Research Mission of the German Marine Research Alliance (DAM)
»Marine carbon sinks in decarboniation pathways«

FACT SHEET

Biologische Methoden

Increased carbon storage through the expansion of marine meadows and forests

Coastal vegetated ecosystems, such as salt marshes, seagrass beds, and mangrove and kelp forests grow on less than one percent of the ocean and coastal area but contribute a significant portion of the natural carbon sequestration in the seabed, as well as many other ecosystem services. Plans to expand these valuable coastal habitats to enhance their natural carbon dioxide uptake sound promising. But how realistic are they really and in what ways can coastal ecosystems be expanded in a targeted way? The research mission CDRmare provides answers and ideas for solutions.

The big climate goal: a net zero of carbon dioxide emissions

There is a consensus in scientific climate research that humankind will only mitigate climate change and its growing impacts and risks, if we reduce the amount of our annual carbon dioxide emissions into the atmosphere to net zero. Germany, for example, aims to balance its greenhouse gas emissions (including methane and nitrous oxide) by 2045.

Man-made carbon dioxide emissions result from the burning of fossil raw materials such as oil, natural gas and coal, as well as from changes in land use. So far, no one knows how humankind can completely avoid or compensate for these emissions in the future in an ecologically and socially acceptable way. On the contrary, experts assume that Germany will still be emitting residual greenhouse gases in the middle of the 21st century. These are expected to amount to 10 to 20 percent of current emissions, corresponding to annual emissions of 60 to 130 million metric tons of greenhouse gases, a large proportion of which are methane and nitrous oxide.

However, there is still no societal consensus on how high possible residual emissions may be and which sectors may cause them. At present, residual emissions, for example in cement production, air and heavy-duty transport, and also agriculture and waste incineration, are residual. To compensate for the residual emissions, humankind will have to remove the same amount of carbon dioxide from the atmosphere.

Mangrove forest (Rhizophora) on the coast of Barú Peninsula (Colombia). Photo: Carolina Hortúa Romero

Using nature-based solutions: Coastal vegetated ecosystems as carbon reservoirs

Such increased carbon dioxide removal could be partly achieved with the help of the ocean, for example through the re-establishment and large-scale expansion of coastal vegetated ecosystems in tidal and shallow water areas (up to 40 metres water depth). These include salt marshes, seagrass beds, and mangrove and kelp forests. Together, their distribution areas account for less than one percent of the world's ocean area, including the intertidal zone. However, these meadows and forests of the ocean contribute a significant portion to the total carbon stored in the seabed.

Salt marshes, seagrass beds, and mangrove and kelp forests are considered highly productive ecosystems and carbon sinks. Through photosynthesis, the plants absorb carbon dioxide from the atmosphere and seawater and bind the carbon contained therein in their biomass.

As the plant communities in mangrove forests, seagrass beds, and salt marshes all form roots and grow on sandy or muddy substrates, they are able to store much of the sequestered carbon in the substrate - on the one hand as living biomass in their own root systems; on the other hand, as dead plant parts, which sink to the bottom and become trapped in the coastal sediment. In addition, the marine meadows and forests filter suspended particles from the water and deposit the particles as well as dead animal and plant material between their stems and roots. This constant rain of particles causes the plant communities to slowly grow upwards.

However, not only local plant material is stored, but also plant remains that have been brought in from land or washed up from other marine areas. Once the organic material is trapped belowground, it is preserved, because the coastal sediment is low in oxygen and saline. Microbes thus lack the oxygen to decay the organic material in short time frames.

Salt marshes, mangrove forests and seagrass beds are often more efficient at absorbing and storing carbon than forests on land. Compared to tropical rainforests, for example, depending on the location, they store five to 30 times the amount of carbon per area. The enclosure of animal and plant remains way from the atmosphere and under oxygen-poor conditions cause the salt marshes, mangrove forests and seagrass beds to accumulate more and more organic material in their sediments over time. These carbon deposits may be more than 10 metres thick and grow as long as the ecosystems thrive. Ideally, they persist for many centuries, sometimes even millennia.

