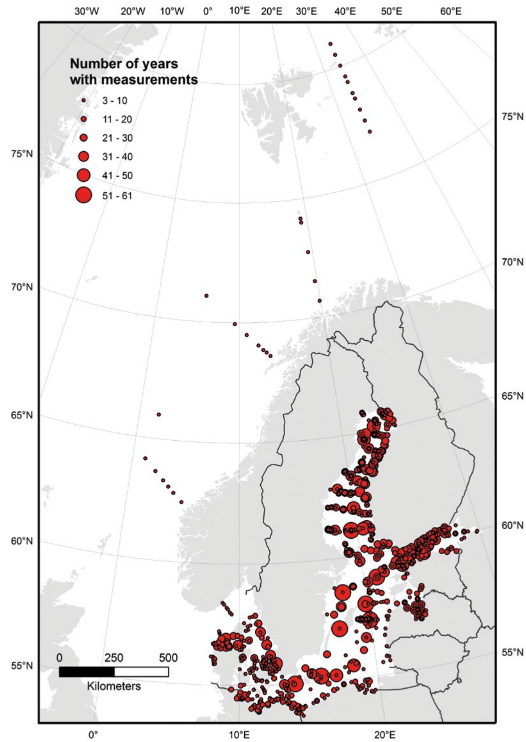
Monitoring

For assessment of the development of OA, a monitoring program is needed. For 40 years, acidification parameters have been measured, in some areas consistently and in others sporadically, but the essential parameters for acidification assessment have not been measured as regularly as other parameters.

For an adequate assessment of acidification, at least two and preferably three of the following parameters should be measured: pH, AT, DIC, and CO_2. Historically, pH and AT have been measured most regularly.

AT and pH are not monitored consistently across the Baltic Sea (Fig. 1). Longer time series exist for the open Baltic Sea, but besides a few long time series in the open Baltic the existing data are scattered and mostly concentrated around Denmark and Finland (Fig. 1).

↓ Oysters are valuable marine species, but oyster larvae are sensitive to low pH conditions, which may affect oyster fisheries and aquaculture.



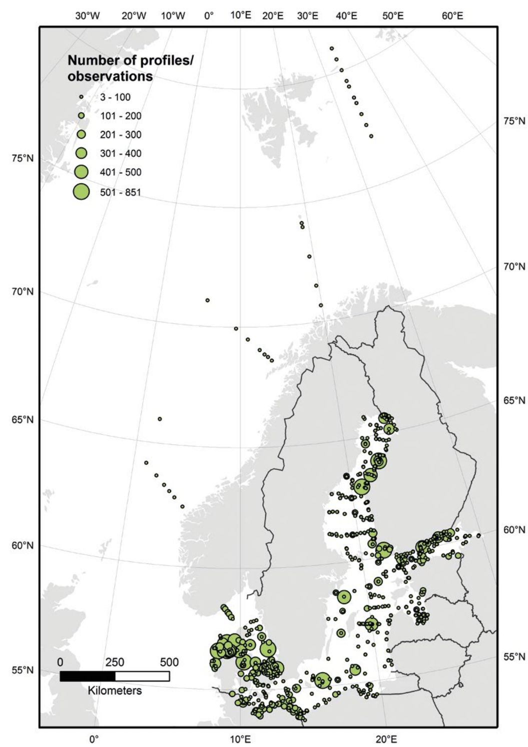


Figure 1 →

Length of time series number of profiles/ observations of pH across the Baltic Sea. Data from ICES and Danish monitoring program, compiled from the TRIACID project.

