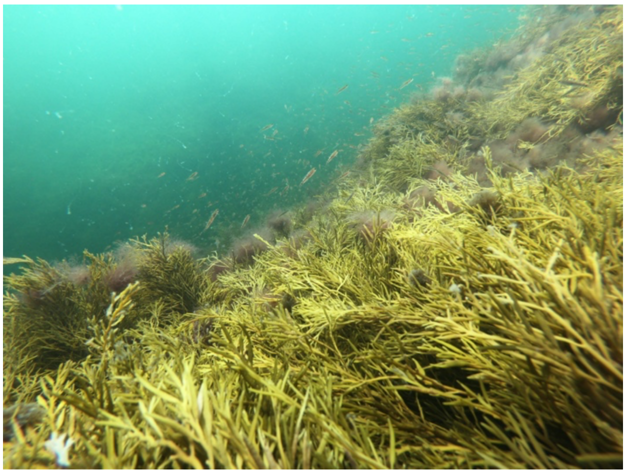
DEPARTMENT OF MARINE SCIENCES

SWEDISH BLUE CARBON ASSETS IN COASTAL VEGETATED ECOSYSTEMS

A compilation of current knowledge



Ena Fee Briesemeister

Thesis project for Master of Science (120 hp) with a major in Sea and Society
MAR480 V21 Examenskurs för masterexamen i Hav och samhälle
Second Cycle

Semester/year:	Spring 2021
Supervisors:	Maria E. Asplund (Department of Biological and Environmental Sciences, University of Gothenburg)
	Martin Gullström (School of Natural Sciences, Technology and Environmental Studies, Södertörn University)
	Mats Björk (Department of Ecology, Environment and Botany, Stockholm University)
Examiner:	Gunilla Toth (Department of Marine Sciences, University of Gothenburg)

Image on the front page Halidrys siliquosa, taken by Maria E. Asplund.

Abstract

Coastal vegetated ecosystems offer a variety of ecosystem services, one of them being the ability to trap and store atmospheric carbon. The provision of this natural process makes these ecosystems referred to as blue carbon sinks, as they are contributing to climate change mitigation. At the same time, these ecosystems are at high risk of being fragmented or lost due to climate change and other human induced impacts, mainly as a result of increased temperature, eutrophication, frequency and intensity of storm events, land-use changes and coastal infrastructure. If blue carbon sinks are lost or heavily fragmented, stored carbon assets are released back into the atmosphere, turning the blue carbon sink into an emitter of carbon in terms of greenhouse gases (i.e. carbon dioxide and methane). Understanding the mechanisms that influence the storage of carbon in coastal vegetated ecosystems and identifying areas that are acting as blue carbon sinks is of high importance for the development of data-based management strategies. To assess the current state of knowledge of Sweden's blue carbon sinks in marine and terrestrial ecosystems, a systematic literature review was performed. A compilation of all available blue carbon related data for coastal vegetated ecosystems was created considering aspects such as location of existing data, storage levels of carbon, methane fluxes and the geographical distribution of coastal blue carbon ecosystems. Fifteen relevant publications were identified, complied and synthesised. While mapping the studied locations of the publications, data hotspots at the east- and west coast were identified near marine research field stations (Kristineberg and Askö). Further, a gap in the data was detected as there was no data found for coastal blue carbon ecosystems across the entire coastline of the Bothnian Bay. All data concerning carbon assets were found for seagrass ecosystems, with a focus on the species of *Zostera marina*. For other species that can contribute to blue carbon sinks, such as kelp or other macrophytes, little or no published data was found in the conducted systematic literature review. A similar finding was made for terrestrial coastal ecosystems and regarding methane fluxes from coastal vegetated ecosystems. These findings amplify the need for more research and extended data collection on Swedish coastal vegetated ecosystems. Based on the current knowledge, it is not possible to make relevant data-based estimations of the carbon assets and storage potential of Swedish blue carbon ecosystems.

Keywords: Blue carbon sink, coastal vegetated ecosystems, seagrass meadows, carbon assets

Popular Science Abstract

Coastal vegetated ecosystems, like seagrass meadows, mangroves and salt marshes, are considered blue carbon sinks, which are of high importance as they are able to efficiently store atmospheric carbon in their sediment. The natural process of carbon trapping and storing is important for climate change mitigation and one of several important benefits for humans, biodiversity and the environment of coastal vegetated ecosystems. At the same time, these important ecosystems are at risk as they are greatly impacted by climate change and human pressures. When blue carbon sinks are lost or heavily destroyed, the stored carbon is released back into the atmosphere, making the carbon sink a source for emission of greenhouse gases such as carbon dioxide and methane. To avoid these emissions and to preserve the coastal vegetated ecosystems, knowledge is needed to create data-based management solutions for conservation and restoration. To create an overview of available data for blue carbon ecosystems in Sweden, the currently available literature was screened and relevant publications selected. Along the Swedish coastline, there are two data hotspots (Kristineberg in Fiskebäckskil and Askö south of Stockholm), which could be explained by their location near two marine research stations of universities. The majority of the published data concerning the amount of stored carbon in an ecosystem was found for Swedish seagrass (*Zostera marina*) meadows, for which data of above- and belowground carbon stocks is available. Overall, there is not enough data currently available to make an estimation on how much carbon is stored in Swedish blue carbon ecosystems. Additionally, data is missing for other relevant vegetation types than seagrass meadows, for example kelp and other species of macroalgae as well as terrestrial coastal ecosystems like wetlands.

Acknowledgements

I want to extend my gratitude to the people involved in my master thesis. First, I want to thank my supervisors Maria E. Asplund at Gothenburg University, Martin Gullström at Södertörn University and Mats Björk at Stockholm University for their continuous support throughout the master thesis project, their valuable input and the guidance that I received from them.

This thesis would be still in pieces without the support from Tijmen and my family. Thank you for your belief and help in difficult moments.

Ena Fee Briesemeister
Göteborg, 23.05.2021

Table of Contents

List of Abbreviations

Abbreviation	Meaning
CO_2	Carbon dioxide
DIC	Dissolved inorganic carbon
GHG	Greenhouse gas
GIS	Geographic information system
IPCC	Intergovernmental Panel on Climate Change
OC	Organic Carbon
NDC	Nationally Determined Contribution
NOOA	National Oceanic and Atmospheric Administration
POC	Particulate organic carbon
SOC	Soil organic carbon
TOC	Total organic carbon
UNEP	United Nations Environment Programme

