# A review of blue carbon in the Netherlands

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## Contents

## Summary

Blue carbon (the carbon stored in marine and coastal ecosystems – in biomass, buried in sediments and sequestered from the atmosphere and ocean) is considered as an issue of interest regarding its potential as a climate change mitigation measure in the OSPAR maritime area (OSPAR, 2015). Because blue carbon has not yet been properly explored in the North East Atlantic, OSPAR requested the Dutch government to provide information about:

- Blue carbon in the Netherlands and;
- Opportunities to enhance blue carbon in the Netherlands.

To address this the following questions were answered:

1) Are there examples of blue carbon in the North Sea and the Wadden Sea and what are their links to biodiversity?
Only carbon sequestered in marine sediments can be safely considered to represent a long-term marine carbon storage. Mangroves, saltmarshes and seagrass beds are internationally acknowledged as blue carbon ecosystems. Both salt marshes and seagrass beds are present in the Netherlands. There is however relatively little known about carbon sequestration in marine vegetated habitats in Europe and the Netherlands compared to other parts of the world, e.g. North America. Saltmarshes and seagrass meadows are hot spots for biodiversity and they provide important and valuable ecosystem functions. Both saltmarshes and seagrass meadows are well below historical reference values for biodiversity in the Netherlands.

2) What are possible meaningful Dutch initiatives in the North Sea and the Wadden Sea and what are their links to biodiversity?
Currently, the main focus in the Netherlands regarding $CO_2$ is to minimise $CO_2$ emissions and $CO_2$ footprint of a project. There are no marine projects initiated in the Netherlands with the specific aim to sequester carbon as climate change mitigation. However, there are Dutch projects related to blue carbon, as the (potential for) carbon sequestration has been specifically addressed. The projects and their relevance to carbon sequestration and biodiversity are:

- Mega-nourishment project: the sand engine
  Ongoing project with the aim to protect hinterland from floods. The potential for carbon sequestration through calcite dissolution (via groundwater to the North Sea) has been studied and the sand engine was found to be a carbon sink. There is no link to biodiversity.
- Fish migration river
  This is a proposed project intended for nature restoration (especially for migrating fish). The project also involves saltmarsh development and therewith contributes to blue carbon as well as biodiversity.
- WaddenWerken
  This is a proposed project to develop a soft defence system for the Afsluitdijk. This project also involves saltmarsh development and therewith contributes to blue carbon as well as biodiversity.
- Wadden Sea harbours
  This is a proposed project with the aim to connect harbour development with nature development. This project also involves saltmarsh development and therewith contributes to blue carbon as well as biodiversity.
- Oyster reefs
  Ongoing project with the aim to protect tidal flats from erosion by creating oyster reefs. It involves shellfish growth which was previously considered as a contribution to blue carbon. However, recent research indicates the opposite. Oyster reefs could potentially contribute to biodiversity.

- Mussel beds
  Ongoing project intended for nature restoration. It involves shellfish growth which proposition to contribute to blue carbon has recently be rejected (see above). Restoration of natural mussel beds will contribute to Natura 2000 targets and potentially increase biodiversity.
- Seagrass recovery
  Ongoing projects intended for nature restoration. It involves seagrass development and therewith contributes to blue carbon as well as biodiversity.

3) What is the Dutch state of play compared to Europe and the rest of the world?
Worldwide, specific blue carbon projects have been identified, using mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and having secured financing for those activities. These also involve marshes and seagrass, the ecosystems relevant for the Netherlands. Because there are no specific blue carbon projects in the Netherlands, but only projects recognized for their (potential) contribution to carbon sequestration (see answer to question 2 above), the Dutch state of play is considered to be very limited.

## Glossary of terms

*Blue carbon*
The carbon captured by the world's oceans (Nelleman et al., 2009).

Blue growth
A long term strategy to support sustainable growth in the marine and maritime sectors as a whole (http://ec.europa.eu/maritimeaffairs/policy/blue_growth/). The Food and Agriculture Organisation of the United Nations (FAO) launched the Blue Growth Initiative, through which it will assist countries in developing and implementing blue economy and growth agendas (http://www.fao.org/zhc/detail-events/en/c/233765/). One of the ways to implement blue growth is by promoting regulatory regimes and approaches to restore vital coastal habitats, biodiversity and ecosystem services, including carbon capture.

*Building with Nature*
The Dutch "Building with Nature" (BwN) innovation programme shows how to utilize natural processes and provide opportunities for nature while realising hydraulic infrastructure. BwN projects will contribute to a smaller $CO_2$ footprint of marine engineering projects (Fiselier & Vreeman, 2012). There are, however, no BwN projects specifically designed for blue carbon development.

*Carbon sequestration*
The process of increasing the carbon content of a reservoir other than the atmosphere (Nelleman et al. 2009).

*Mitigation*
A human intervention to reduce the sources of, or enhance the sinks for greenhouse gases (Nelleman et al., 2009).

*Salt marsh*
Salt marshes occupy the upper parts of the intertidal zone and the supralitoral, i.e. the interface between land and sea and extend vertically from well below the mean high-tide level up to the highest water mark. They constitute precious and irreplaceable habitat for a wide range of organisms, although the number of species per unit area may be relatively low (Wolff et al., 2010). Salt marshes represent a strong natural carbon sink (Nellemann et al., 2009).

*Seagrass beds*
Seagrass beds are a very sensitive habitat in the intertidal zone. Sea seagrass beds of the two species *Zostera noltii* and *Z.marina* thrive all along the Atlantic shores from Scandinavia to northern Africa but only small beds of mostly low plant density occur in the Netherlands (Wolff et al., 2010).

*Sink*
Any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere (Nelleman et al., 2009)

*Source*
Any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol into the atmosphere (Nelleman et al., 2009)

# 1 Introduction

Blue carbon is the carbon found in marine and coastal ecosystems – in biomass, buried in sediments and sequestered from the atmosphere and ocean (Bredbenner, 2013). During the meeting of the OSPAR Biodiversity Committee (BDC) in March 2015, blue carbon was considered as an issue of interest regarding its potential as a climate change mitigation measure in the OSPAR maritime area (OSPAR, 2015). Blue carbon has not yet been properly explored in the North East Atlantic. It was agreed during the meeting that contracting parties should identify what was already being done regarding blue carbon nationally, including its links to biodiversity (OSPAR, 2015). OSPAR therefore requested the Dutch government to provide information about:

- Blue carbon in the Netherlands and;
- Opportunities to enhance blue carbon in the Netherlands.

To address this request, the Dutch Ministry of Economic Affairs asked IMARES to answer the following questions:

- Are there examples of blue carbon in the North Sea and the Wadden Sea and what are their links to biodiversity?
- What is the Dutch state of play compared to Europe and the rest of the world?
- What are possible meaningful Dutch initiatives in the North Sea and the Wadden Sea?

This report is the result of a literature review, answering the above questions. In chapter 2, the concept of blue carbon is described in a world-wide perspective. The next chapter (3) describes examples of blue carbon in the North Sea and Wadden Sea, including their links to biodiversity. The Dutch state of play compared to other countries is described in chapter 4 and conclusions are presented in chapter 5.

## 2 Blue carbon

### 2.1 Description of blue carbon

As already mentioned in the introduction of this report, blue carbon is a term used for carbon found in marine and coastal ecosystems – in biomass, buried in sediments and sequestered from the atmosphere and ocean (Bredbenner, 2013). It is also referred to as "the carbon captured by the world's oceans" (Nellemann et al., 2009).