Kelp forests, i.e. forests of brown algae, on the other hand, cannot store the carbon they bind directly in sediment, because they do not have roots and grow on rocky substrate. Instead, lose or dead algal material is carried away by ocean currents. It is washed up on the coasts or sinks into the depths of the ocean, where some of it is then deposited in the seabed sediment.

Carbon sink, coastal protection, nursery: The many services of coastal ecosystems

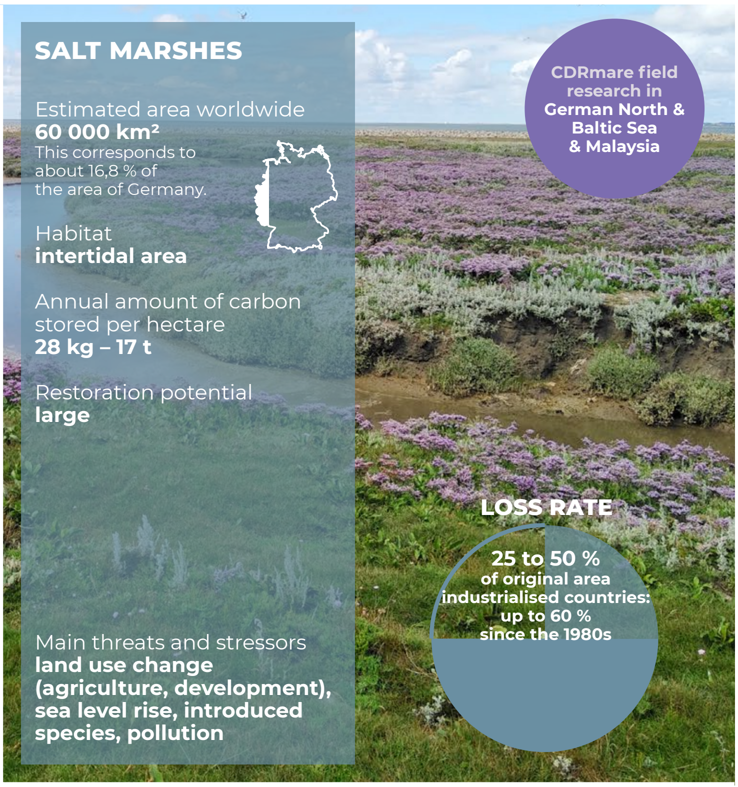
Experts refer to the carbon sequestered by salt marshes, seagrass beds, and mangrove and kelp forests as blue carbon. However, humans do not only benefit from healthy coastal vegetated ecosystems because they remove carbon dioxide from the atmosphere. As so-called ecosystem engineers, they form a three-dimensionally structured habitat in which numerous other animal and plant species of the ocean and coastal area find habitat, shelter and food. According to reports, 4000 square metres of seagrass bed, for example, can host about 40,000 fish and around 50 million invertebrates such as lobsters, mussels and shrimps. In addition, the offspring of seafood species grow in their thicket of leaves, including species such as the Pacific herring and Atlantic cod.