List of Figures and Tables

1. Introduction

As the global amount of atmospheric carbon increases constantly (United Nations, 2015), the need for climate mitigation measures to avoid a drastic climate change has been acknowledged by scientists and policy makers worldwide (UNEP, 2017). One proposed solution to prevent this development is through nature-based mitigation strategies, where conservation and restoration of natural sinks will benefit long-term storage of carbon and removal of CO_2 from the atmosphere. There have been efforts on land, for example reforestation and afforestation (de Coninck, 2018), to increase carbon sequestration and storage potential and strengthen the carbon sink function of terrestrial forests. In recent years (Kuawae et al., 2019) the potential of marine carbon sinks has been highlighted (Mcleod et al., 2011) as a natural climate mitigation option (Duarte et al., 2013). A quantitative understanding of how human actions can affect the carbon uptake rates of marine ecosystems is, however, not yet understood (Bindoff et al., 2019; IPCC, 2019). The general approach is to maintain the integrity of the natural carbon sinks to enhance the long-term removal of greenhouse gases (GHGs) from the atmosphere by conserving and restoring marine ecosystems (Bindoff et al., 2019). Salt marshes, mangrove forests and seagrass meadows are the key vegetated coastal ecosystems for carbon storage, commonly referred to as coastal blue carbon ecosystems (Mcleod et al., 2011). In comparison to terrestrial carbon storing forest ecosystems, blue carbon ecosystems are highly efficient in storing carbon. Their storage capacity of carbon is disproportionally large compared to the global spatial extent of blue carbon systems (Laffoley & Grimsditch, 2009). Due to the importance of coastal vegetated ecosystems, twenty percent of the countries that signed the Paris Agreement (United Nations, 2015) pledged in their Nationally Determined Contributions (NDC) (Herr & Pidgeon, 2016) to use and preserve nature-based solutions as a climate change option (Kuawae et al., 2019).

1.1 Anthropogenic Impacts on Coastal Vegetated Ecosystems

Coastal vegetated ecosystems are under great pressure from human activities and have undergone major losses during the last decades (Jackson et al., 2012; Waycott et al., 2009). Globally, these ecosystems are being lost at a high rate; within the last 100 years, 25-50% of all vegetated coastal ecosystems have disappeared (Mcleod et al., 2011), while the estimate for the current yearly loss of coastal vegetated ecosystems is on average 0.2-3% (FAO, 2014; IPCC, 2019). Anthropogenic impacts on the coast resulting in land-use changes (Herr et al., 2012), such as urbanisation, aquaculture, infrastructure and coastal development may impact and alter coastal ecosystems (Bindoff et al., 2019). Human induced climate change has profound impacts on coastal vegetated ecosystems (Harley et al., 2006; Spalding et al., 2014) with effects such as sea-level rise, eutrophication and increased water temperature (IPCC, 2019). Losses of coastal vegetation may transform carbon sinks to sources of atmospheric carbon and other GHGs (e.g. methane), due to emitting these upon decaying (Oreska et al., 2020). The disappearance or degradation of salt marshes, mangrove forests or seagrass meadows can be detrimental and affect multiple ecosystem services such as food security and livelihood for humans (especially in tropical countries) (Barbier et al., 2011; Kuawae et al., 2019) as well as important habitats for biodiversity and coastal protection (Möller, 2019; Temmermann et al., 2013). Furthermore, the impacts on the marine life due to the loss of nursery grounds for fish and invertebrates is also high and may alter the food chain (Spalding et al., 2014; Waycott et al., 2009). Moreover, the removal or fragmentation of these ecosystems destabilises the coast and makes it vulnerable for erosion (Möller, 2019; Temmermann et al., 2013)

1.2 Blue Carbon

The term "blue carbon" was coined by the United Nations Environment Programme in 2009 to describe the carbon dioxide that is absorbed by living marine organisms and sequestered in coastal vegetated ecosystems (Nellemann et al., 2009). Vegetated coastal ecosystems such as salt marshes, mangrove forests and seagrass meadows are commonly referred to as blue carbon ecosystems (Mcleod et al., 2011; Nellemann et al., 2009).

1.2.1 Marine Carbon Cycle

In the vegetated coastal ecosystem, there are six different carbon pools between which carbon is exchanged, including dissolved organic carbon in the seawater, dissolved inorganic carbon (DIC) in the seawater (Watanabe et al., 2006), inorganic carbon in shells and skeletal (Suzuki & Kawahata, 2004), organic carbon in living marine organisms (Fourqurean et al., 2012), particulate inorganic carbon in sediment (carbonates) (Suess, 1973; Sundquist 1985), and sedimentary organic carbon (SOC) (Hori et al., 2019; Kennedy et al., 2010; Miyajima et al., 1998; Miyajima & Hamaguchi, 2019). Each of the six carbon pools in a coastal ecosystem plays a role in the sequestration of carbon in the ocean and thereby influences (directly or indirectly) the storage capacity (Mcleod, et al., 2011). Atmospheric carbon dioxide (CO_2) enters and leaves the ocean at the atmosphere-water interface through gas exchange processes (Tokoro et al., 2019; Wanninkhof, 1992), through which the carbon dioxide is dissolved in the seawater, where some of it separates into bicarbonate (dissolved inorganic carbon, DIC) and carbonate ions (*Figure 1*). Some of the DIC in the seawater is absorbed by marine plants (Suzuki & Kawahata, 2004), and converted through photosynthesis into organic matter (Beer et al., 2014; Hori et al., 2019). The absorbed and converted DIC is part of the plant's biomass; marking the start of the marine carbon sequestration process, as organic carbon is produced through primary production of the vegetation and the phytoplankton (Fourqurean, et al., 2012). The carbonate ions, which were produced by dissolving carbon in the seawater, are used by marine organisms as building materials, for example for shells and skeletons, making up the inorganic carbon pool (Suzuki & Kawahata, 2004; Tokoro et al., 2019). Carbon is subsequently released through diffusion processes at the atmosphere-water interface (Beer et al., 2014).