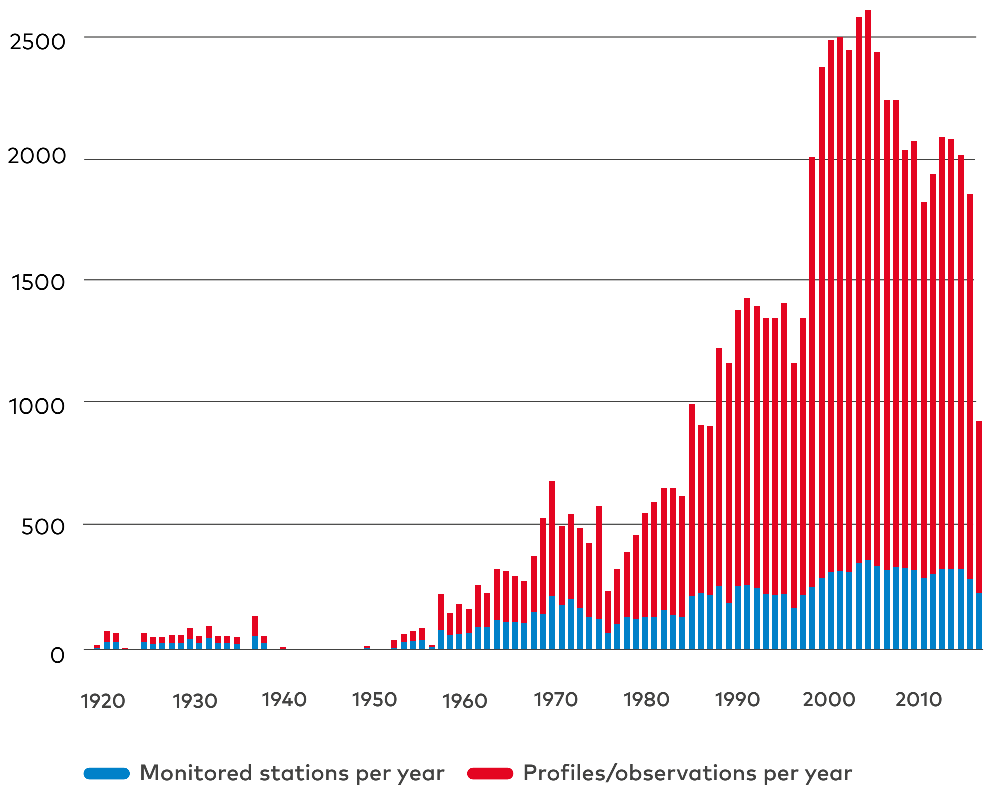


Figure 2 ↑
Number of profiles/observations of pH over time. Data from ICES and Danish monitoring program, compiled from the TRIACID project.

Data from the Danish monitoring program and the ICES database has formed the basis for a 40 to 50 years long time series of observations. The number of pH observations increased from the 1970s and peaked in the early 2000s, reaching a contemporary level of ~1500 profiles per year (Fig. 2). This is substantially lower than the number of observations for nutrients, chlorophyll, and oxygen.

The consequence of the scattered sampling is that acidification trends only can be assessed for the regular open-water stations and a limited number of coastal stations.

Temporal development in ocean, fjord, and coastal waters

The coastal areas are highly influenced by inputs from their catchment. Therefore, changes in land use, precipitation and