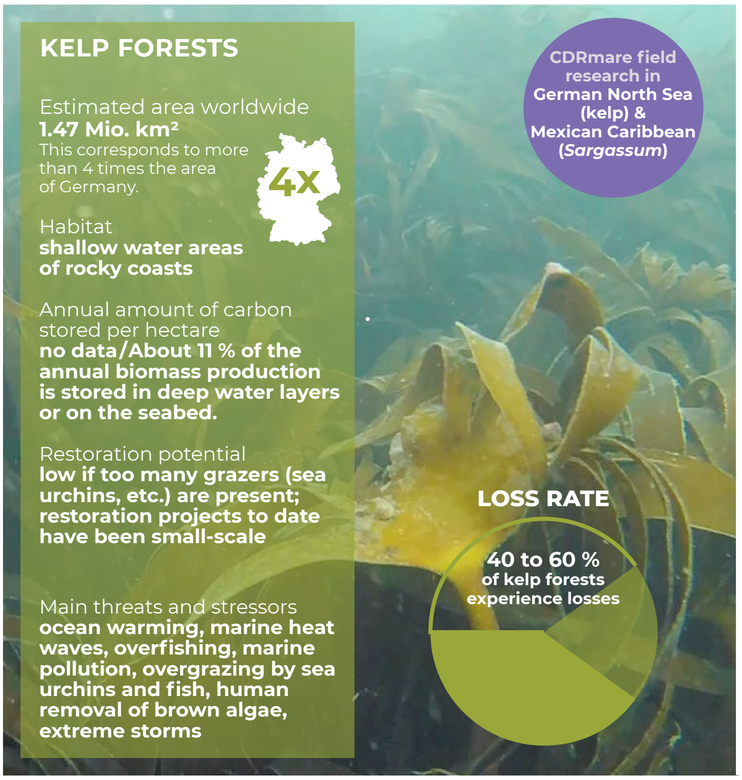
But that's not all: salt marshes, seagrass beds, and mangrove and kelp forests produce oxygen. They filter pathogens, suspended matter, dirt and pollutants from the water, slow down ocean currents, waves and storm surges and thus protect the coasts from erosion and, through the accumulation of sediment, from rising sea levels. At the same time, they provide food (fish, mussels, crabs), contribute to people's recreation and health, and attract tourists in many places, creating additional jobs and sources of income for coastal populations. Healthy coastal vegetated ecosystems thus help coastal societies to adapt to climate change in the best possible way.

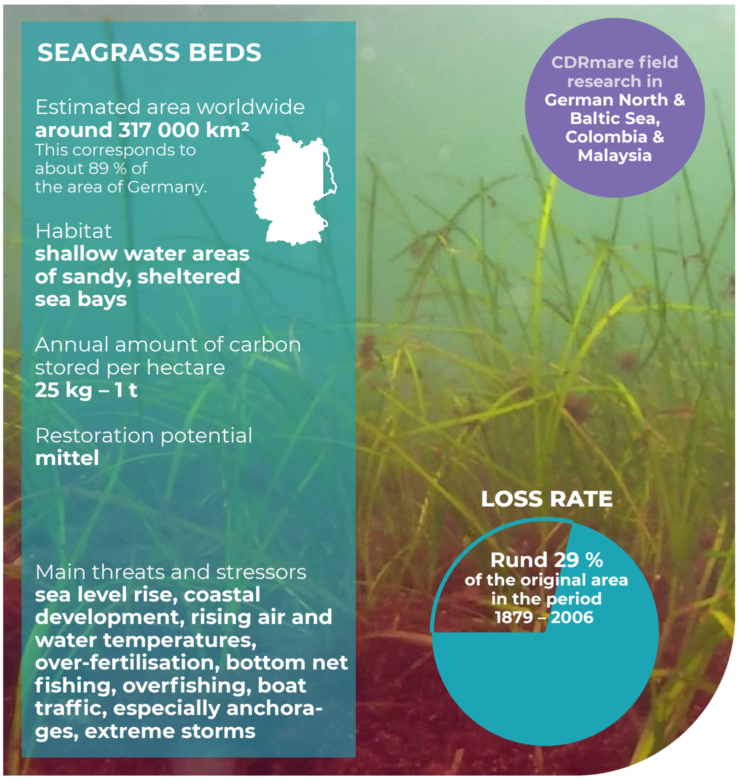
Investments in the re-establishment and expansion of existing salt marshes, seagrass beds, and mangrove and kelp forests therefore exhibit multiple benefits. They contribute to reducing the concentration of carbon dioxide in the atmosphere (climate change mitigation), strengthen biodiversity if performed correctly, and help minimise climate risks (climate adaptation).

The degradation of coastal ecosystems

Despite, and also because of, their important ecosystem services, the area of coastal vegetated ecosystems is shrinking worldwide. Once again, humans are responsible. As a result of climate change, coastal development and construction, agriculture and aquaculture, marine pollution, overfishing and other intensive use, up to 50 percent of all salt marshes, about one third of all seagrass beds and about 35 to 50 percent of mangrove forests have been lost over the past 100 years. Of the world's kelp forests, 40 to 60 percent are experiencing clear area losses.