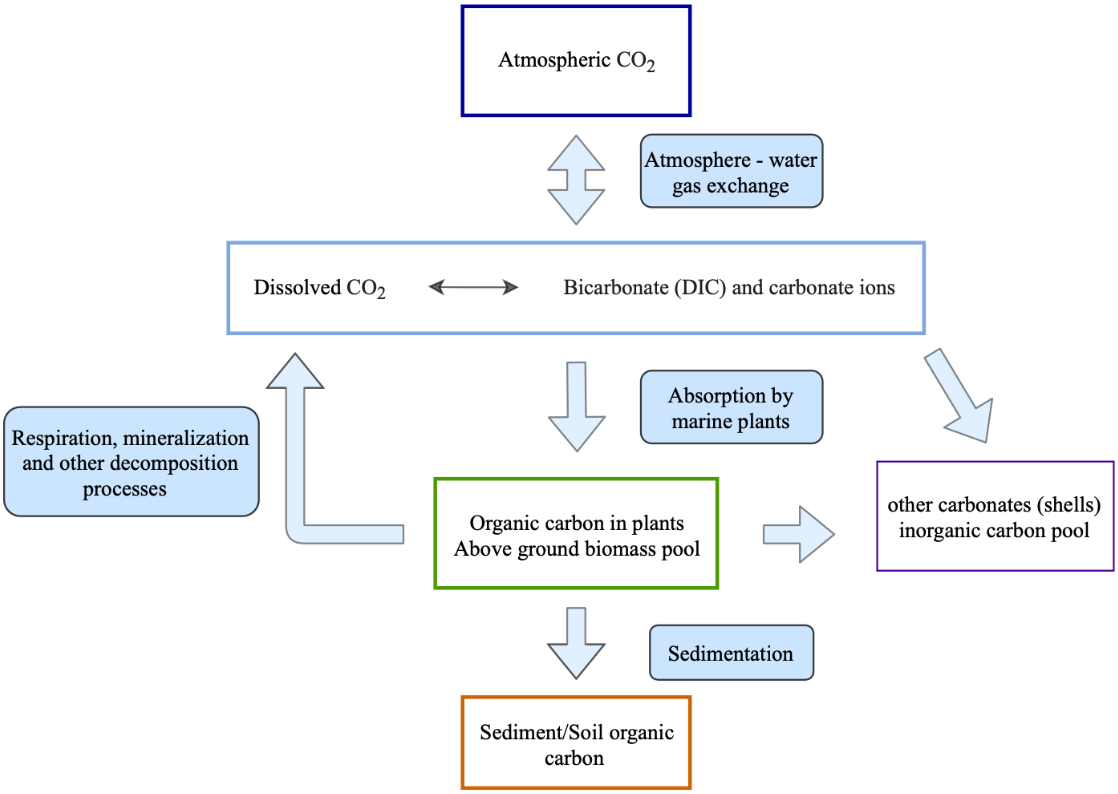


Figure 1: ***Conceptual figure of the marine carbon cycle*** *adapted from Hori et al. (2019) and Tokoro et al. (2019).*

As marine plants are a food source for marine herbivores, the carbon moves through the marine food web. Through the process of sedimentation, plants bury carbon (SOC) in the sediment (Duarte et al., 2013). The time carbon spends in the different marine carbon pools differs, where for instance sequestration in the sediment means the long-term storage of carbon (Mcleod et al., 2011). Shorter storage of carbon in the marine ecosystem can be in the plant biomass, the marine food chain as organic carbon and as a material for the production of shells and skeletons (Duarte et al., 2013; Hori et al., 2019; Mcleod et al., 2011).

1.2.2 Carbon Sequestration in Seagrass Meadows

In this thesis, there is a focus on the process of carbon storage in cold-temperate seagrass meadows. Seagrass meadows are submerged vegetation which acquire carbon by photosynthesis from dissolved CO_2 in the seawater and bicarbonate ions (Beer et al., 2014). Seagrass ecosystems are globally among the most efficient blue carbon sinks (Mcleod et al., 2011), as high amounts of organic carbon (OC) are stored for long-term in the soil and sediment (Hendriks et al., 2008) as well as for short-term in the seagrass' biomass (Fourqurean et al., 2012; Gullström et al., 2018). The captured carbon is incorporated into the plant's biomass, making up the biomass carbon pool (short-term storage) (Fourqurean et al., 2012; Miyajima & Hamaguchi, 2019). Some of the organic carbon stored in the seagrass biomass carbon pool is converted into sedimentary organic carbon (SOC). The refractory carbon is the possible long-term storage of carbon in the coastal vegetated ecosystem (*Figure 2*). More than half of the OC in the sediment is derived from belowground biomass of the vegetation (autochthonous origin) (Kennedy et al., 2010; Miyajima, et al., 2017; Miyajima & Hamaguchi, 2019). Allochthonously derived organic carbon (*Figure 2*) is important in the process of carbon sequestration in seagrass meadows, as it compromises a significant part of the stored carbon in seagrass meadows (Agawin & Duarte, 2002; Gullström et al., 2018). By analysing the stable isotope composition of carbon (δ13C), the source of the organic matter can be identified (Asplund et al. 2021; Kennedy et al., 2010; Miyajima & Hamaguchi, 2019;). The range of the sink function of blue carbon systems is greater than the habitat itself, as organic carbon is exported from the vegetated to unvegetated habitats at greater depth where it is deposited and stored for long-term (Mcleod et al., 2011). Assessment of such exported carbon to deeper areas or unvegetated adjacent areas is out of scope of this thesis, although it is a relevant part of marine carbon sequestration (see Duarte & Krause-Jensen, 2017).

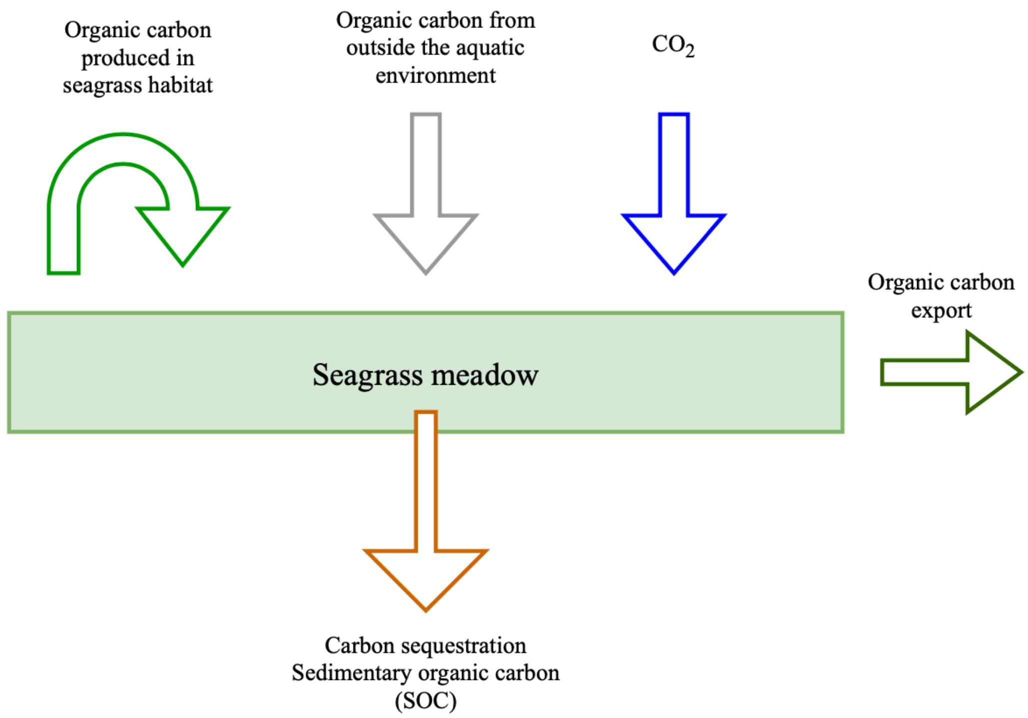


Figure 2: ***Conceptual figure of organic carbon input and carbon sequestration in seagrass meadows*** *adopted from Duarte et al. (2013); Mcleod et al. (2011) and Miyajima & Hamaguchi (2019).*