Marine and coastal ecosystems, specifically vegetated coastal habitats (i.e. seagrass meadows, mangrove forests and salt marshes), are welldescribed systems for their role in mitigating global climate change through the storage and sequestration of carbon dioxide (Duarte et al., 2005; Nelleman et al., 2009). The international community considers mangroves, salt marshes, and seagrasses as blue carbon ecosystems that provide value for climate change mitigation (AGEDI, 2014). Of these blue carbon ecosystems, seagrass meadows are currently the least well-studied and thus present an area for significant exploration and knowledge expansion (AGEDI, 2014). Furthermore, relatively little is known about the role of blue carbon in vegetated habitats of Europe compared to e.g. North America (Sifleet et al., 2011; Ouyang & Lee, 2014). Other blue carbon systems may include marine molluscs. Cultivation of molluscs, and the preservation of their shells, is suggested as a mean of sequestering carbon dioxide (Wolff & Beaumont, 2011). There have been ideas to see whether it would be possible to use shellfish farming as a means to sequester CO2 (http://www.shellfishsequestration.org/). The overall carbon uptake was found in the same order as the carbon sequestration by salt marshes when only addressing the carbon content of the shell material (Fiselier & Vreeman, 2012). However, in the process of biogenic calcification, one mole of $CO_2$ is released for each mole of generated CaCO3 (the carbonate counter-pump) (Munari et al., 2013). When CaCO3 is removed from seawater, its pH shifts toward the acidic, and the CO2 concentration and pCO2 of the water increases, leading to increased concentrations of CO2 in the atmosphere (Zeebe and Wolf-Gladrow, 2001). Munari et al. (2013) evaluated CaCO3 and CO2 production/sequestration due to calcification by the Mediterranean mussel *Mytilus galloprovincialis* and showed that the $CO_2$ fluxes produced by the mussel were higher than $CO_2$ sequestered in shell formation. Results from this study strongly suggest that shell formation in cultivated shellfish cannot be part of carbon trading systems. Moreover, there is a growing evidence indicating that biocalcification can contribute substantially to temperate near-shore coastal ecosystems carbon cycling, and that numerous calcifying organisms living in such ecosystems are CO2 generators (Munari et al., 2013).

Carbon stored and sequestered in ecosystems is theoretically always vulnerable to release at some undetermined point in the future. The carbon captured in oceans does not remain stored for decades or centuries (like for example rainforests), but rather for millennia (Nelleman et al., 2009). The long-term residence of anthropogenic CO2 in the oceans is uncertain, as this carbon does not penetrate deep enough to remain in the ocean over extended time scales. Hence, only carbon sequestered in marine sediments, as in the case of blue carbon sinks, can be safely considered to represent a long-term marine carbon storage (Nellemann et al., 2009).

### 2.2 Blue carbon sinks

Marine vegetated habitats are strongly autotrophic, which means that these ecosystems fix CO2 as organic matter photosyntheticaly in excess of the CO2 respired back by biota, thus removing CO2 from the atmosphere (Duarte et al., 2005; Nellemann et al., 2009). Some of this excess carbon is exported to adjacent ecosystems, such as open ocean and beach ecosystems. The remaining carbon is buried in the sediments, where it can remain stored over millenary time scales, thereby representing a strong natural carbon sink (Nellemann et al., 2009). Duarte et al. (2005) suggest that only 5% of the excess production of benthic coastal habitats meet a fate in burial, with the main part supporting the high respiratory requirements of open ocean ecosystems.

Vegetated coastal habitats are widely distributed (Figure 1) and are estimated to be globally responsible for the burial of 120–329 Tg C $yr^{-1}$, which accounts for at least half of the lower estimate for global carbon burial in marine sediments (Nellemann et al., 2009). Blue carbon sinks therefore play a major role in the oceanic carbon cycle.

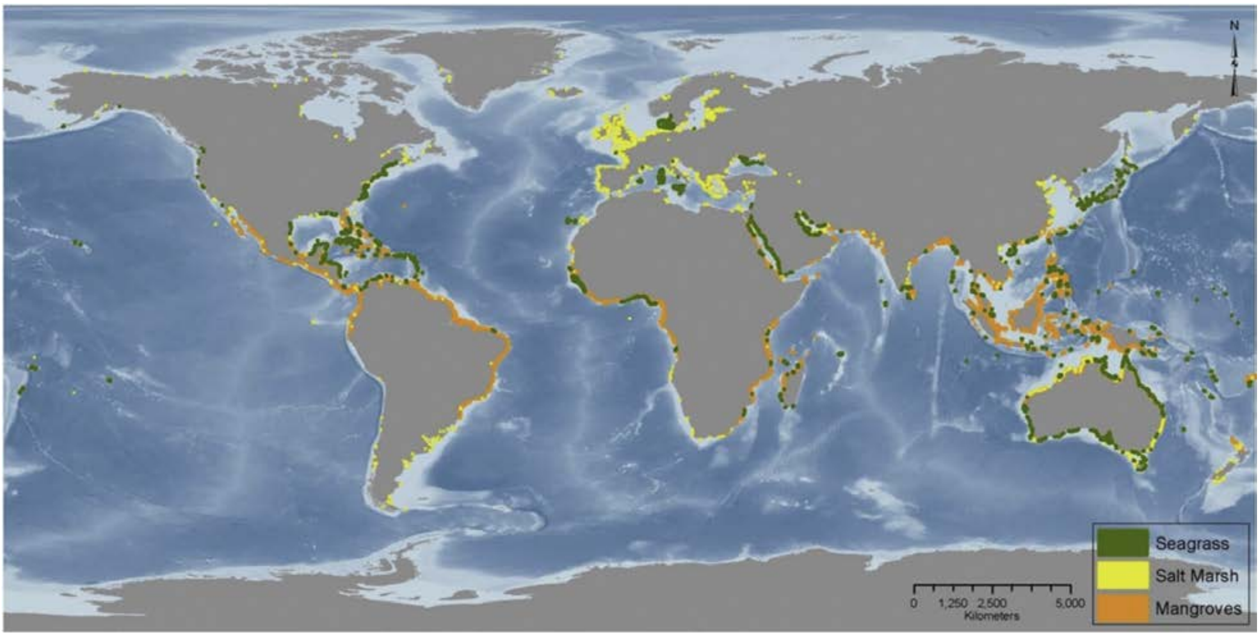


Figure 1 Global distribution of seagrasses, tidal marshes, and mangroves (Pendleton et al., 2012).

Not all blue carbon sinks are equally effective, with salt marshes having the highest carbon burial rate per unit area, followed by mangroves and seagrass, see Table 1 (Nellemann et al., 2009). Carbon burial rates of estuaries and coastal shelves are much lower than the three main blue carbon ecosystems. Individual blue carbon sink ecosystems also vary greatly in their capacity to bury carbon, with the maximum reported rate corresponding to 17.3 tonnes C $ha^{-1}$ $yr^{-1}$ in a salt marsh (Nellemann et al., 2009). When comparing the carbon stock instead of the storage rate, the marine vegetated habitats show a different ranking (Table 2). One hectare of mangroves comprises about 468 tonnes C per hectare (1714 t $CO_2$ $ha^{-1}$). Salt marshes have slightly less carbon per hectare than mangroves, about 393 tonnes per hectare. Seagrasses have the least amount of carbon per hectare, approximately 72 tonnes (Siikamäki et al., 2013).

