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Reducing eutrophication crucial to prevent coastal methane emissions

A large part of the anthropogenic emissions of carbon dioxide have been absorbed by the oceans. However, many Swedish coastal areas are currently affected by eutrophication, making them a source of greenhouse gases, mainly in the form of methane. Reducing eutrophication is crucial for limiting methane emissions and thus mitigating climate change.

The latest reports from the International Panel on Climate Change (IPCC) show that reducing greenhouse gas emissions is becoming increasingly urgent if the Paris Agreement's target of limiting global warming to 2 degrees is to be met. This makes it particularly urgent to reduce methane emissions, as these emissions have an especially large impact on the climate in the short term. At the UN Climate Change Conference in Glasgow in 2021, participating countries adopted a joint target to reduce methane emissions by 30 per cent by 2030.

Methane is a shorter-lived but much more potent greenhouse gas than carbon dioxide. Methane emissions caused by human activities are small compared to the corresponding carbon dioxide emissions (only around 3 per cent in terms of carbon), but are nevertheless estimated to have contributed more than 20 per cent to global warming over the last 250 years.[1] This makes methane the second most important greenhouse gas for climate change after carbon dioxide.

Methane levels in the atmosphere have more than doubled since the beginning of the 20th century and the increase has accelerated in recent years. However, there are still large knowledge gaps regarding the contributions from anthropogenic as well as natural processes and how these may change in a warming world.

Research now suggests that eutrophic coastal environments may be important, but previously partly overlooked, sources of methane. According to preliminary calculations made by researchers at Stockholm University Baltic Sea Centre, methane emissions from the largely eutrophic Swedish territorial waters could amount to as much as 30 000 tonnes annually. This corresponds to just over 800 000 tonnes of carbon dioxide equivalents on the 100-year scale (where one tonne of methane is estimated to be equivalent to 28 tonnes of carbon dioxide), or 2.5 million tonnes of carbon dioxide equivalents on the 20-year scale (where one tonne of methane is seen as equivalent to 84 tonnes of carbon dioxide). These numbers can be compared with Sweden's total reported territorial emissions of greenhouse gases (excluding land use and forestry), which are estimated to amount to just over 45 million tonnes of carbon dioxide equivalents per year on the 100-year scale or just over 54 million tonnes on the 20-year scale.[2]

Blue carbon – a small part of the carbon cycle

Through gas exchange between water and air, the ocean absorbs some of the carbon dioxide released into the atmosphere. If there are nutrients in the water, the carbon dioxide can be used for the growth of plants, algae and bacteria, and ultimately by organisms higher up the food chain. This allows additional carbon dioxide to be absorbed into the water. When organic matter sinks to the bottom, some of it will be buried and can thus be stored for a very long time – sequestered.

Some marine environments are seen as particularly effective at capturing and storing carbon, such as mangrove swamps and seagrass beds, but macroalgae – such as the Baltic Sea bladderwrack – can also

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[1] Saunois, M. et al. The Global Methane Budget 2000–2017. Earth System Science Data 12, 1561–1623 (2020).

[2] https://www.naturvardsverket.se/data-och-statistik/klimat/sveriges-utslapp-och-upptag-av-vaxthusgaser/ samt https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0107/TotaltUtslappN/ Data från 2022.

be effective. The carbon stored in these ecosystems is known as 'blue carbon'. Restoring these types of environments can be an important nature-based measure to mitigate climate change.

However, new calculations show that in the Baltic Sea, the ecosystems that store blue carbon hold a relatively small proportion of the total carbon stock. The proportion of vegetated bottoms in Swedish territorial waters is estimated to be less than 5 per cent. Instead, the seabeds in the Baltic Sea are dominated by vegetation-free bare sediments. This is partly due to human impact in the form of eutrophication and exploitation (e.g. boat traffic, dredging and piers), but the extent of vegetated bottoms is also limited by natural factors such as the physical characteristics of the bottom and the lack of light and/or oxygen in deeper areas.