The relationship between a seagrass meadow and its underlying sediment is influencing the seagrasses' carbon storage potential, as the dynamics of a seagrass meadow is dependent on and influenced by the sediment properties and the meadow is influencing the stability of the sediment (Fonseca, 1989; Gacia & Duarte, 2001). The water flow of seawater is reduced by the seagrass leaves, which enhance the deposition and accumulation of particles in the seagrass meadow (Miyajima & Hamaguchi, 2019; Ward et al., 1984). The resuspension of sediment is being suppressed by the flow reduction (Duarte et al., 2013). Especially the accumulation and trapping of organic particles is essential for the carbon sequestration in the seagrass ecosystem (Hendirks et al., 2008; Miyajima & Hamaguchi, 2019). Further, seagrass meadows are stabilizing the sediment with their rhizomes and roots (Duarte et al., 2013; Miyajima & Hamaguchi, 2019; Röhr et al., 2018). There is variation in productivity among the different seagrass species, but generally the greater the productivity, the higher the sedimentary organic carbon stock (Duarte et al., 2010). The most widely distributed seagrass species at the cold-temperate Swedish coast is *Zostera marina*, while other seagrass species found are *Ruppia* spp. and the rarely distributed *Zostera noltii* (Baden et al., 2003; Baden & Pihl, 1984; HELCOM, 2013). The location of seagrass meadows and environmental factors influence the storage ability and stock of biomass OC and the sedimentary OC pool of seagrass meadows (Dahl et al., 2016; 2020a; Kuawae et al., 2019; Mcleod et al., 2011). Biotic factors such as grazing (Jephson et al., 2008) and abiotic factors of sediment density (Avnimelech et al., 2001; Dahl, et al., 2016), productivity concerning carbon storage (Mcleod et al., 2011) and rate of photosynthesis (Beer et al., 2014) determine the carbon storage potential.

1.3 Scope

Across the northern hemisphere, temperate seagrass meadows, rockweed beds and kelp forests are key habitats in coastal vegetated ecosystems (Krause-Jensen & Duarte, 2016; Reynolds et al., 2018). All these habitats provide several important ecosystem functions and maintain biodiversity (Reynolds et al., 2018; Temmermann et al., 2013).

Swedish seagrass meadows differ across locations; seagrass meadows located at the west coast in the Skagerrak and Kattegat are commonly dense and situated in moderate to sheltered muddy sites with a depth range from one to six meters (Rönnbäck et al., 2007), whereas seagrass meadows located at the east coast in the Baltic Sea are in comparison found in more exposed areas covering sandy bottoms at a depth range from three to eight meters (Dahl et al., 2016; Jankowska et al., 2016). Despite the location, all Swedish seagrass meadows are of high importance due to their many ecosystem services (Heckwolf et al., 2021; Nyqvist et al., 2009) and due to the important role in the marine food web (Reynolds et al., 2018). Similar to the global trend, the areal extent of the Swedish seagrass meadows has been declining over the last decades; in the Skagerrak archipelago the spatial extent of the seagrass meadows reduced by 60% since the 1980s (Baden et al., 2003). Kelp forests are found in different locations than seagrass meadows, as kelp grows on rocky substrates while seagrasses occupy soft bottoms. Kelp forests can grow down to 30 meters depth, as long as there is enough light available (Krause-Jensen et al., 2019). *Laminaria* spp. and *Saccharina latissima* are the most widely spread species of kelp found at the Swedish west coast, mainly distributed in more sheltered areas (Bekkby & Moy, 2011), while the Baltic coast has few kelp habitats due to the low salinity of the Baltic Sea. Similar to Swedish seagrass meadows, Swedish kelp forests are important habitats for maintaining biodiversity and provide many important ecosystem services (Krause-Jensen et al., 2019; Smale et al., 2013). Different species of rockweed can be found on sandy or muddy bottoms at the Swedish coast from a depth range of one to five meters (Riemann et al., 2016). In recent years, the role of macroalgae for blue carbon storage has been emphasized (Krause-Jensen & Duarte, 2016). This habitat building species, in comparison to other blue carbon ecosystems, grows on rocky coasts in Sweden. Further macroalgae ecosystems are exporting carbon to nearby environments (e.g. seagrass meadows or deeper accumulation basins), where it is stored for long-term (Krause-Jensen et al., 2018).

1.3.1 Thematic Scope

The thematic focus of this literature review is on coastal blue carbon ecosystems. Sweden, as a country of the European Union, signed the Paris agreement (United Nations, 2015) claiming that blue carbon ecosystems should be a potential resource for a natural climate mitigation measure (Kuawae et al., 2019). The thematic scope of this review is on the sequestration of carbon (Mcleod et al., 2011) and the potential methane emissions (Oreska et al., 2020) of Swedish blue carbon sinks.

1.3.2 Geographic Scope

Based on the thematic scope, the geographical scope limits the ecosystems that are to be included in the review. The focus is on coastal blue carbon ecosystems along the Swedish coastline. As coastal terrestrial ecosystems are part of this study, it is important to further define the spatial limits. The definition of NOAA fisheries for coastal wetlands (NOAA Fisheries, 2021) has been used to limit the spatial extent of coastal terrestrial ecosystems that are included in this study. According to NOAA fisheries' definition, coastal wetlands are characterised by being coastal watersheds or by the entire area of tidal streams draining to the ocean (NOAA Fisheries, 2021). The spatial scope of the coastal vegetated ecosystems extends out to the maximum depth of submerged vegetation. This extent is defined by the availability of light for the photosynthesis of the marine plants (Beer et al., 2014; Mcleod et al., 2011). Included in the geographic scope are therefore habitat building terrestrial ecosystems and in the shallow coastal areas with the potential to sequester carbon and act as a blue carbon sink. Terrestrial and semi-submerged ecosystems along the coastline, which are included in the scope of this investigation, are seagrass meadows, alder marshes, coastal wetlands, salt marshes and reed. Among the submerged vegetative habitats are macroalgae and submerged rooted macrophytes (including seagrass and other macrophytes) (Belgrano, 2018; Rönnbäck et al., 2007).

1.4 Research Question and Aim

The overall aim of this master thesis is to create an overview of Sweden's coastal blue carbon ecosystems and their relative importance as potential long-term carbon sinks based on a systematic literature review. With focus on Swedish coastal blue carbon habitats, three specific research questions are guiding further analysis: (1) What type of data and knowledge concerning Swedish blue carbon is currently available? (2) What are significant gaps in the existing data? (3) How are studies concerning blue carbon stocks distributed geographically? and (4) How much carbon is stored, and is methane released in the different areas?

By mapping the data on Swedish blue carbon ecosystems, an inventory of the Swedish blue carbon assets can be produced, showing the total carbon burial capacity and hotspots of blue carbon systems according to the currently available data from the literature. Further knowledge and data gaps can be identified, which are indicating future research directions.

2. Method Description

To create an inventory for the current state of knowledge for Swedish blue carbon assets, a systematic literature review followed by a meta-analysis of the selected material was conducted. This method requires structure and documentation and aims to depict a complete picture of the selected research area (Lasserson et al., 2021). First the creation of the search string and the selection process are going to be described, followed by a presentation of the data. The selected material is used to show the current knowledge and data gaps as well as data hotspots within the geographical and thematic scope. Subsequently, it is then used to create a compilation of the blue carbon stock in Sweden.