Table 1 Carbon burial rates in marine vegetated habitats (Nellemann et al., 2009)

| Blue carbon ecosystem | Carbon burial rates (tonnes C ha$^{-2}$ yr$^{-2}$) | | |
|---|---|---|---|
| | **Mean** | **Minimum** | **Maximum** |
| Mangroves | 1.39 | 0.20 | 6.54 |
| Salt marsh | 1.51 | 0.18 | 17.30 |
| Seagrass | 0.83 | 0.56 | 1.82 |

Table 2 Summary of carbon stock for blue carbon ecosystems (Siikamäki et al., 2013)

| Blue carbon ecosystem | Carbon stock (tonnes C ha$^{-2}$) | | |
|---|---|---|---|
| | **Biomass** | **Soil** | **Total** |
| Mangroves | 148 | 320 | 468 |
| Salt marsh | 3.3 | 390 | 393 |
| Seagrass | 1.5 | 70 | 72 |

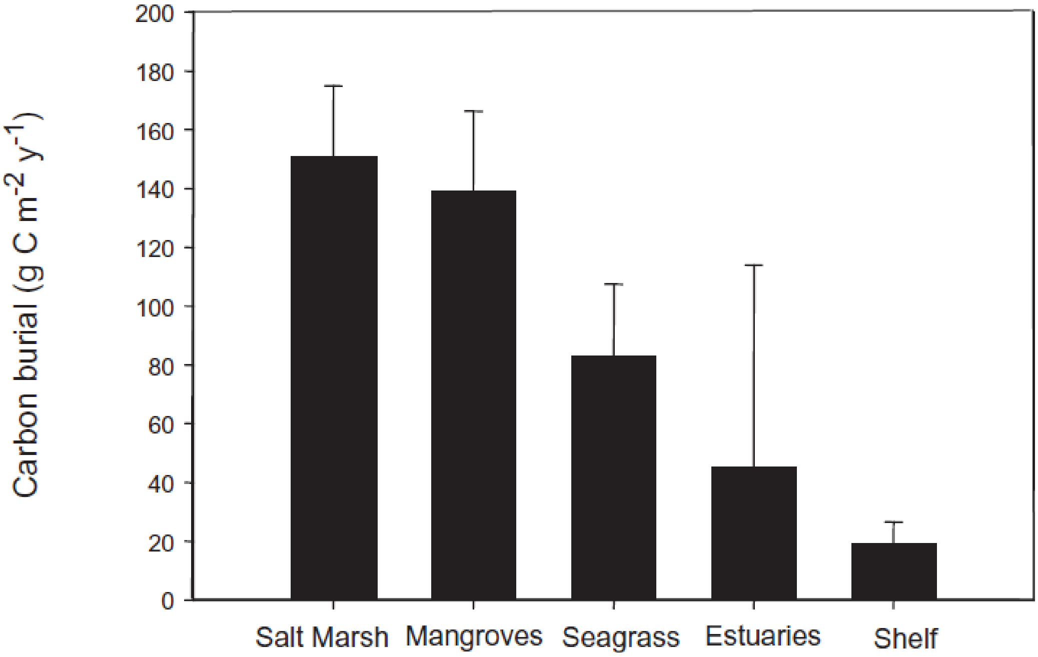


Figure 2 Average (±SE) carbon burial rates in different coastal ecosystems (Duarte et al., 2005).

Estimations of carbon storage in soil of salt marshes are also reported for different countries (Sifleet et al., 2011). The highest carbon storage was reported for the Gulf of Mexico and the lowest for Canada. The average carbon stock in the Netherlands was 1,201 tonnes $CO_2$ per ha (Table 3) corresponding to about 328 tonnes C/ha. Relatively little is known about C-sequestration in European salt marshes. The four observations in the Netherlands are from three studies: Buth (1987); Chmura et al. (2003) and Oenema & DeLuane (1988). Buth (1987) and Oenema & DeLuane (1988) studied salt marshes in the Eastern Scheldt, South-west Netherlands. The review of Chmura et al. (2003) reports carbon sequestration values from Callaway et al. (1996); and Oenema and Delaune (1988). Callaway et al. (1996) also studied a salt marsh in the Eastern Scheldt, along with two sites in the UK. The values reported in Table 5 for the Netherlands are thus only based on values measured in salt marshes in the Eastern Scheldt and not in the Wadden Sea. Ouyang and Lee (2014) studied the carbon accumulation rate of salt marshes and found that it changes with latitude, tidal range, halophyte genera and habitat elevation.

Table 3 Estimates of carbon stored in the top meter beneath salt marshes using available soil carbon density data (Sifleet et al., 2011)

| Location | Number of observations | Range Mg $CO_2$e/ha | Average Mg $CO_2$e/ ha |
|---|---|---|---|
| Northeast Canada | 37 | 660 – 2,680 | 1,266 |
| Gulf of Mexico (Louisiana, Texas, and Mississippi) | 26 | 367 – 6,967 | 1,902 |
| New England (Connecticut, Massachusetts, and Maine) | 20 | 733 – 2,200 | 1,342 |
| Chesapeake Bay, Maryland | 12 | 902 – 1,613 | 1,191 |
| California | 6 | 330 – 1,588 | 863 |
| North Carolina | 6 | 174 – 2,038 | 1,159 |
| United Kingdom | 6 | 990 – 1,503 | 1,332 |
| Florida | 5 | 567 – 1,694 | 1,020 |
| Netherlands | 4 | 733 – 1,503 | 1,201 |
| Denmark | 2 | 770 – 990 | 880 |
| Rhone Delta, France | 1 | | 2,677 |
| British Colombia, Canada | 1 | | 623 |

## 2.3 Threats to blue carbon sinks

As described in the previous sections, marine vegetated habitats are the main blue carbon ecosystems. The loss of marine vegetated habitats therefore represents the loss of a natural carbon sink, eroding the capacity of the biosphere to remove anthropogenic $CO_2$ emissions (Nellemann et al., 2009). Over the last decades, a large part of the area covered by blue carbon sinks has been lost already and the rest is severely threatened (Duarte et al., 2005; Nellemann et al., 2009).

The decline of marine vegetated habitats causes not only the loss of carbon sinks but can also cause carbon emissions. Blue carbon can be released to the atmosphere when these ecosystems are converted or degraded (Pendleton et al., 2012). Theuerkauf et al. (2015) studied the effect of the rate of shoreline retreat on the carbon budget of a saltmarsh and indicated a threshold value where a salt marsh turns from a carbon sink to a carbon source. The carbon budget of a saltmarsh proved to be highly sensitive to the rate of shoreline retreat and rapidly-eroding marshes may already be net sources of carbon (Theuerkauf et al., 2015). Therefore, from a sequestration point of view it is very important to conserve existing marshes, mitigate shoreline erosion, and consider shoreline erosion in the design of saltmarsh restoration projects (Theuerkauf et al., 2015).

Bu et al. (2015) determined reclamation effects on the previously sequestered soil C pool in salt marshes after nine years following reclamation. Soil organic C pool in reclaimed lands declined to 60% (0–20 cm) and 79% (0–100 cm) of those in salt marshes.

Wrack accumulation (i.e. the accumulation of seaweeds) is a form of disturbance common throughout the world that removes large areas of plant biomass in salt marshes. Disturbance to salt marsh habitat due to wrack accumulation can cause significant release of below-ground C; which could shift salt marshes from C sinks to C sources, depending on the intensity and scale of disturbance. This mechanism of C release is likely to increase in the future due to sea level rise; which could increase wrack production due to increasing storminess, and will facilitate delivery of wrack into salt marsh zones due to higher and more frequent inundation (Macreadie et al., 2013).