Reducing pressures on habitats such as seagrass beds and bladderwrack forests is important for several reasons. It improves water quality and marine biodiversity and strengthens ecosystem resilience, and can also increase carbon uptake. However, even if these areas were to double in size in the Baltic Sea, they would absorb relatively small amounts of carbon, as most of the seabed will continue to consist of vegetation-free sediments. More significant for the climate are methane emissions from shallow coastal areas.

Decomposition on the bottoms cause methane emissions

When plants, animals and other organisms in the sea die, they are decomposed by bacteria, partly in the water column, but also on and in the seabed sediments. Decomposition consumes oxygen and releases carbon dioxide, which returns to the water. Decomposition of large amounts of organic material can result in all the oxygen being consumed. If the sea is eutrophic, there is a lot of organic material and therefore eutrophication can cause the spread of anoxic bottoms, which is one of the major environmental problems of the Baltic Sea. In these so-called 'dead zones', however, decomposition of organic matter continues, including by methane-producing microorganisms called archaea.

In eutrophic marine areas, methane production can be high, both because of a lack of oxygen and because there may be large accumulations of organic matter to be decomposed. Recent studies show that methane production can also occur in shallower environments that are not completely oxygen-free. For example, methane-producing archaea have been found in anoxic pockets between seaweed plants in bladderwrack forests and in algae communities adjacent to the plants. It is estimated that about one third of the carbon dioxide uptake in the vegetated areas of the Baltic Sea is offset by methane released to the atmosphere.

Measurements from vegetation-free areas show that such areas can be net sources of both carbon dioxide and methane to the atmosphere. This makes Sweden's territorial waters as a whole a source of greenhouse gases to the atmosphere, according to calculations.

From sediment to atmosphere – two routes

The methane formed in sediments can reach the atmosphere in two ways. Firstly, it leaks from the sediments in dissolved form and mixes with the water upwards in the water column. If it reaches the sea surface, it can then be transported to the atmosphere through gas exchange. However, the dissolved methane can be used as an energy source by microorganisms in the water, resulting in its conversion to carbon dioxide and water. The depth of the seabed is therefore of great importance for whether the methane leaking from the sediments reaches the atmosphere or not. Normally, coastal bottoms shallower than about 50 metres are considered to dominate methane emissions from the oceans, despite their relatively small surface area.[3] This is because they are shallow enough to allow the methane to reach the surface water and the atmosphere before it can be used by microorganisms.

When methane production is high and sediments become saturated with methane, methane gas can also be produced. The methane gas leaves the sediments in the form of bubbles that transport the methane to the surface much faster and more efficiently than the dissolved methane that is slowly mixed upwards in the water mass – in about 20 minutes the bubbles can travel several hundred metres. The methane bubbles gradually dissolve in the water, contributing to the concentration of dissolved methane, which can then either be used by microorganisms or released into the atmosphere.

A recent expedition indicates that methane bubbles in the Baltic Sea can travel much further than previously believed. At the deepest point in the Baltic Sea, the Landsort Deep, at a depth of just over 400 metres, the researchers discovered intense release of bubbles containing methane and other substances from the seabed, which travelled several hundred metres to the sea surface. Although the emissions of methane to the atmosphere from this specific, extremely deep area in themselves are insignificant, the discovery could mean that methane production from a larger part of the Baltic Sea than previously thought could reach the atmosphere and affect the climate.

Areas where there is a lot of accumulated organic matter, due to eutrophication and/or ocean currents, and where oxygen conditions are poor, could potentially be hotspots for methane production. The Baltic Sea has many such potential areas, including fibre banks caused by industrial emissions from paper mills. According to an experimental study, the production of methane in such fibre banks in Sweden could amount to 3.7 million tonnes of carbon dioxide equivalent per year at the 100-year scale (11 million tonnes at the 20-year scale).[4]

Some of this methane will probably be removed in the water instead of released to the atmosphere, but the flux is still high compared to what the Baltic Sea Centre's researchers have estimated the total methane emissions from Swedish territorial waters to be. This shows that there are still large uncertainties in the calculations, but still supports the importance of considering methane emissions from the oceans.