2.1 Study Area

Sweden's coastline spans from the Skagerrak at the Norwegian border, through the Kattegat and the Baltic Sea to the Bothnian Bay. Due to the strong salinity and temperature gradients (Omstedt & Axell, 2003), the Swedish coastal ecosystems are highly diverse (Naturvårdsverket, 2018). The research questions in section 1.4 were used as criteria for the selection of habitat building species.

The selected species needed to either act as or be potential blue carbon habitat species, meaning that the species have a carbon uptake or storage mechanism. Further, they needed to fit the geographical and spatial scope of the study. Reeds (*Phragmites*) and alder marshes were chosen as coastal terrestrial and non-submerged species and habitats. Species found in Swedish estuaries and along rocky coasts are rockweeds (*Fucus*), kelp (*Laminaria* and *Saccharina latissima*) and macroalgae. The selection of fully submerged vegetation of coastal vegetated ecosystems concerned mainly the species of seagrass (*Zostera*) and other macrophytes (*Ruppia* and the closely related genera *Potamogeton* and *Zannichellia*).

2.2 Methodology

To generate relevant results to answer the research questions, a search string that was used in different search engines was produced, including topic-specific search terms. Three different search blocks equal to the number of key concepts of the research questions, knowledge, location and assets were included to form the search string. Each search block was enclosed by parentheses to ensure the desired logic of precedence over the given one of the search engines. The different databases have different rules of precedence, but all recognise the tool of the parentheses to modify the order of precedence and to link search terms into merged search blocks. Boolean operators were used as conjunctions between the search terms, altering the preciseness of the search string. The search blocks of the developed search string were connected by using the Boolean operator AND. This had the effect that a combination of search terms from each of the search blocks need to appear in the results. An increase in the amount of search blocks and connecting them with the operator AND would lead to a narrowed down result. The challenges with the aim of this search string were to use a search that is narrow enough for the research question while also include all relevant materials.

The first search block consisted of a location search term (see *Table 1*), which is the stem of the word with an added asterisk (* symbol in the selected databases) to include different word endings (in this case: Sweden, Swedish). There was no difference in results in capitalisation of the search term. The largest search block had 22 search terms (see *Table 1*) for habitat building species. Both, the scientific and the commonly known names of the species were included. The search terms were connected by the Boolean operator OR, which means that at least one of the search terms of the search block needs to be included in the results. A higher amount of search terms connected with the Boolean operator OR leads to a broader search. The third search block included five search terms for elements, the name and the chemical abbreviation. As the search terms for habitat building species, these were also connected by the Boolean operator OR. If a search term consisted of two or more words, quotation marks were used as a tool for phrases. This differed for the Scopus database where brackets were used for phrases in the search. A selection of search terms (a total of seven search terms of the habitat building species) had an added asterisk to include the plural form or a different grammatical ending of the search term.

Location	Habitat building species	Element
Swed*	"salt marsh" "tidal marsh" wetland* ruppia "widgeon grass" zannichellia potamogeton pondweed* kelp "saccharina latissima" laminaria seagrass* eelgrass* zostera "alder marsh" "macro algae" reed phragmites macrophyte* "submerged rooted macrophyte*" fucus rockweed*	carbon carbon dioxide CO_2 methane CH4

Table 1: **Developed Search String:** *The search terms within the columns were enclosed with parentheses and connected with the Boolean operator OR. The three search blocks, i.e. the three columns, were connected using the Boolean operator AND.*

The designed search string was used in four different databases all of which were accessed with the university login: *SuperSearch* Gothenburg University online library search engine

(Gothenburg University, 2021), *Web of Science* (Clarivate, 2021), *Scopus* (Elsevier B.V, 2021) and *Google Scholar* (Google, 2021). Minor adjustments to the search string were necessary to ensure the compatibility of the search string with each of the search engines. For the search with SuperSearch most adjustments to the search string were necessary to fit the requirements for a valid search. The number of used asterisks in the search string needed to be reduced to a total amount of four and the search string exceeded the allowed number of search terms. Therefore, one search term ("laminaria") for habitat building species was removed. This removal did not alter the results as the English name for the species is included in the search terms and "Saccharina latissima" is known as *Laminaria* as well (Guiry, 2021).

2.3 Settings and Limits

In all search engines, the search was limited by using specific settings. The advanced search option was selected over the basic search option in all databases to refine the search results. Further, the search should be limited to the topic and the search string should not be applied to the whole text. Each database has specific settings for executing the limit to topic or a similar limit; this setting was chosen in each database. The setting "TOPIC" (TS in the search string) was added to the search string in *Web of Science*, TITLE-ABSTRACT-KEY was added in *Scopus* and *SuperSearch* limited to "Subject". *Google Scholar* does not offer similar options, so other limits were set to refine the search results. The region was set to Sweden, the language to English and the file format to PDF.

2.3.1 Limit Language

In all databases, the delimiting setting for language was used and the language set to English. Especially for the grey literature such as policy documents and local and regional reports, the ability of speaking Swedish would have been advantageous. Most academic literature is, however, published in English.

2.4 Search Results and Selection Process

The scope of the developed search string was narrow to be in line with the methodology of a systematic review (Jesson et al., 2011). Accordingly, the identified studies have been reviewed with pre-set criteria for including or excluding studies.

2.4.1 Inclusion and Exclusion Criteria

In order to be further included in the study, each publication must pass different inclusion criteria at any stage of the selection process. Most important to the aim and research questions was the geographical area. The relevance of the area with a local (Sweden) and coastal scope was of high importance (exclusion code: location). The definition of coastal was important regarding coastal or terrestrial wetlands. For this purpose, the definition of coastal wetlands by NOAA Fisheries has been used (NOAA Fisheries, 2021). Coastal wetlands are hence characterized by being in coastal watersheds and/or the entire area of tidal streams which drain into the ocean. The criteria of relevance defines the subject. The selected study needed to concern carbon or methane, which meant that other studies will be excluded (exclusion code: focus). Further, the study needed to be about the topic of carbon storage, carbon sequestration, carbon content or the emission of methane (exclusion code: subject). The selection was independent of the author, the journal or book and the year of publishing.

2.4.2 The Selection Process

At the first stage of the selection process, 1331 publications from the four different databases were included. The initial step was the removal of 205 duplicates, leaving 1126 publications for the title screening. All screening decisions were based on the pre-set inclusion and exclusion criteria. The majority of the publications (a total of 752) were excluded in the title screening stage, leaving 374 publications, which were incorporated into *Mendeley* (Mendeley, 2020) to be screened. In the second stage, the abstracts of the 374 publications were scanned to identify relevant studies. After the abstract screening, 35 publications were selected. These publications were fully scanned in order to be certain about the relevance to the research question of the study. A total of 15 studies were selected to be included in the literature review as they met all inclusion criteria. If background datasets were available for the selected studies, they were included as well (see Kindeberg et al., 2019). *Figure 3* shows the described selection process (based on the PRISMA model (Moher et al., 2015)), including the selecting criteria for including or excluding a publication.