## 2.4 Blue carbon and biodiversity

Vegetated coastal habitats – mangrove forests, salt marshes and seagrass meadows – have much in common with rain forests: they are hot spots for biodiversity, they provide important and valuable ecosystem functions, including a large carbon sink capacity, and they are experiencing a steep global decline (Duarte et al., 2008, Duarte, 2009 in Nellemann et al., 2009). The destruction of marine vegetated habitats has dramatic consequences on local biodiversity (Duarte et al., 2005). Vice versa, restoration of these habitats results in blue carbon development as well as biodiversity. Therefore protecting important blue carbon sink habitats and large-scale restoration of lost blue carbon sinks is a win-win strategy as it mitigates CO2 emissions and improves coastal resources (Nellemann et al., 2009). This is also the case for the two habitats relevant for the Netherland, salt marshes and seagrass meadows. Biodiversity in the Dutch marine waters is estimated to be about 40% of a historical, more natural reference value (Wortelboer, 2010). Both seagrass meadows and saltmarshes are well below historical reference values. Projects aimed at restoration of these habitats would thus enhance biodiversity as well as blue carbon.

Livestock grazing is a well-used management tool to maintain biodiversity in European marshes. Elschot (2015) studied the effects of small and large grazers on the marsh vegetation and important marsh dynamics, such as sediment accretion and soil carbon stocks in the Wadden Sea. Cattle reduced the vegetation height and increased soil compaction through trampling. This reduced the marsh surface elevation change, while it increased carbon stocks in the soil. Both are important aspects for climate change mitigation.

Oyster and mussel beds provide hard substrate, shelter and food to associated species in NW European estuarine areas. Mussel beds are known to generally enhance habitat heterogeneity and species diversity at the ecosystem level and oyster reefs are expected to enhance local biodiversity as well (Troost, 2010). Furthermore, mussel beds are an important element of Natura 2000 habitats in the Netherlands.

## 2.5 Definition of a blue carbon project

There exists a lack of uniformity on the definition of a blue carbon project. Because there is a wide range of projects worldwide, labelling themselves as blue carbon projects, Bredbenner (2013) developed the following types:

I. Blue Carbon "Washed". These projects are located in coastal and marine ecosystems and use the moniker blue carbon but without any actions specifically motivated by climate change mitigation. The research of Bredbenner (2013) returned zero projects in this category but left this category in as a reference point to illustrate the full range of blue carbon activities.

II. Research. These projects encompass a range of activities designed to advance knowledge in blue carbon, such as executing research studies and filling knowledge gaps. This work however does not include any demonstration sites or any planned activity for generating carbon credits. Examples of these projects' research activities include mapping, habitat data collection, predictive modelling, analysing forest cover change, taking carbon inventories, measuring greenhouse gas fluxes, and habitat restoration.

III. Payment for Ecosystem Services Projects. This includes broadly-scoped projects that are conserving and/or restoring an ecosystem for a full suite of services, such as shoreline protection and improved water quality. These services include the ecosystem's value as a carbon sink and in sequestering carbon, but climate change mitigation is not typically the only focus of this type of project. These projects will generally include a plan for receiving payments for ecosystem services and mechanisms for infusing such funds into ecosystem management and community development, i.e. improved education and health care.

IV. Blue Carbon Projects. These projects use mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and have secured financing for those activities. This financing might take the form of generating carbon offset credits, or it may include funding specific for conservation and/or restoration activities.

These categories were used to identify the blue carbon projects in the Netherlands.

# 3 Blue carbon in the Netherlands

## 3.1 Saltmarshes in the Netherlands

About 40,000 ha of salt marshes are present in the Wadden Sea, which is about 20% of the total area of salt marshes along the European Atlantic and Baltic coasts (Wolff et al., 2010). Based on data from 2009, the saltmarsh area is 6745 ha in the Dutch Wadden Sea (CBS, PBL, Wageningen UR, 2012). In addition, 3565 ha saltmarsh is present in the Dutch Delta (CBS, PBL, Wageningen UR, 2012), thus we assume that the total saltmarsh area in the Netherlands is 10310 ha. The average carbon stock for saltmarshes in the Netherlands was reported at 328 tonnes C/ha. (Sifleet et al., 2011) and a value of 393 tonnes C/ha was reported for saltmarshes in general (Siikamäki et al., 2013). The average burial rate of carbon for saltmarshes is 1.51 tonnes C $ha^{-2}$ $yr^{-2}$ with a range of 0.18 to 17.3 (Nellemann et al., 2009). Based on these values the carbon stock in Dutch saltmarshes can be roughly estimated between 3382 and 4052 thousand tonnes C and the burial rate between 2 and 178 thousand tonnes C/year (Table 4). It should be noted that these are rough estimates based on generic values found in literature without considering (local) factors of influence such as sediment processes, erosion, time frames and vegetation.

Table 4 Blue carbon estimates in saltmarshes in the Netherlands. These values are just an indication based on generic values found in literature (Nellemann et al., 2009; Sifleet et al., 2011; CBS, PBL, Wageningen UR, 2012; Siikamäki et al., 2013) without considering (local) factors influencing C sequestration and emission

| **Area** | **Carbon stock** | | **Burial rate** | |
|---|---|---|---|---|
| **(ha)** | **(tonnes C/ha)** | **(tonnes C)** | **(tonnes C/ha/yr)** | **(tonnes C/yr)** |
| 10310 | 360.5 (328-393) | 3382000 - 4052000 | 1.51 (0.18-17.3) | 2000-178000 |

Because there is very little known about blue carbon in Europe, and the Wadden Sea in specific (see chapter 2), an important part of the ongoing (2014-2017) project "Interaction of fish, plants, carbon & sediment: management and ecosystem functions of Wadden Sea salt marshes – INTERFACE" (https://www.biologie.uni-hamburg.de/biozentrum-klein-flottbek/forschung/apoe-jensen/drittmittelprojekte/interface/interface-contents.html) is to investigate C-sequestration and C-dynamics in Wadden Sea saltmarshes. The aim is to:

- quantify rates of C-sequestration in Wadden Sea salt marshes.
- assess the impact of different hydrological conditions (naturally vs. artificially drained marshes), soil compaction (caused by livestock grazing) and species composition on C-sequestration and organic matter decomposition.

This project is mainly conducted in a large tidal basin setup in Germany. There are, however, related field experiments in the Dutch Wadden Sea. Elschot (2015) studied effects of vegetation patterns and grazers on tidal marshes in the back-barrier marsh of Schiermonnikoog, located in the Dutch Wadden Sea. Large grazers had a strong positive effect on carbon accumulation and carbon storage in the marsh soil was strongly related to marsh age. A rate of 126 g $m^{-2}$ $yr^{-1}$ (or 1.26 tonnes C/ha/yr) over 15 years and 27 g $m^{-2}$ $yr^{-1}$ over 120 years was found, thus at the youngest marshes the increase in per $m^2$ organic carbon accumulation were highest. The values found at Schiermonnikoog were lower than the average rate of 151 g $m^{-2}$ $yr^{-1}$ as was estimated for salt marshes in general (Table 5). The author mentions that this could be explained by the low sedimentation rates found on European back-barrier marshes compared to mainland marshes (Elschot, 2015).

Examples of saltmarsh development within the Netherlands are found in the (proposed) projects fish migration river, the "WaddenWerken" and Ports of the the Wadden Sea, see section 3.3.