Photos: Mangroves – Martin Zimmer, ZMT // Salt meadow – Ella Logemann, Uni Hamburg // Kelp – AWI Centre for Scientific Diving // Seagrass – Jens Schneider von Deimling, Uni Kiel // Graphic: Rita Erven, CDRmare/GEOMAR

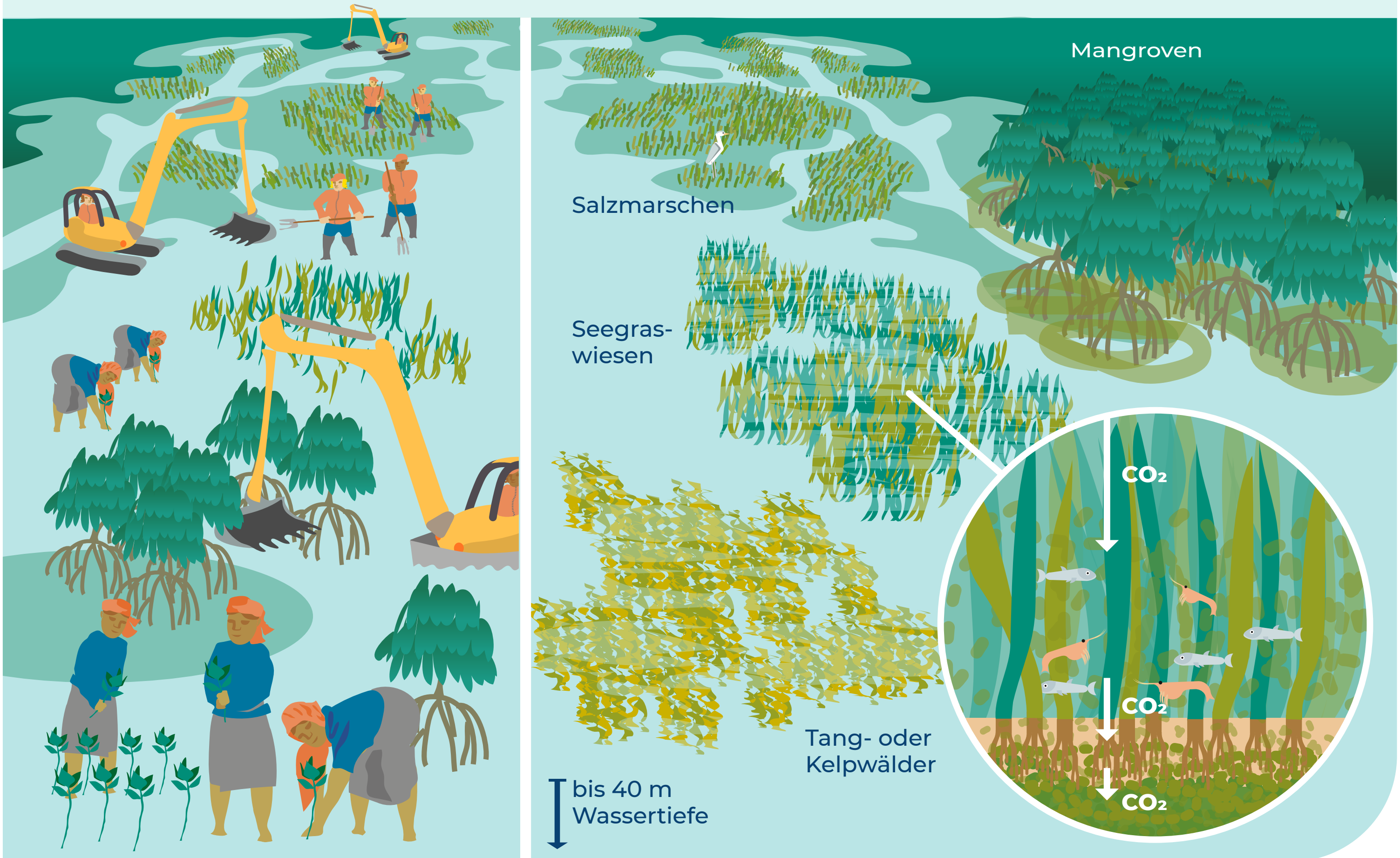
Coastal ecosystems as carbon reservoirs

Costs:
Our estimates range from **US$1 to US$60 per tonne of CO_2 for mangrove forests** and **US$100 to US$1000 per tonne of CO_2 for salt marshes and seagrass beds.**