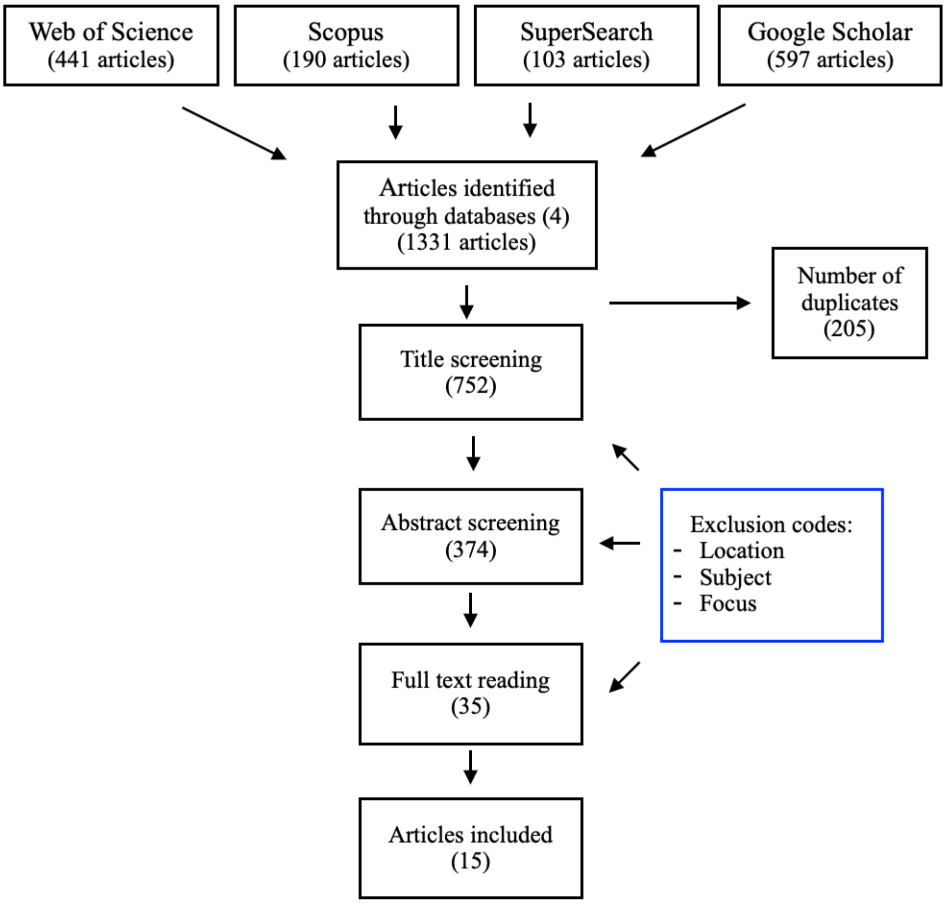


Figure 3: **Decision diagram for including or excluding studies:** *Based on the PRISMA model (Moher et al., 2015).*

2.4.3 Data Processing

In order to create a compilation of the material on Swedish carbon assets, relevant data was extracted from the selected literature and organised in a table. Descriptive data such as the study location, the methods used to conduct the study and the time frame, as well as the habitat, the habitats status, the species name (common and scientific), the depth of the sediment samples and the emissions interface (atmosphere–sediment, sediment–water and water–atmosphere) were collected. Information about the studied biomass (above- and below-ground), the measured carbon content of the biomass, sediment properties, carbon sequestration rates and other values associated with carbon content or storage of the studied area were picked from the material and added to the database. All relevant parameters that report on any of the different carbon pools in the marine ecosystem, i.e. dissolved organic carbon in seawater, dissolved inorganic carbon in seawater (DIC), inorganic carbon (shell and skeletal), organic carbon in living marine organisms, particulate inorganic carbon in sediment (carbonates), sedimentary organic carbon (SOC), were compiled and included in the database.

2.5 Validation of the Search String

In an iterative process, the search string results were narrowed down to a number that was a good trade-off between precision and recall (neither too many false positives nor false negatives). This process involved adjusting the search string and ensuring the results became more relevant towards the aims and research questions of this thesis. In this process, it was still possible to miss relevant papers which may not have satisfied the resulting search string. In order to validate this, a simpler search was performed on a smaller scale to evaluate the search string. Used search terms were "Sweden", "blue carbon" and "seagrass meadows". This smaller evaluation was designed to show if there were any missing papers due to a false negative evaluation of the Boolean search string. The small-scale search resulted in finding two publications which include relevant data for this thesis. The study by Gullström et al. (2012) can be found in all databases of the search engines used (SuperSearch, Scopus, Web of Science and Google Scholar). The study by Gullström et al. (2012) reports on sedimentary organic carbon content. The reason it was not included in the search results lies in the configuration of the search string and the settings in the different search engines. The paper would have matched the search blocks for location and species but not for carbon, as this term does not appear in the title, abstract or the keywords of the paper. The settings in all search engines were set to limit the search to the topic or subject. Therefore, this study did not show up as a result in any of the search engines. The second paper found through the small-scale search is a study by Röhr et al. (2018), showing the variability of carbon stocks across global sampled locations and explaining the variation through environmental variables. Similar to the first paper that did not match the search string, the study by Röhr et al. (2018) did not mention the location term "Sweden" in the abstract, the title or the keywords. Therefore, it was not included in the results of the search engines. These two papers show the limits of the method of a systematic literature review.

2.6 Grey Literature Search

The first attempt to find grey literature, defined as a diverse field of publications which are not formally published in scientific articles (Schöpfel, 2010), was done using the same systematic approach as for the academic literature as described in section 2.1, using an altered search string in the advanced search section of google. The returned results (n=495) were screened according to the inclusion and exclusion criteria and showed no relevant material. As the systematic search did not work as intended, the grey literature search was conducted in a non-systematic way. For the grey literature search, variations of the search terms of the search string were used and the returned material briefly screened, as well as government websites on national and European levels and websites of other responsible organisations. For the grey literature search, the limit to English reports was a delimiting factor; websites may be in English, however the published reports on national and local levels are not. Overall, the search for grey literature did not return a great number of results. The few reports that were in English and relevant to the research questions did not include relevant data. The majority of the papers show the overarching ambitions and targets which are necessary for climate change mitigations (for example: European Comission, 2020; Garpe, 2011; Swedish Environmental Protection Agency, 2018).

3. Results

The section 3.1 shows results of the data compiled from the systematic literature review, while results from the semi-structured review of the grey literature is presented separately in section 3.7.