## 3.2 Seagrass in the Netherlands

Seagrass (*Zostera marina* and *Zostera noltii*) has severely declined since 1930 in the Dutch Wadden Sea due to deceases, the development of the dike "Afsluitdijk" and eutrofication (PRW, 2015). Currently, seagrass beds are mainly located in the north part of the German waters (Figure 3). In 2007, the area covered by seagrass in the Dutch Wadden Sea was 303 ha, mainly with a coverage of less than 5% (van der Graaf et al., 2009). The seagrass beds occur mainly along the Groningen coast and in the outer part of the Ems estuary. Some smaller beds are found on the leeside of the island of Terschelling and along the southwesterly border of Balgzand. Based on the seagrass area reported for 2007 (303 ha (van der Graaf et al., 2009)) and a mean carbon burial rate of seagrass of 83 tonnes C/km$^2$/yr (Nellemann et al., 2009), the carbon burial rate by seagrass beds in the Dutch Wadden Sea could be estimated at 252 tonnes C/yr. It should be noted that developing accurate C budgets for seagrass meadows is complex (Macreadie et al., 2014). The estimated value should therefore only be used as an indication.

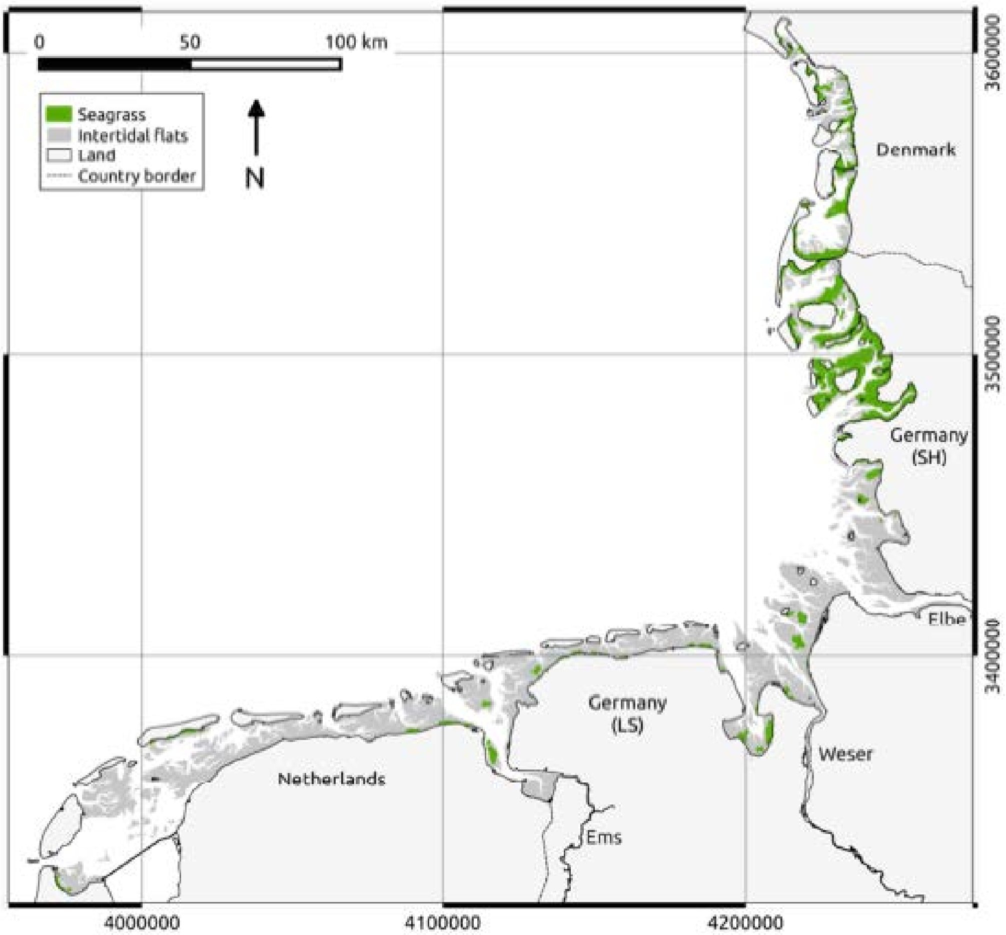


Figure 3 Map of litoral seagrass in the Wadden Sea based on monitoring data from 1988-2010 (PRW, 2015).

The potential seagrass area in the Wadden Sea has been estimated based on habitat suitability (Figure 4). Two parts of the Dutch Wadden Sea have the potential for 10-20 km$^2$ of seagrass beds. This is much higher than the actual coverage in 2007 of 3 km$^2$, indicating a great potential for seagrass recovery.

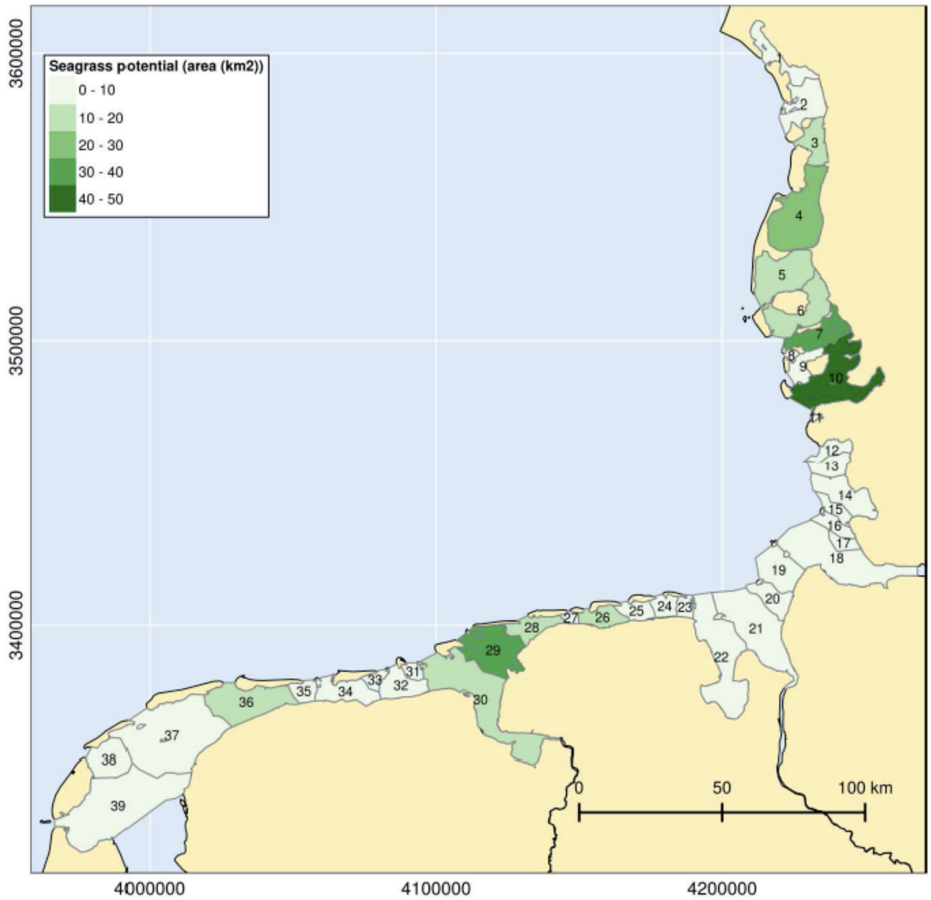


Figure 4 Potential seagrass area in the Wadden Sea (PRW, 2015). The Dutch areas are numbered from 30 to 39.