Scalability:
A l**arge-scale expansion of coastal vegetated ecosystems is theoretically possible**. Estimating how much area would be available is the subject of the CDRmare research. Important: Coastal populations and society must agree to an expansion.

Duration of carbon storage:
From several decades to millennia

Level of technical development:
Around the globe, coastal ecosystems are being restored, but often only to their original areas. A **massive expansion** of their areas is theoretically possible but **has not yet been attempted in practice anywhere**.



The restoration and large-scale expansion of coastal vegetated ecosystems in tidal and shallow waters could enhance the carbon dioxide uptake of the ocean. These include salt marshes, seagrass beds, and mangrove and kelp forests. Graphic: Rita Erven, CDRmare/GEOMAR

Protect, restore, expand: strategies to increase carbon removal by marine forests and meadows

However, there is also good news: Degraded or lost coastal ecosystems can be partially re-established, as many projects from many parts of the world demonstrate. However, their contribution to increased carbon dioxide removal from the ocean could be enhanced if highly productive coastal habitats were not only protected and re-established but also afforested beyond their recently lost areas or actually expanded. This would require humans to re-establish salt marshes, seagrass beds, and mangrove and kelp forests even in areas where they have not naturally occurred so far and may never have occurred in the past. In addition, plant species would have to be selected and assembled that, as a community of species, would most efficiently drive those ecosystem processes that translate into the desired ecosystem services.

Experts refer to this approach as ecosystem co-design. It is believed that three goals can be achieved simultaneously:

> The carbon dioxide uptake of coastal vegetated ecosystems could be increased, thus offsetting some of the residual emissions.

> Biodiversity in coastal waters could be increased if the right approach is taken. It must be said, however, that an expansion of coastal vegetated ecosystems would be at the expense of other local ecosystems, such as sandy beaches and tidal flats.

> Humans and nature would have significantly better opportunities to adapt to climate change and defy its dangers due to the many additional ecosystem services provided by coastal ecosystems (food, coastal protection, etc.).

In fact, however, the approach of expanding coastal vegetated ecosystems over large areas still raises many questions that are to be answered within the framework of the research mission CDRmare.

How much carbon dioxide do coastal vegetated ecosystems actually remove from the atmosphere?

Currently, coastal vegetated ecosystems remove an estimated 0.129 to 1.61 billion tonnes of carbon dioxide from the atmosphere per year. Converted into carbon, this amounts to 35 to 440 million tonnes. The range of this estimate is so large, among other things, because many processes and interactions within the very complex plant communities and their ecosystems vary vastly regionally and with different environmental conditions, and they are not yet properly understood. An open research question, for example, is how much carbon dioxide salt marshes, seagrass beds, and mangrove and kelp forests in different regions of the earth absorb and store in the form of organic carbon and what proportion they release again as greenhouse gases in the course of their life cycle.

Carbon dioxide, for example, is emitted by marine meadows and forests upon plant respiration or when manatees, sea urchins or other marine inhabitants feed on the plant material and convert it into energy and carbon dioxide through their metabolism. If, on the other hand, microbes decay the organic matter stored in coastal sediments, methane and nitrous oxide are produced under certain conditions. What quantities of these two climate-active gases are released from coastal ecosystems under which conditions is not yet well understood. What is certain, however, is that where methane and nitrous oxide escape from coastal sediments, the belowground carbon reservoirs of coastal ecosystems shrink, and with them their climate change-mitigating effect. Therefore, in order to be able to assess whether the massive expansion of coastal ecosystems would be a possible way to increase the carbon dioxide uptake of the ocean, their greenhouse gas uptake and release as well as the carbon storage in the seabed must be precisely understood and balanced.