Warming may increase methane production

Global warming has led to an average increase in air temperature of about 1 degree over the last 100 years[5], which has also affected the oceans, that absorb much of the heat. In the Baltic Sea region, warming has been faster than the global average, which is clearly visible in a shallow sea like the Baltic Sea. So far, the water temperature is estimated to have risen by an average of 3.3 degrees since the beginning of the 20th century, with 2.4 degrees in the last 30 years alone.[6] According to model simulations, the surface water temperature of the Baltic Sea could increase by between 1.1 and 3.2

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[3] Weber, T., Wiseman, N. A. & Kock, A. Global ocean methane emissions dominated by shallow coastal waters. Nat Commun 10, 4584 (2019).

[4] Alizée P. Lehoux, Anastasija Isidorova, Fredrik Collin, John Koestel, Ian Snowball, Anna-Karin Dahlberg, Extreme gas production in anthropogenic fibrous sediments: An overlooked biogenic source of greenhouse gas emissions, Science of The Total Environment, Volume 781, 2021.

[5] IPCC: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. , 2021.

[6] According to modelling at Stockholm University Baltic Sea Centre.

degrees by the end of this century, depending on the future trajectory of greenhouse gas emissions (RCP 2.6 and RCP 8.5 respectively).[7]

With rising water temperature, methane production in sediments is expected to increase, as the decomposition of organic matter is faster and less oxygen can be dissolved in the water. At the same time, the solubility of methane in water also decreases, making it easier to form bubbles. Both of these factors lead to more methane from the sediments reaching the atmosphere. This probably means that even with an unchanged eutrophication situation in the Baltic Sea, methane emissions to the atmosphere can be expected to increase as a result of global warming. The same trend can be expected in other shallow coastal seas, and the total methane emissions may in turn further accelerate warming.

Extensive research is currently underway, including within the CoastClim research collaboration between the Universities of Stockholm and Helsinki, to more accurately quantify greenhouse gas emissions from the Baltic Sea, and how these may be affected by, for example, temperature changes and reduced eutrophication. However, existing knowledge suggests that ongoing climate change makes it particularly urgent to reduce the supply of nutrients to the Baltic Sea and thus eutrophication, in order to limit methane emissions. Another question is to what extent the deposits of organic material in the sediments can continue to cause methane formation even if eutrophication is reduced.

Indirect emissions from agriculture

According to Swedish climate reporting, Sweden's methane emissions in 2021 amounted to 5 million tonnes at the 100-year scale (15 million tonnes at the 20-year scale). Agriculture accounts for the majority of these emissions (more than 70 per cent), as methane is emitted during the storage of manure and by ruminant animals.[8] At the same time, the anthropogenic nutrient input to the Baltic Sea from Sweden is dominated by leakage from agriculture.[9] By contributing to eutrophication, this nutrient leakage ultimately also causes a large part of the methane emissions from the coasts. If these indirect greenhouse gas emissions are taken into account, the climate impact of the agricultural sector is even greater.

Through HELCOM's Baltic Sea Action Plan, all countries around the Baltic Sea and the EU are committed to reducing nutrient inputs to the Baltic Sea to such a level that the sea is unaffected by eutrophication. Since the 1980s, the input has been significantly reduced; by 40 per cent for nitrogen and 60 per cent for phosphorus.[10] However, significant reductions in emissions are still required to achieve the goal. For Sweden, the nitrogen input to the Baltic Proper needs to be reduced by 25 per cent from the current almost 40,000 tonnes per year and the phosphorus input by 30 per cent from the current more than 700 tonnes per year.[11] To achieve this, continued investment in wastewater treatment is required, not least from individual sewers, but above all extensive measures in agriculture, to increase nutrient use efficiency and thus reduce leakage from agricultural land.

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[7] Meier, H. E. M. et al. Climate change in the Baltic Sea region: a summary. Earth System Dynamics 13, 457–593 (2022).