Before the construction of the storm surge barrier in the Dutch Delta in 1986, about 1200 ha of seagrass beds were present (Giesen et al., 2014). Since then, the area showed a strong decline. In 2013 a total of 189 ha was found in the Eastern- and Western Scheldt, of which 32 ha had a coverage of more than 5% (Pranger et al., 2013). Assuming a mean carbon burial rate of seagrass of 83 tonnes C/km2/yr (Nellemann et al., 2009), the carbon burial rate by seagrass beds in the Dutch Delta could be estimated at 157 tonnes C/yr.

## 3.3 Blue carbon projects

### *3.3.1 Introduction and overview of projects*

There are no marine projects initiated in the Netherlands that could be considered a blue carbon project according to the definition of Bredbenner (2013) (see section 2.5), i.e. projects thus projects with the specific aim to sequester carbon as climate change mitigation. However, there are projects related to blue carbon, as the (potential for) carbon sequestration has been specifically addressed. A list of these projects, including their link to biodiversity (see section 2.4) is presented in Table 5. A description of the projects is provided in the next section (section 3.3.2).

Table 5 Overview of blue carbon related projects in the Netherlands. None of these projects can be classified as a type blue carbon project according to the definitions of Bredbenner (2013), see chapter 2.5

| **Project** | **Status** | **Aim of project** | **Blue carbon aspect** | **Biodiversity link** |
|---|---|---|---|---|
| Mega-nourishment project: the sand engine | Ongoing | Protect hinterland from floods | Calcite dissolution (via groundwater to the North Sea) | No link to biodiversity |
| Fish migration river | Proposal | Nature restoration (especially for migrating fish) | Saltmarsh development | Biodiversity of saltmarshes in the Netherlands is below the natural reference thus these projects could contribute to biodiversity |
| WaddenWerken | Proposal | Soft defence system (protect dike from floods) | Saltmarsh development | |
| Ports of the Wadden Sea | Proposal | Connect harbour development with nature development | Saltmarsh development | |
| Oyster reefs | Ongoing | Protect tidal flats from erosion | Shellfish growth | No link to biodiversity |
| Mussel beds | Ongoing | Nature restoration | Shellfish growth | Restoration of natural mussel beds will contribute to Natura 2000 targets |
| Seagrass recovery | Ongoing | Nature restoration | Seagrass development | Biodiversity of seagrass beds in the Netherlands is below the natural reference thus these projects could contribute to biodiversity. Furthermore, the aim of the project is nature restoration |

### *3.3.2 Details of blue carbon projects*

**Sand engine**

The sand engine is an innovative mega nourishment at the Dutch Coast (Figure 5). It is intended to protect the hinterland from floods in the next twenty years by slowly depositing sand upon the beach through wave and wind action.

Figure 5 An aerial view of the completed sand engine project (Dekker et al., 2014).

According to the definition of Bredbenner (2013) this project is not a ‘blue carbon project’ as it has no actions specifically motivated by climate change mitigation. Although the project was not specifically designed for carbon sequestration, stakeholders involved in the construction of the sand engine wished to know if the sand engine captures $CO_2$. This research question was motivated by an initiative of the Dutch government to reduce CO2 emissions. In response, the capacity of the sand engine to store C through calcite dissolution was researched by Wijnakker (2015). The C sequestration capacity of the sand engine has been estimated with fieldwork, laboratory experiments and a groundwater model Analyses revealed that the C captured is inorganic and can be seen as CO2 capturing. It has been estimated that the sand engine captures 4.2*105 kg $CO_2$ a year and 8.3 Mkg $CO_2$ in twenty years (Wijnakker, 2015). All groundwater from the sand engine will be lost to the North Sea. Since the North Sea is an effective CO2 sink, the $CO_2$ sequestered by the sand engine can, as a consequence, be regarded as captured (Wijnakker, 2015).

Measurements in the sand engine project are being studied to enable the development of a new design tool. The envisaged design tool is based on a spreadsheet application that will offer engineers a simple method for calculating $CO_2$ footprints based on key figures. One of the components of the tool is a database of key figures for blue carbon systems (Dekker et al., 2014).

**Fish migration river**

In 1932 the Afsluitdijk was created, a huge 32-kilometer wall which closes off the lake “IJsselmeer” from the Wadden Sea. The fish migration river project involves the creation of a tidal river of several kilometres (re)connecting the Wadden Sea with the lake IJsselmeer (Figure 6). The aim is to help restore the ecological damage that has been caused by the Afsluitdijk, especially for migrating fish. The project has thus no specific aim in capturing blue carbon. However, the fish migration rivers also features saltmarsh formation and has therewith been acknowledged as a potential blue carbon project (Fiselier & Vreeman, 2012). The project has no actions specifically motivated by climate change mitigation.

Figure 6 Impression of the fish migration river at the Afsluitdijk, enabling the formation of saltmarsh at the Wadden Sea side of the dike. Source: http://www.deafsluitdijk.nl/wp-content/uploads/2014/11/InteractievePDFVismigratierivierDEF.pdf

**WaddenWerken**

This proposal consists of the creation of intertidal marshes as part of a soft defence system for the Afsluitdijk. The overall concept involves the creation of 1500 ha of salt marshes using 50 million tonnes of sand. Fiselier & Vreeman (2012) estimated the $CO_2$ footprint of this project based on estimated emission and storage rates. Long term sequestration rate was based on an average between maximum (carbon sink capacity: 7 to 9 ton CO2/ha.year) and minimum rates (soil carbon contents of the deeper soil layers: 2 to 3 tons of CO2/ha.year). The net carbon balance of the project is estimated to be (Fiselier & Vreeman, 2012):

- 1,844,023 tonnes $CO_2$ in 100 year or 12.3 tonnes $CO_2$/ha.year, assuming carbon sequestration by sediments only and on site substitution (i.e. all excess carbon is stored in the area) .
- 1,486,883 tonnes in 100 year or 9.9, tonnes $CO_2$/ha.year, also including methane related emissions of 4 to 6 tonnes $CO_2$/ha.year.
- -1,141,154 tonnes in 100 year or -7,6 tonnes $CO_2$/ha.year, also including off-site substitution (settling elsewhere).

**Ports of the Wadden Sea**

The project Ports of the Wadden Sea focusses on the dredging of shipping lanes in intertidal areas (Figure 7) with the aim to connect harbour development with nature development. The dredged material may be used to build new salt marshes or to maintain or even upheave existing sand bars and salt marshes (Fiselier & Vreeman, 2012). As with the projects described above, there are no actions in this project specifically motivated by climate change mitigation. Nevertheless, the project has been considered as valuable physical pilot within the BwN program allowing in depth studies of carbon sequestration processes in intertidal areas (Fiselier & Vreeman, 2012). An example of a pilot within the Ports of the Wadden Sea project is the saltmarsh development at Koehoal (close to Harlingen, see Figure 7) using a 'mud motor'. This pilot project studies the potential of stimulating growth of salt marshes within the Wadden Sea by making optimum use of the sediment transport capacity of ambient flows. To safeguard navigation, about 1.3 million m3 of mainly fine sediments are dredged in the harbour basins of the Port of Harlingen (http://www.ecoshape.nl/en_GB/mud-engine--wadden-sea-.html). The dredged sediment is dumped in the Wadden Sea, in the vicinity of the harbour. Within this pilot the dredged sediments are dumped further north of Harlingen as a semi-continuous source of sediment: the mud motor. The dumped sediment is expected to be transported by natural processes further into the area where it would lead to the formation and extension of salt marshes. Three favourable effects are mentioned (http://www.ecoshape.nl/en_GB/mud-engine--wadden-sea-.html):

1. less recirculation towards the harbour, hence less maintenance dredging;
2. promotion of the growth and stability of salt marshes, improving the Wadden Sea ecosystem;
3. stabilizing the foreshore of the dykes, and therefore less maintenance of the dyke.