3.1 The Selected Publications

The systematic literature review resulted in the selection of fifteen relevant publications (*Table 2*) out of initially 752 screened articles. As the publications have a high variation concerning the data they provide as well as the difference in the type of study that was performed, they were grouped in different categories. Experimental and estimative studies (n=7), studies on abiotic factors (n=5) and studies with a broader focus (n=3) were the three categories. A high variation among the selected studies already indicates a degree of variation in the reported data.

3.1.1 Experimental and estimative studies

Estimations of carbon assets in the carbon pools of coastal vegetated ecosystems were found in the literature. The estimates were either based on modelled data (Wijnbladh et al., 2006) or estimates for other locations which then were used for Sweden (Jephson et al., 2008). Further results from experimental setups evaluating mechanisms of the surveyed species were found in four articles (see *Table 2*). The experiments are either conducted in an artificial set up location or directly in the ecosystem but with artificial modifications.

Reference	Research Theme	Group	Data
Cole & Moksnes, 2016	Framework for valuing ecosystem services of Swedish *Zostera marina* meadows	Experimental or estimative	Carbon sequestration rate
Wijnbladh et al., 2006	GIS data grid to model the environmental parameters of coastal ecosystems	Experimental or estimative	Primary production rates, Biomass, Carbon flux
Björk et al., 2004	Assessment of the influence of a shared habitat on the photosynthesis performance of *Ulva intestinalis*	Experimental or estimative	DIC
Visch et al., 2020	Suitable locations for *Saccharina latissima* (kelp) aquaculture by considering wave exposure and geographical location affecting the growth and biofouling	Experimental or estimative	δ13C
Bucholc et al., 2014	Potential of macrophytes as a resource for the biofuel production	Experimental or estimative	Carbon content
Klenell et al., 2004	Active carbon uptake of *Laminaria digitata* and *Laminaria saccharina*	Experimental or estimative	DIC
Dahl et al., 2018	Impact assessment of hydrodynamic activity leading to a resuspension of organic carbon in the sediments of seagrass meadows	Experimental or estimative	Above and below ground biomass, SOC
Kindeberg et al., 2019	Variation in depth profiles of 47 *Zostera marina* meadows in the northern hemisphere	Studies on abiotic factors	POC δ13C
Dahl et al., 2016	Analysis of the organic carbon content in the sediment of *Zostera marina* meadows in four European areas	Studies on abiotic factors	Above and below ground biomass, SOC
Dahl et al., 2020a	Seasonal variation in sedimentary carbon stocks of Swedish seagrass meadows	Studies on abiotic factors	Biomass (C stock), DOM, TOC
Jephson et al., 2008	Trophic interactions of *Zostera marina* ecosystems at the Swedish east and west coast	Studies on abiotic factors	Aboveground biomass, TOC
Dahl et al., 2020b	Analysis of sediment characteristics for carbon storage and effects of hydrodynamic exposure on trapping of organic material in seagrass meadows	Studies on abiotic factors	Soil organic Carbon (SOC)
Jansson & Nohrstedt, 2001	Estimate of carbon dioxide emissions of Stockholm County set into relation to the natural carbon sinks	Studies with focus problem	Carbon sink capacity
Haamer, 1996	Evaluation of improvement of the water quality through mussel farming in an eutrophied fjord system	Studies with focus problem	Carbon flux SOC
Nilsson et al., 2001	Inventory of Swedish mires	Studies with focus problem	Methane emissions

Table 2: **The fifteen selected publications of the systematic literature review.**

3.1.2 Studies on abiotic and biotic factors

Actual carbon assets in marine carbon pools based on the data of the samples taken in the ecosystem were found in five articles. Abiotic factors influence the trapping and storage of carbon in *Zostera marina* ecosystems (*Figure 4*). Before extrapolating sediment profiles to greater depth, sediment profiles with a non-homogenous variation of POC distribution need to be assessed (Kindeberg et al., 2019). Sediment characteristics, such as density, grain size and porosity, influence the sedimentary carbon storage in *Zostera marina* meadows (Dahl et al., 2016), as well as the relation between the sedimentary organic carbon content and hydrodynamic exposure (Dahl et al., 2020b). Cold-temperate seagrass meadows show seasonal variation in the level of stored carbon, which also differs between sheltered and more exposed seagrass sites (Dahl et al., 2020a). Trophic interactions were altered within a seagrass meadow impacted by small grazers in high density, which in turn had impacts on the aboveground seagrass biomass (Jephson et al., 2008).

Influence of abiotic and biotic factors on carbon pools in seagrass meadows

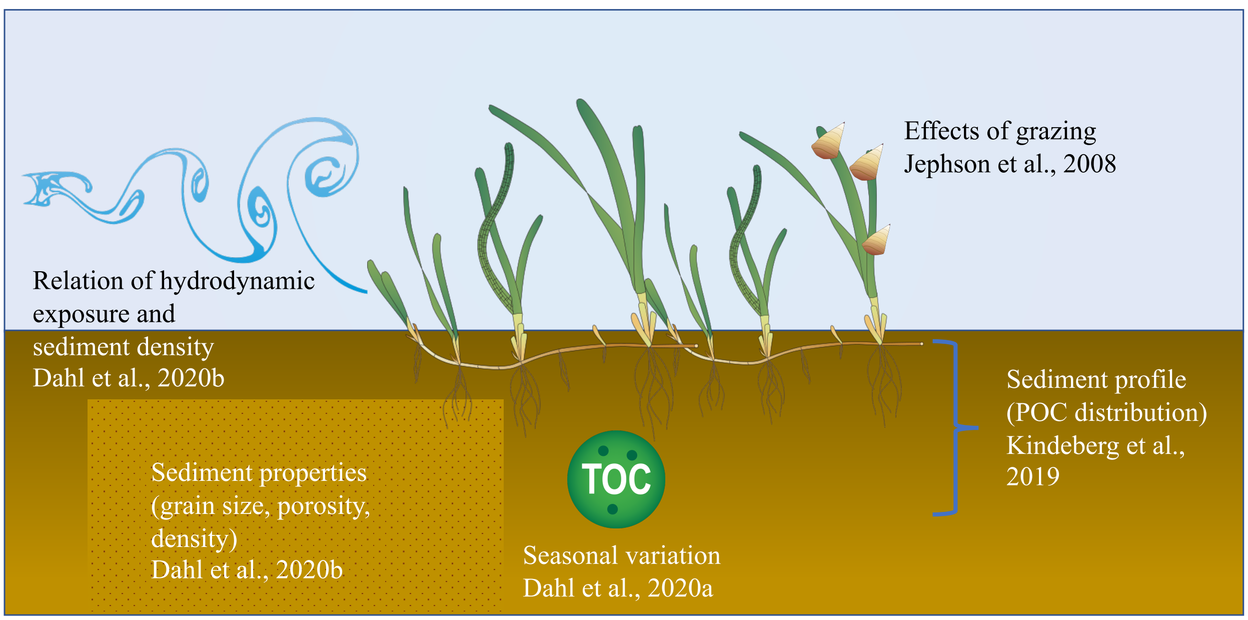


Figure 4: ***Abiotic and biotic factors influencing the carbon storage potential of Zostera marina meadows.*** *Conceptual figure based on publications found in the review process. Images via (UMCES, 2021), Images by: Catherine Collier, Jane Hawkey, Diana Kleine, Tracey Saxby (UMCES, 2021).*