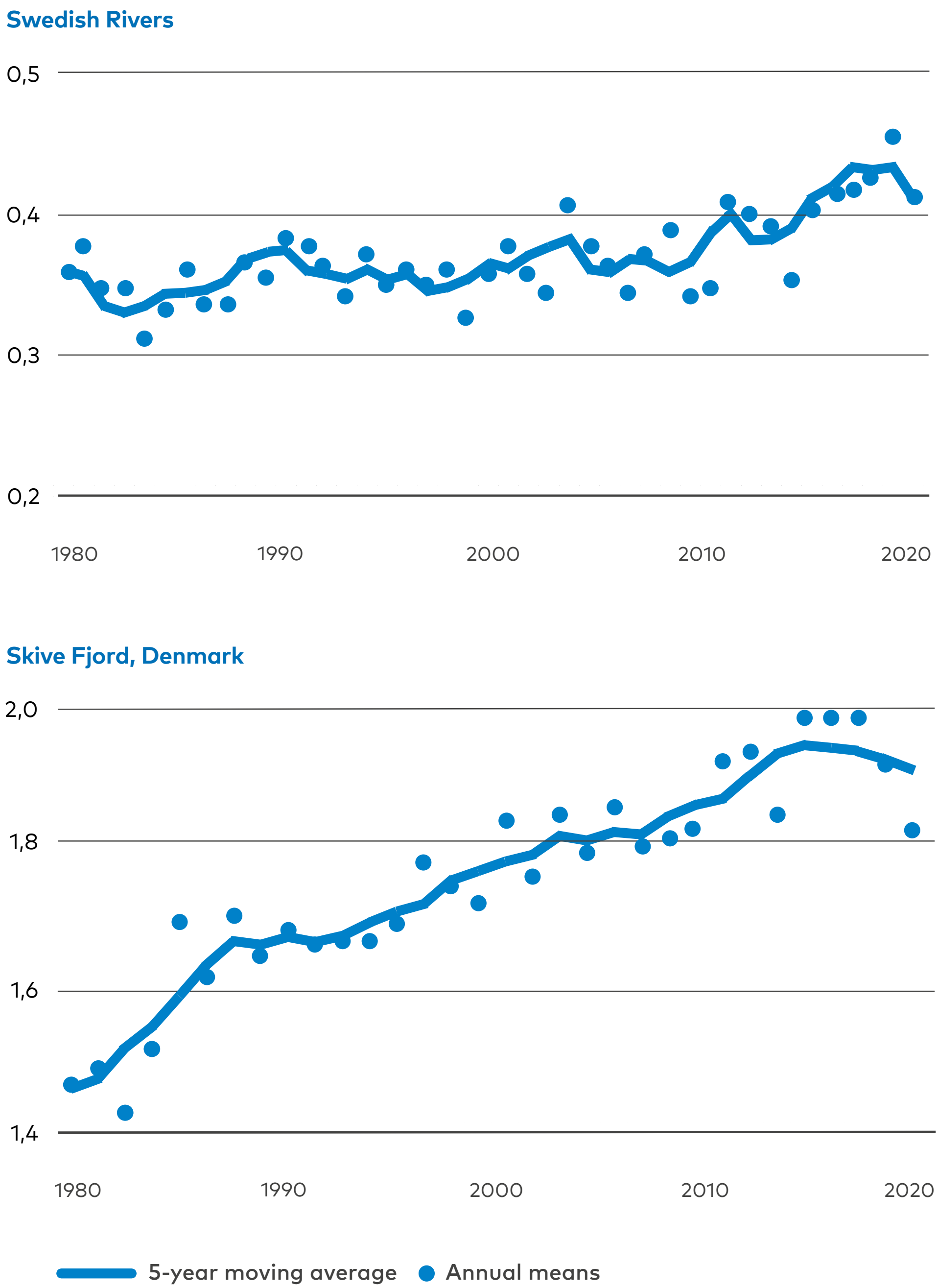


Figure 3 ↑
Flow-weighted concentration of alkalinity in Swedish rivers (www.slu.se) and Danish streams discharging into Skive Fjord.

Acidification causes (times OA)

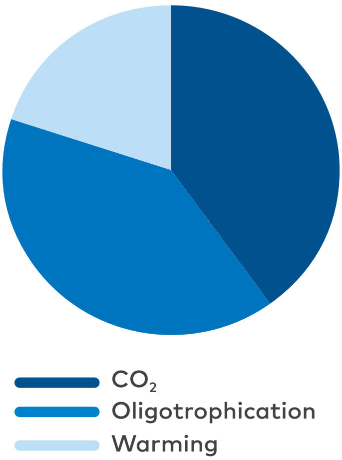


Figure 4 ←
The main causes of acidification in the Baltic Sea, weighted in relation to their relative contribution to changes in pH in three Danish estuaries.

discharge are essential factors for the understanding of the trends in the coastal recipient. Alkalinity inputs change with land use and enhanced weathering from climate change. An increase in the riverine alkalinity due to changing precipitation pattern and land-use has been observed for the Baltic Sea (Fig. 3).