Note that blue carbon is not recognised as favourable effect.

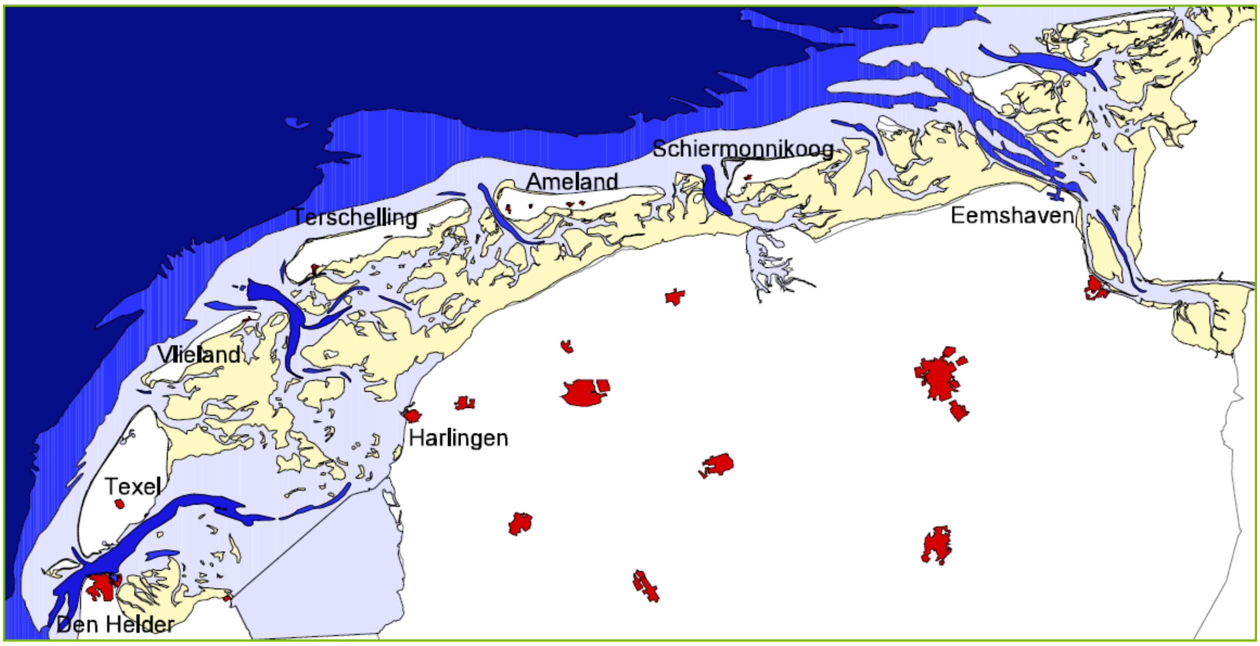


Figure 7 Wadden Sea harbours. Source: http://www.waddenzeehavens.nl/wp-content/themes/twentyeleven/achtergrondinformatie/SEOW_eindrapport.pdf

### Oyster reefs

Pilot studies using artificial oyster reefs to protect tidal flats in estuaries from erosion have been conducted in the Oosterschelde estuary. As part of the BwN program three large reefs (200x10*0.2 m) were created in 2010 near Viane en De Val in the Oosterschelde estuary, see Figure 8 (Tangelder et al., 2013). The carbon footprint of oysterreefs has not been calculated within the BwN program because the calcification process makes this very complex (Fiselier & Vreeman, 2012). However, as described above, recent studies suggest that there is no potential for shellfish to sequester carbon and shellfish can even contribute to the $CO_2$ in the atmosphere (Munari et al., 2013).

Currently, there are no projects known in the Netherlands to have a specific target for carbon sequestration using oyster reefs.

Figure 8 Artificial oysterreefs at De Val (left) and Viane (right) in the Oosterschelde estuary, the Netherlands (Tangelder et al., 2013).

**Mussel beds**

In July 2015, a 4 year scientific research program into nature restoration in the Dutch Wadden Sea was funded (http://www.bese-elements.com/) which will start in January 2016. It has been acknowledged within the project that certain marine habitat deliver carbon sequestration. The research program is focussed on nature restoration of saltmarshes, including the recovery of mussel beds in the Wadden Sea by using biodegradable structures made of starch from potato waste. The flow of carbon will be studied within this nature restoration project.

**Seagrass recovery**

Within the project 'Seagrass recovery Wadden Sea" measures are being taken to recover seagrass meadows in the Dutch Wadden Sea. In 2011 seagrass seeds have been spread on three locations (Schiermonnikoog, Uithuizen and Den Oever) in an area of 1 ha each (Fens & van Buren, 2014). In 2012 this exercise was repeated at locations adjacent to the first sites. More locations have followed.
Seagrass recovery has also been conducted in the Dutch delta (Pranger et al., 2013). During 2007-2013, seagrass was transplanted from natural populations (donor locations) to 10 different mitigation locations in the Eastern Scheldt. At six of the ten locations the seagrass started well but was reduced to almost zero after three years. The other four locations show various developments, with high reductions as well as increased developments.
The seagrass recovery projects are not conducted with the aim to store carbon, but because of: the ecological value of seagrass habitat; the capture of sediment by seagrass and therewith contributing to a natural buffer against seawater rising (i.e. elevation of tidal flats); the positive effect on water quality and therewith contributing to the European Water Framework Directive targets. Because seagrass habitat is considered a blue carbon sink (see section 2.2), seagrass recovery projects can be considered as potential blue carbon projects.

# 4 The state of play in the Netherlands

The international program, the Blue Carbon Initiative, is working to mitigate climate change through the restoration and sustainable use of coastal and marine ecosystems. The Initiative is however, currently not active in Europe. A global review on blue carbon projects has identified projects in North America, South America, Asia and Africa (Bredbenner, 2013). Bredbenner (2013) investigated blue carbon initiatives world-wide and identified a total of 34 blue carbon projects. From these 34 projects, there was sufficient information to analyze 28 projects (Table 6). Of these projects, 14 were considered as 'true' blue carbon projects (type IV), i.e. projects using mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and having secured financing for those activities (Bredbenner, 2013).

Table 6 Blue carbon projects analysed by Bredbenner (2013). Project types are: II. Research projects (encompassing a range of activities designed to advance knowledge in blue carbon) III. Payment for Ecosystem Services Projects (including the ecosystem's value as a carbon sink and in sequestering carbon, but climate change mitigation is not typically the only focus of this type of project) IV. Blue Carbon Projects (using mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and having secured financing for those activities).

| LOCATION | ECOSYSTEM | TYPE |
|---|---|---|
| Brazil (a) | Seagrass | II |
| Brazil (b) | Seagrass | II |
| Brazil (c) | Seagrass, Mangrove, Marsh | II |
| China (a) | Mangrove | II |
| China (c) | Mangrove | II |
| Tanzania | Mangrove | II |
| Maryland, USA (a) | Tidal Marsh | II |
| Maryland, USA (b) | Tidal Marsh | II |
| Maryland, USA (c) | Tidal Marsh | II |
| Central Africa | Mangrove | III |
| Madagascar | Mangrove | III |
| West Africa | Mangrove | III |
| Indonesia (b) | Mangrove | III |
| Costa Rica | Mangrove | III |
| Massachusetts, USA | Tidal Marsh | IV |
| Panama | Mangrove | IV |
| Kenya | Mangrove | IV |
| Senegal | Mangrove | IV |
| Mozambique | Mangrove | IV |
| Ghana | Mangrove | IV |
| India | Mangrove | IV |
| China (b) | Seagrass, Mangrove, Marsh | IV |
| Indonesia (a) | Mangrove | IV |
| Indonesia (c) | Seagrass, Mangrove, Marsh | IV |
| Indonesia (d) | Seagrass, Mangrove, Marsh | IV |
| Indonesia (e) | Mangrove | IV |
| Indonesia (f) | Mangrove | IV |
| SWAMP | Mangrove, Marsh | IV |