In the research mission CDRmare, scientists investigate the carbon balances and greenhouse gas emissions of local coastal ecosystems in four selected coastal regions of the world. Salt marshes and seagrass beds are being studied on the German Baltic and North Sea coasts, as well as in the Caribbean (Colombia) and on the Malaysian Pacific coast. Field research on mangroves takes our scientists to Colombia and Malaysia. Studies on large algae take place on Helgoland (focus on kelp forests) and in the Mexican part of the Caribbean (focus on Sargassum).

For how long do vegetation-rich coastal ecosystems store carbon?

The duration of carbon storage in coastal vegetated ecosystems depends on the storage site. Carbon that plants store as part of their aboveground biomass in leaves, stems, branches or twigs is removed from the atmosphere for weeks to decades. In contrast, the belowground carbon stores can persist for many centuries or even millennia under oxygen-free conditions, if the vegetation protecting them remains intact. In the Spanish Portlligat Bay, for example, seagrass beds cover carbon stores that are over 6000 years old.

However, researchers still do not know exactly which factors determine the lifetime of the belowground carbon deposits and which degradation processes take place under which conditions in the sediment. Precise statements on current and future carbon stores in coastal vegetated ecosystems are therefore not yet possible. Along the same line, storage (and release) rates cannot yet accurately be predicted in many cases.

As part of the research mission CDRmare, researchers take sediment samples in all the salt marshes, seagrass beds and mangrove forests studied in order to find out over what period of time the corresponding amounts of carbon were stored. The coastal sediments are also subject to extensive chemical analyses to find out which biological and chemical degradation processes take place in the sediment, which components of the stored carbon are washed out and which parts form the climate-relevant long-term carbon deposits.

The carbon dioxide removal potential of various large algae species is explored in two sub-projects: off the coast of the Mexican Caribbean peninsula Yucatán, scientists investigate, among other things, the biomass production, carbon content and storage potential of floating Sargassum algae. Off Helgoland, the studies focus on the kelp forests growing there. In all cases, it is being investigated how much additional carbon the ecosystems could store if their area was expanded.

What impact will climate change have on coastal ecosystems and will marine meadows and forests be able to absorb and store large amounts of carbon dioxide even under warmer conditions?

Climate change poses a major threat to coastal ecosystems. As a result of rising air and water temperatures, plants and animals are shifting their habitat polewards; heat stress increases their susceptibility to diseases. As a result of rising sea levels, former tidal areas are permanently flooded and lost as habitat; ocean acidification and oxygen depletion make survival underwater even more difficult. Extreme events such as severe storms and ocean heat waves also cause enormous damage. Wind and waves uproot mangroves, tear seagrasses from the seabed and sometimes wash away salt marshes and large algae forests. Sea heat waves particularly affect kelp forests and seagrass beds and, according to the Intergovernmental Panel on Climate Change, have led to the large-scale degradation of local plant communities in various regions in recent years.

Weather extremes and their local impacts are difficult to predict. In addition, the impacts of climate change are amplified by other human-induced stressors or disturbances. These include bottom-net fishing, marine pollution, coastal development and the construction of dams along major rivers. Barrages prevent the input of sediments, which mangroves in particular need for their areal expansion as well as for their vertical height growth (adaptations to sea-level rise). All of the above stress factors reduce the ability of coastal ecosystems to compensate for climate impacts and adapt to change.

Therefore, the question arises in which regions of the world coastal vegetated ecosystems will survive and be able to contribute to climate change mitigation through their carbon dioxide uptake in the future, and where investments in their protection and large-scale expansion would be promising. There is also a need to discuss whether the large-scale expansion of marine meadows and forests would really be an appropriate way to enhance marine carbon uptake in the face of increasing climate extremes - and if so, by what innovative methods natural, restored and newly established plant communities could be protected from the impacts of climate change. It would be conceivable, for example, to cultivate more heat-resistant brown algae and seagrasses. Whether such an approach would succeed and make ecological sense is still uncertain, however, given the complexity of marine ecosystems.