AT has increased throughout most of the Baltic Sea with increasing inputs from land, and hence the acidification buffer capacity has increased.

Despite increasing alkalinity in the Baltic Sea, pH is declining at a rate faster than OA, caused by the combination of increasing atmospheric CO_2, reduced nutrient input, and warming (Fig. 4). The Baltic Sea is experiencing acidification to a variable degree, depending on location.

Seasonal variability in ocean, fjords, and coastal waters

In addition to the considerable spatial variation in pH, there is also great seasonal variation. During summer when there is plenty of light available CO_2 is transformed into organic

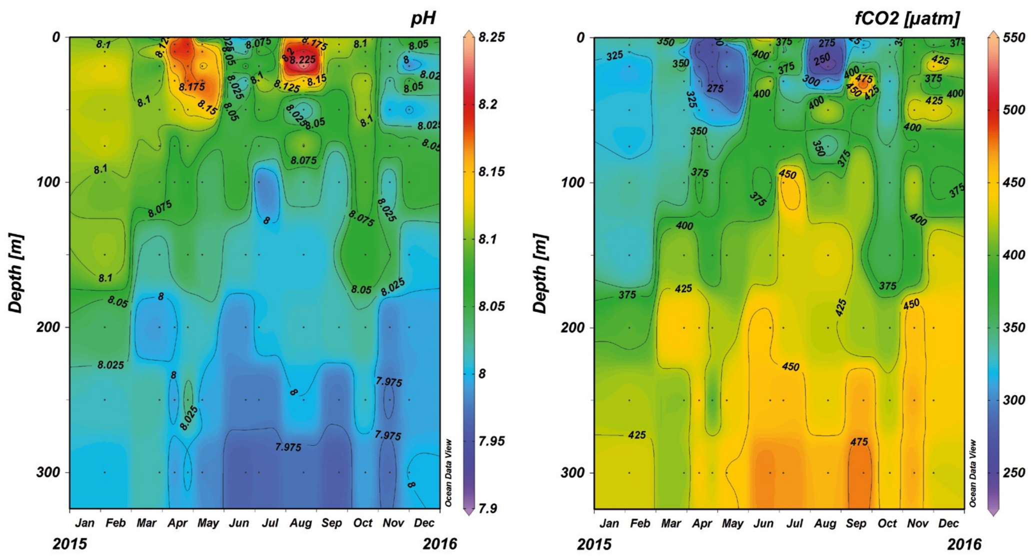
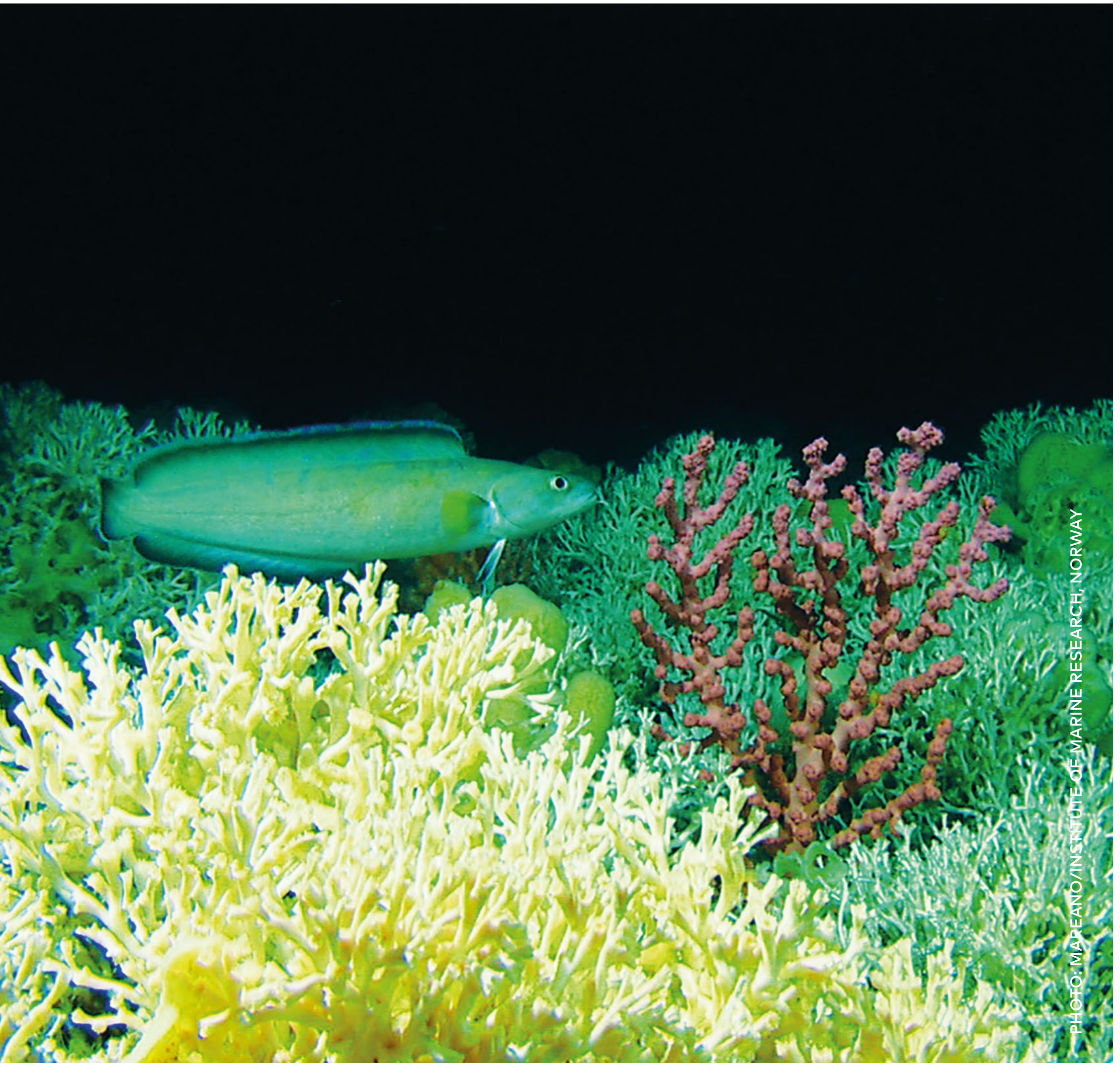