Worldwide, specific blue carbon projects have been identified, using mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and having secured financing for those activities (Table 6). These also involve marshes and seagrass, the ecosystems relevant for the Netherlands. Although there are several Dutch projects recognized for their (potential) contribution to carbon sequestration, as described in section 3.3, there are no projects specifically aimed to mitigate climate change by blue carbon development (see Table 5 in section 3.3.1). There are also no projects known to be financed for their contribution to blue carbon. According to the definitions of Bredbenner (2013), there are no blue carbon projects in the Netherlands. The Dutch state of play can thus be considered as very limited.

# 5 Discussion and conclusions

**Examples of blue carbon in the North Sea and the Wadden Sea and their links to biodiversity**
As described in section 2.1, only carbon sequestered in marine sediments can be safely considered to represent a long-term marine carbon storage. Mangroves, saltmarshes and seagrass beds are internationally acknowledged as blue carbon ecosystems. Both saltmarshes and seagrass beds are present in the Netherlands covering an area of 10310 ha and 492 ha, respectively. The areas are found in the Wadden Sea (6745 ha saltmarsh and 303 ha seagrass beds) and Delta (3565 ha saltmarsh and 189 ha seagrass beds). Based on generic carbon burial rates found in literature, the estimated carbon burial rate in these areas is 15568 tonnes C/yr (saltmarsh) and 409 tonnes C/yr (seagrass).
There is, however, relatively little known about carbon sequestration in marine vegetated habitats in Europe and the Netherlands compared to other parts of the world, e.g. North America. It should thus be noted that these values are just an indication as (local) factors influencing carbon sequestration and emission are not considered.
Saltmarshes and seagrass meadows are hot spots for biodiversity and they provide important and valuable ecosystem functions. Both saltmarshes and seagrass meadows are well below historical reference values for biodiversity in the Netherlands. Projects aimed at restoration of these habitats would thus enhance biodiversity as well as blue carbon.

**Possible meaningful Dutch initiatives in the North Sea and the Wadden Sea**
We used the definitions of various types of blue carbon projects by Bredbenner (2013), see section 2.5, to identify blue carbon projects in the Dutch parts of the North Sea and Wadden Sea. We found that there are no marine projects initiated in the Netherlands that: use the moniker blue carbon (type I) or; conduct research on blue carbon (type II) or; are funded for providing ecosystem services including carbon sequestration (type III ) or; use mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and have secured financing for those activities (type IV).

Currently, the main focus in the Netherlands regarding $CO_2$ is to minimise $CO_2$ emissions and $CO_2$ footprint of a project (Fiselier & Vreeman, 2012; Dekker et al., 2014; Wijnakker, 2015). This has led to assessments of $CO_2$ emissions and capture for different flood protection projects (i.e. sand engine and WaddenWerken) indicating that these projects lead to a net carbon storage (Fiselier & Vreeman, 2012; Wijnakker, 2015). The Dutch “Building with Nature” (BwN) innovation programme shows how to utilize natural processes and provide opportunities for nature while realising hydraulic infrastructure. BwN solutions are often based on the use of natural systems, such as tidal marshes and mangrove forests. It has been recognised within BwN that such systems are regarded as blue carbon systems (Fiselier et al., 2015). BwN projects will contribute to a smaller $CO_2$ footprint of marine engineering projects (Fiselier & Vreeman, 2012). There are, however, currently no BwN projects specifically designed for blue carbon development.

Other projects related to blue carbon are aimed at nature restoration, i.e. fish migration river, seagrass recovery and mussel beds. The first two involve the development of internationally acknowledged blue carbon ecosystems (saltmarsh and seagrass) and could potentially fall into blue carbon project type IV, when the mitigation value is promoted and used for financing. The latter involves the development of a potential blue carbon sink, mussel beds. However, a recent study indicates that shellfish farming cannot be part of carbon trading systems (Munari et al., 2013). Moreover, the authors cite the growing evidence indicating that biocalcification can contribute substantially to temperate near-shore coastal ecosystems carbon cycling, and that numerous calcifying organisms living in such ecosystems are $CO_2$ generators.
The 4 year scientific research program into nature restoration in the Dutch Wadden Sea, which will start in January 2016, will also include the flow of carbon. Results will help to determine the potential of molluscs to either contribute or mitigate $CO_2$ emissions to the atmosphere.

Another project involving molluscs, is the pilot study using oyster reefs to protect tidal flats in estuaries. As for mussels, the potential of oysters to mitigate climate change would probably be nihil.

Some of the projects described in this report have a direct link to biodiversity: saltmarsh development , seagrass restoration, mussel bed restoration and oyster reef creation. Blue carbon and biodiversity are often linked together, but there are some considerations when addressing both objectives in a project as addressed by Vierros (2013): "A carbon-focused conservation strategy does not automatically target areas most valuable for biodiversity, nor will it necessarily aim to produce broader benefits for associated species, ecosystems and livelihoods, even if such benefits might be a by-product of the carbon strategy". Vierros (2013) suggests that an optimal coastal management strategy would seek to maximize both carbon storage and biodiversity benefits. On a national level, a combination of biodiversity and carbon storage approaches could provide countries struggling to implement the demands of multiple conventions a way to harmonize their approaches in national biodiversity and climate change strategies. This requires a new funding mechanism based on a holistic view of the benefits that are provided for climate and biodiversity (Vierros, 2013). Considering the Wadden Sea is a Natura 2000 area, conformity with related nature objectives may override carbon sequestration considerations.

**Dutch state of play**

Worldwide there have been 34 blue carbon projects identified, of which 28 projects had sufficient information available for review (Bredbenner, 2013). Of these projects, 14 were considered to be 'true' blue carbon projects, i.e. projects using mitigation value to promote conservation and/or restoration of a blue carbon ecosystem and having secured financing for those activities (Bredbenner, 2013). No projects were identified in the Netherlands. Furthermore, there is relatively little known about C sequestration in marine vegetated habitats in Europe and specifically the Wadden Sea. The Dutch state of play is therefore considered as very limited.

**Concluding remarks**

In addition to blue carbon, coastal and marine ecosystems provide a wide range of other important ecosystem services, such as climate change adaptation, water filtration, shoreline stabilisation, storm and flood protection, sustaining biodiversity, and habitat provision for commercially and recreationally important species of fish and shellfish, as well as iconic species (AGEDI, 2014). As described above, the ongoing and planned initiatives for development of saltmarshes and seagrass provide such services. These type of projects could have great potential for blue carbon. The projects also fit in the blue growth strategy focusing on promoting regulatory regimes and approaches to restore vital coastal habitats, biodiversity and ecosystem services, including carbon capture.

# 6 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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## Justification

Rapport C151/15
Project Number: 431 58100 14

The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Drs. M. van den Heuvel-Greve
Researcher

Signature:

Date: 4th of November 2015

Approved: Drs. F. Groenendijk
Head Maritime Department

Signature:

Date: 4th of November 2015