In the research mission CDRmare, scientists conduct extensive climate change experiments on the German North Sea coast and in the tropics. Along the German North Sea coast, large temperature-controlled seawater basins (mesocosms) are used for this purpose, as well as special foil domes with which selected experimental areas in the tidal range can be heated down to the subsurface. In this way, the scientists can study the short-term effects of rising temperatures on primary production, carbon storage and greenhouse gas emissions of native salt marshes and seagrass beds. Of particular interest are thresholds of various environmental parameters that, if exceeded, would lead to the long-term degradation of plant communities and a depletion of their carbon stores. Based on their results, the scientists will make statements on the climatic resilience of the world's marine meadows.

Their measurement data also flows into computer models that simulate a large-scale expansion of coastal ecosystems. In the process, the researchers investigate how stable and adaptable the biotic communities and their carbon stores would be under different climate conditions. They also examine the extent to which the biodiversity and additional benefits of marine meadows and forests would increase if they were to grow over a significantly larger area than they do today. They also analyse what negative consequences an increase in area could have.

A green sea turtle explores a seagrass bed off the coast of Tenerife coast.
Photo: Liam McGuire / Ocean Image Bank

Which methods can be used to comprehensively record and monitor large coastal ecosystems in order to also quantify their additional carbon dioxide removal?

If you want to expand coastal vegetated ecosystems over large areas and quantify their carbon dioxide uptake and storage, you need to know large coastal areas very well and monitor them over long periods of time. So far, however, many salt marshes, seagrass beds, and mangrove and kelp forests have not even been mapped comprehensively. Progress should now be made with imaging remote sensing methods. These include satellite images as well as ship-, airplane- and drone-based measuring methods. In some places, these techniques have already been used to explore coastal areas. However, the extent to which they are suitable for providing data for accurate quantification of carbon dioxide removal and for finding suitable areas for the expansion of coastal ecosystems has been investigated little so far.

In the research mission CDRmare, scientists develop, test, and implement various remote sensing methods for monitoring vegetation in tidal and shallow water areas. They are also combining remote sensing methods. Among other things, it is planned to couple satellite image evaluations with underwater sonar techniques. With the help of these innovations, it should be possible to quantify the surface biomass of coastal ecosystems in the North Sea, the Baltic Sea, and on the coasts of Colombia and Malaysia, and to extrapolate carbon stocks measured on site - such as the carbon storage under a few square metres of mangrove forest - to the entire regional and global area of these coastal ecosystems. On the other hand, high-resolution remote sensing data sets are needed to search for previously unvegetated coastal sections where salt marshes, seagrass beds, or mangrove and kelp forests could be newly established.

Would a large-scale expansion of coastal vegetated ecosystems actually be an effective measure to offset residual emissions and halt climate change?

To answer this question, researchers need so-called Earth system models in which both the global carbon cycle and the role of coastal ecosystems, their climate-induced changes, and their possible expansion can be simulated. So far, however, the Earth system models lack components to represent marine meadows and forests.

In the research mission CDRmare, scientists will for the first time integrate coastal vegetated ecosystems into a modern Earth system model and simulate their role in the Earth's global carbon cycle. For this purpose, many already published data sets on the global extent and carbon balance of marine meadows and forests will be incorporated into the model, as well as the research results collected in CDRmare itself. Such an extended Earth system model enables researchers to fathom how much additional carbon dioxide could be removed from the atmosphere by expanding coastal ecosystems, to what extent this would influence climate change, and how the plant communities themselves will react to the expected environmental changes.

Based on the basic research carried out in CDRmare, the experts want to develop innovative methods for expanding the area of coastal vegetated ecosystems as well as political recommendations for action with which the carbon dioxide uptake of marine meadows and forests could be increased in an environmentally compatible and socially acceptable way - on German coasts as well as worldwide.