Figure 5 ↑
Seasonal and depth variation in pH (left) and CO_2 concentration (right) in the Norwegian west coast.

carbon by aquatic plants and algae (photosynthesis) using the energy from the sun. Hence, CO_2 in the surface layer of the water is consumed during summer months, which gives rise to an increase in pH. Because of the enhanced production in the surface waters, organic matter is exported to the bottom layers, where it is mainly respired, producing CO_2. This decoupling of production and respiration works as transport of CO_2 from the surface to the bottom with some time lag, giving rise to a spatial and temporal displacement in CO_2 concentration and pH (Fig. 5).

Recommendations for OA monitoring in the coastal zone

The temporal and spatial variation in pH makes it more challenging to monitor changes, particularly when pH is undersampled. Therefore, it is recommended to increase the frequency and coverage of pH sampling. Increased sampling can be achieved using existing platforms/ships/moorings and through investment in new technology. Due to the temporal variability in the coastal areas, regular sampling is crucial to assess the trend.



↑
Example of a deep-water stony coral reef with Lophelia species off the Norwegian coast. One of the habitats that are most susceptible to acidification.

ENVIRONMENTAL IMPACTS

When CO_2 dissolves in water, it becomes carbonic acid (a weak acid), which rapidly becomes bicarbonate and carbonate ions under basic conditions, but it is also causing a decrease in pH. Since ocean CO_2 has increased rapidly on a short time scale, the ocean chemistry has shifted to a more acidic state (fewer carbonate ions), although still basic. The carbonate ions are essential for some marine organisms to build hard parts of calcium carbonate ($CaCO_3$) such as skeleton and shells. In addition to direct effects of changes in pH and carbonate ion concentrations on marine organisms and ecosystems, there can also be indirect links, through changes in food web and production, biogeochemical cycling of substances, especially nutrients and micronutrients, and their bioavailability for primary production.