[8] www.naturvardsverket.se/4a73a2/contentassets/a6f415dca04b468099ecc62bbbe76db3/regeringsuppdrag-minskade-utslapp-av-metan.pdf

[9] HELCOM (2022): Assessment of sources of nutrient inputs to the Baltic Sea in 2017. BSEP 187, 113pp

[10] Kuliński, K., G. Rehder, E. Asmala, and others. 2022. Biogeochemical functioning of the Baltic Sea. Earth Syst. Dynam. **13**: 633–685. doi:10.5194/esd-13-633-2022

[11] https://helcom.fi/baltic-sea-action-plan/nutrient-reduction-scheme/national-nutrient-input-ceilings/

Coastal emissions are missing from climate reporting

Accounting for all territorial emissions and carbon sinks is important for the development of climate action and policy.[12] Like other countries, Sweden is required to report its climate impact to the UNFCCC and also to the European Commission. One part of the reporting consists of emissions and removals of greenhouse gases from land use and forestry – LULUCF (Land Use, Land Use Change and Forestry). According to the EU's climate law, the net storage in this sector must increase by 2030, in Sweden's case by just over 3.9 million tonnes of carbon dioxide equivalents, or 10 per cent, compared with the average for 2016-2018.[13]

However, LULUCF reporting only covers cultivated land. Emissions from coasts and seas, as well as from lakes and most wetlands, are therefore not included. There is every reason to develop a system to uniformly measure and report these emissions as well. Sweden can be a pioneer here, as the Government's climate investigators also point out in the report on how Sweden's climate policy can be developed ("46 förslag för klimatomställning i ljuset av Fit for 55”).

The research within CoastClim aims to develop such a framework for carbon accounting in coastal areas. A variety of measurements and sampling in sediment, water and air, together with the development of new modelling tools, will make it possible to assess emissions and carbon uptake with greater certainty in different environments and under different conditions. This, in turn, makes it possible to estimate the effects of various disturbances in the marine environment on the climate, and the climate effects of, for example, the restoration of a coastal area. The framework can thus become an important support for decision-making.

The average price of auctioned emission allowances is currently almost EUR 80 per tonne of carbon dioxide.[14] If methane emissions and carbon uptake in coastal environments were included in climate reporting and emissions trading, they would be given a national economic value. Measures to reduce eutrophication and restore coastal areas could then be economically beneficial, while contributing to climate change mitigation, improving water quality and increasing biodiversity, which is also favourable for societal benefits such as recreation, fisheries and tourism.

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[12] Lindroth, A. & Tranvik, L. Accounting for all territorial emissions and sinks is important for development of climate mitigation policies. *Carbon Balance and Management* **16**, 10 (2021).
[13] https://www.naturvardsverket.se/amnesomraden/klimatomstallningen/sveriges-klimatarbete/sveriges-del-av-eus-klimatmal/
[14] https://www.naturvardsverket.se/vagledning-och-stod/utslappshandel/statistik-och-uppfoljning/

FACTS/METHANE

- Methane, CH_4, is mainly formed during oxygen-free decomposition of organic matter. This can happen through natural processes such as in wetlands and lakes, when animals ruminate or during energy production and waste management.

- At a given moment, 1 kg of methane has the same impact on global warming as 100 kg of carbon dioxide. However, over time, methane is converted to carbon dioxide and water through chemical reactions in the atmosphere.

- Over 100 years, the effect of 1 kg of methane is therefore estimated to be 28 kg of carbon dioxide equivalents. In 20 years, 1 kg of methane is equivalent to 84 kg of carbon dioxide.[15]

- Methane levels in the atmosphere are currently around 1.9 ppm (parts per million) and carbon dioxide levels are around 420 ppm.

- There are still knowledge gaps regarding the size of both natural and human-induced sources of methane, but it is roughly estimated that human activities contribute 50-65% of total methane emissions.[16]

RECOMMENDATIONS

- Include eutrophication issues in climate action.

- Reduce nitrogen and phosphorus inputs from land.

- Develop a system to account for greenhouse gas emissions from oceans and coasts.

[15] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[16] Saunois, M. et al. The Global Methane Budget 2000–2017. Earth System Science Data 12, 1561–1623 (2020).