Salt marshes, Hamburg Hallig.
Photo: Ella Logemann, Uni Hamburg

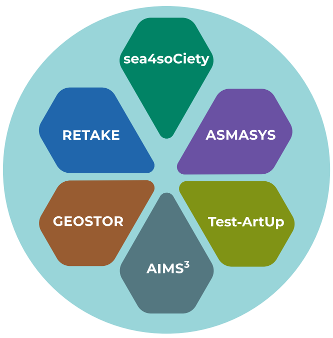
How does the coastal population feel about large-scale changes on their doorstep?

Nature and climate protection measures can only be successfully implemented if the interests of local societies are taken into account from the very beginning if they are involved in all decision-making processes if they can contribute with their own knowledge and expertise, and if they benefit particularly from the protection measures. A well thought-out development of coastal vegetated ecosystems could, on the one hand, bring about an increase in biodiversity as well as more resilient biotic communities. Fish stocks could grow, water quality could improve, and the attractiveness of the region for tourists could increase. Salt marshes, seagrass beds, and mangrove and kelp forests would also provide natural, self-sustaining coastal protection that would facilitate adaptation to rising sea levels.

On the other hand, an expansion of marine meadows and forests would also entail cuts in the lives of the coastal population, precisely because humans use coastal areas intensively and there is little open space available. On German coasts, for example, it is conceivable that dikes would have to be dismantled and pasture land behind them abandoned to make room for salt marshes. Sea bays where seagrass beds are newly planted would have to be closed to bottom net fishing and perhaps to boat traffic. For new kelp forests along the North Sea coast, many tonnes of rock would have to be brought into the sea, because brown algae only grow on stony ground.

Consequently, a lot of educational work would have to be done in the run-up to large-scale coastal transformation. This task, however, requires that decision-makers understand exactly what values and needs the local population has and to what extent they would be willing to support, and participate in, the development of coastal ecosystems.

In the research mission CDRmare, scientists investigate the attitudes of the local population to climate change and possible measures to remove carbon dioxide in selected coastal regions of Germany, Colombia and Malaysia. Their aim is to understand the different coastal cultures, to get a picture of people's ideas about sustainable life at sea, to activate local knowledge and innovative power, and to find out at an early stage which issues or measures could trigger social resistance or meet with the approval of the local population. Based on their findings, regionally specific recommendations for action will then be developed to ensure that, in the case of large-scale expansion of local coastal ecosystems, people, nature, and the climate are given equal consideration and that as many stakeholders as possible benefit from the compromises to be found for planned measures. This task will not be an easy one and represents a special challenge for the researchers.



All research activities described here are carried out within the CDRmare consortium »sea4soCiety – Innovative approaches to improving the carbon storage potential of vegetated coastal ecosystems«.

Within the research mission CDRmare of the German Marine Research Alliance (DAM), which involves about 200 researchers in 6 consortia, different methods of marine CO_2 removal and storage (alkalinisation, blue carbon, artificial upwelling, CCS) are investigated with respect to their potential, risks and trade-offs and brought together in a transdisciplinary assessment framework. CDRmare has been funded by the German Federal Ministry of Education and Research with 26 million euros since August 2021 and will run for three years.

Only text and infographics: **CC BY 4.0 // Cite as:** CDRmare (2023): *Increased carbon storage through the expansion of marine meadows and forests*, CDRmare Research Mission, pp. 1-8, DOI 10.3289/CDRmare.33

sea4soCiety sea4society.cdrmare.de
twitter.com/cdrmare
linkedin.com/company/cdrmare
CDRmare Wissenstransfer transfer@cdrmare.de

DAM GERMAN MARINE RESEARCH ALLIANCE

SPONSORED BY THE Federal Ministry of Education and Research

IMPRINT

GEOMAR Helmholtz Centre for Ocean Research Kiel // Wischhofstr. 1-3 // 24148 Kiel // Germany // **Responsible for content:** Andreas Oschlies, Gregor Rehder, Achim Kopf, Ulf Riebesell, Klaus Wallmann, Martin Zimmer // **Editorial office:** Ulrike Bernitt (ubernitt@geomar.de) // **Text:** Sina Löschke (schneehohl.net) // **Design & graphics:** Rita Erven // **Translation:** Anja Wenzel // June 2023