Direct biological effects

In many studies, it has been concluded that calcifying organisms (e.g. corals, mollusks, crustaceans, echinoderms and coccolithophore algae) are affected negatively by the present acidification. It is believed that acidification together with increasing temperatures are the main reasons for bleaching and decreased growth in coral reefs globally. Corals are also found in Nordic waters, but mainly in the deeper areas in the North Atlantic along the coasts of the Faroe Islands, Iceland and Norway (Fig. 6). In the shallower coastal areas and most of the Baltic Sea, other organisms are affected by acidification. The most well-documented biological effect of OA is reduced calcification that leads to slower growth of shellfish (lobster, shrimps, crab, and mussels), snails, starfish, sea urchin, and coccolithophore (calcifying microalgae). There are also studies that show behavioral changes in other species, such as reduced predatory activity in some fish species.

Indirect biological effects

Many commercially important fish feeds on benthic (bottom-living), calcifying organisms. The commercially most important fish is cod (Gadus morhua), which feeds on crab, brittle star, mussels and sea urchin. Many flatfish species target the same preys. Both mussels and corals are known to form biogenic reefs (Fig. 7). These reefs act as essential habitats for many other species providing shelter and anchorage. Such habitats could come under threat with increasing acidification.

The Baltic Sea is among the most important sites for overwintering sea ducks that forage on mussels and marine gastropods, and these populations will be affected with a decline in natural mussel and gastropod production.

↑ →
Blue mussels (Mytilus edulis) is an important species, both for human consumption, and as prey for fish and birds. They also form biogenic reefs.

PHOTO: JOHANNES JANSSON, NORDEN.ORG

SOCIAL AND ECONOMIC EFFECTS

Fishery, both commercial and recreational, may be negatively impacted due to reduced growth or disappearance of vulnerable species or habitats.

In Denmark and Norway alone (the two most significant contributors) the revenue of commercially fished calcifying organisms are around 200 million EUR. Additionally, many commercially and recreationally important fish feed on calcifying organisms or live in habitats formed by calcifying organisms. The total revenue of the commercial fishery in Denmark and Norway is around 2.5 billion EUR excluding derived industries.

The recreational marine fishery in the Baltic region and Norway is estimated to have a value of 3.5 billion EUR including direct, indirect and induced effects, for production.

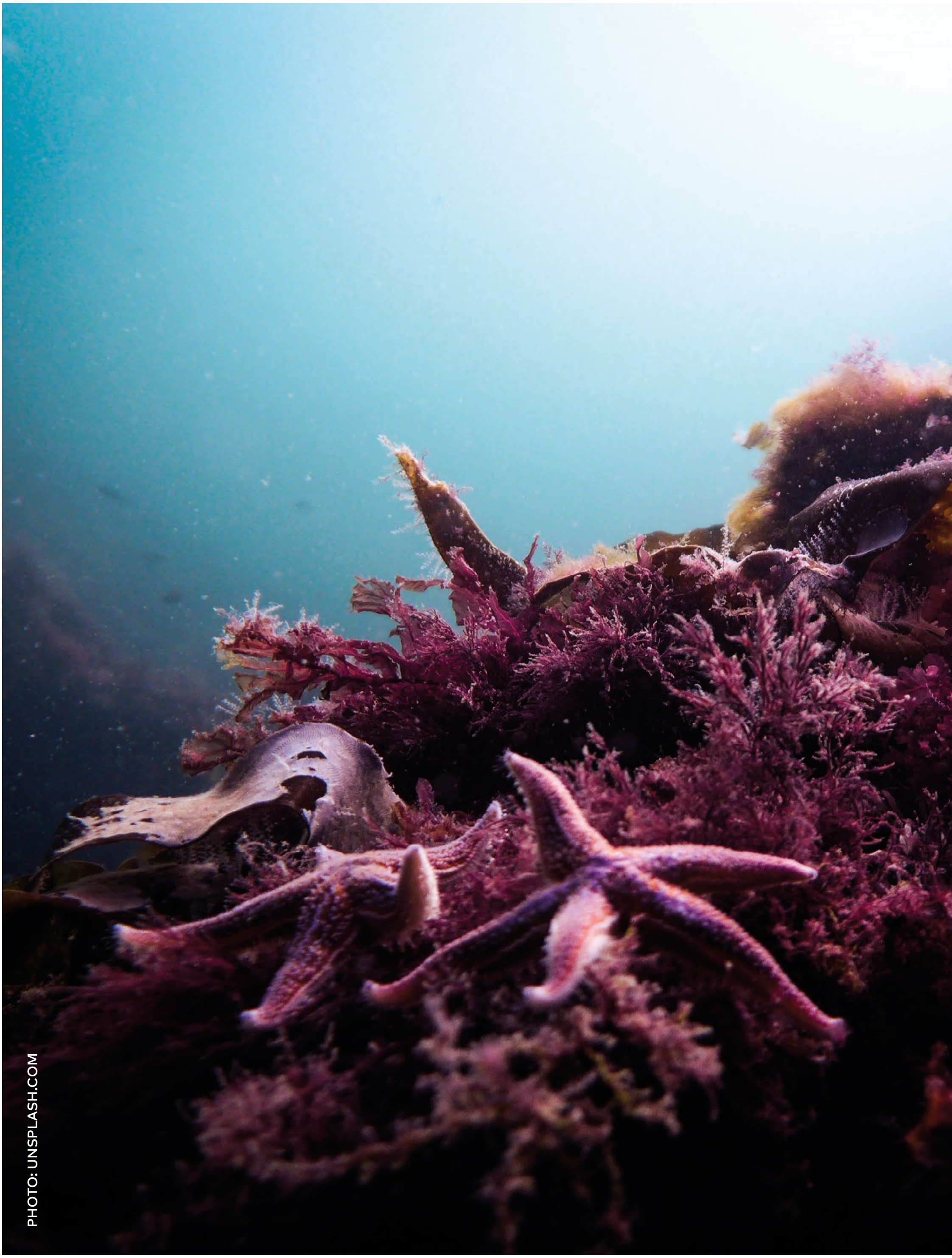
It is impossible to estimate the direct impact of acidification on the economy, but in combination with other human-induced pressures on marine life a decline in natural fish and shellfish production should be expected, if nothing is done to mitigate the environmental impacts acidification.

POSSIBLE ACTIONS TO COUNTERACT ACIDIFICATION AND DERIVED EFFECTS

- Comply with the Paris agreement – reduced carbon emissions will decelerate the acidification of the oceans and coastal areas and limit warming which enhances the acidification effect.

- Reduce eutrophication to prevent hypoxia. The oligotrophication gives rise to some acidification, but over time the organic pool will be reduced. Eutrophication may lead to hypoxic conditions with high CO_2 and low pH, which can severely affect shallower near-shore areas through upwelling.

- Reduce other anthropogenic pressures on most vulnerable species and habitats. Many species may be able to live in more acidic waters than now, but it may reduce their ability to withstand other pressures like eutrophication, fishery, mining, and xenobiotics.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Increasing CO_2 concentration in the atmosphere leads to acidification of marine waters. Ocean acidification is relatively predictable with pH decreasing ~0.02 per decade, whereas changes in coastal pH can be 10 times larger due to changing inputs of nutrients and organic matter from land and warming. Despite that most organisms affected by acidification inhabit the coastal zone, status and trends of coastal acidification as well as possible consequences for marine life are largely overlooked. At present, coastal acidification is not consistently monitored and reported in Nordic countries. The TRIACID project has developed indicators, which are applicable to assess acidification and its potential consequences, provided that pH and other parameters of the carbonate system are monitored. It is recommended to increase focus on this emerging environmental problem.

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