3.2 Geographical Distribution of Data

The geographical distribution of data concerning study locations from the systematic literature review can be seen in *Figure 5*. The map shows all locations where samples have been taken, so there can be multiple locations covered by one study. Therefore, the number of locations (n=59) is higher than the number of studies (n=15). The map does not show the number of samples that have been taken at each location and does not indicate if two or more studies took samples at the same location. By mapping the geographical distribution of the data, hotspots and accumulation of data are visualised and the lack of data or gaps also become apparent. There is a data hotspot north of Gothenburg in the Gullmar Fjord (58°15′N 11°26′E). Multiple studies (n=6; Dahl et al., 2016; 2018; 2020a; 2020b; Jephson et al., 2008; Kindeberg et al., 2019) used the area of the Gullmar Fjord for sampling data for their studies. There is also a difference in the amount of data points for the east coast (n=26 sampling points) and west coast (n=33 sampling points) of Sweden. The distribution of the data shows that no studies conducted in the Bothnian Bay concerning blue carbon ecosystems were found by the systematic literature review (*Figure 5*). Geographically, the point that is furthest to the north is the sampling location in Askö, located south of Stockholm (Dahl et al., 2016) as well as the study location close to Stockholm (Jansson & Nohrstedt, 2001). Along the remaining Swedish coastline of the Baltic Sea and the Gulf of Bothnia until the Finnish border, no studies were found concerning blue carbon ecosystems.

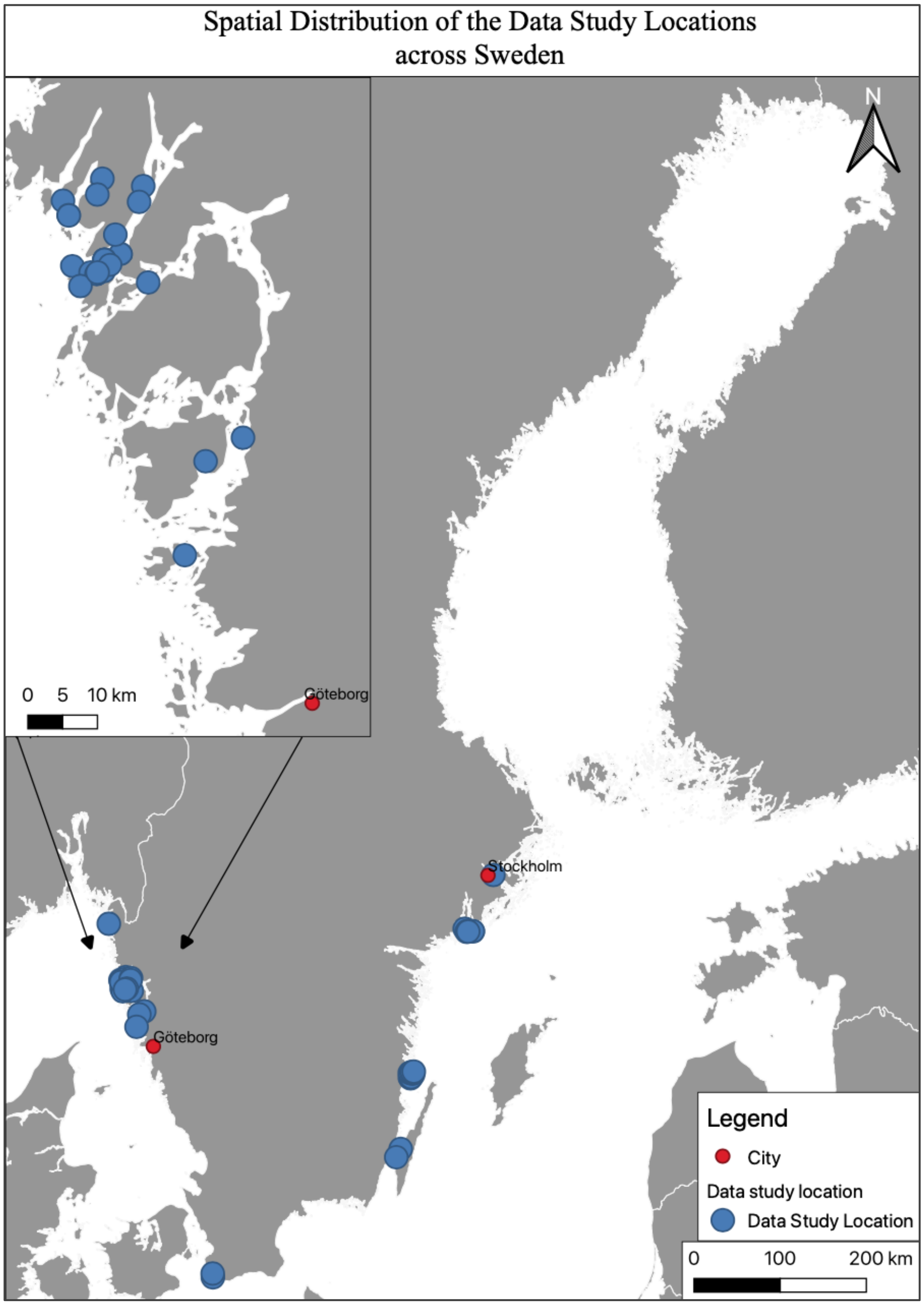


Figure 5: **The spatial distribution of the study sites of the selected literature.** *The map shows the geographical distribution of the 52 sampling sites from the 15 selected publications, including existing areas of data accumulation and areas where large gaps of data exist. Map made using QGIS open-source software. Background map: Eurostat, (2020).*

3.3 Blue Carbon Species

The selected literature covered multiple habitat building species (n=20), which are potential blue carbon habitats. At the study sites of the selected publications, different species were sampled and the relation between the different species and the number of sampling locations is summarized in *Figure 6*. Four publications were excluded in the summary due to either a broad focus or the study was based on an estimation without sampling locations or specific species (see *Table 2* in section 3.1 for all publications). Excluded from *Figure 6* are the publications by Cole and Moksnes (2016) as no sampling location is given; Haamer (1996) as no specific species is mentioned; Jansson and Nohrstedt (2001) as no specific species is mentioned; and Nilsson et al. (2001) as the focus is too broad. *Figure 6* suggests that there is data for a variety of species (n=20 species) in the selected literature. However, this variety is not mirrored in the data, as some species are merely mentioned due to their presence at the studied location. *Figure 6 s*hows that the focus in the majority of studies is on *Zostera marina*; it does, however, not show the availability of data for the species or indicate whether the species is the focus point of the study. All available data on aboveground plant biomass and aboveground carbon pools is within the *Zostera marina* habitat (see *Figure 7*).

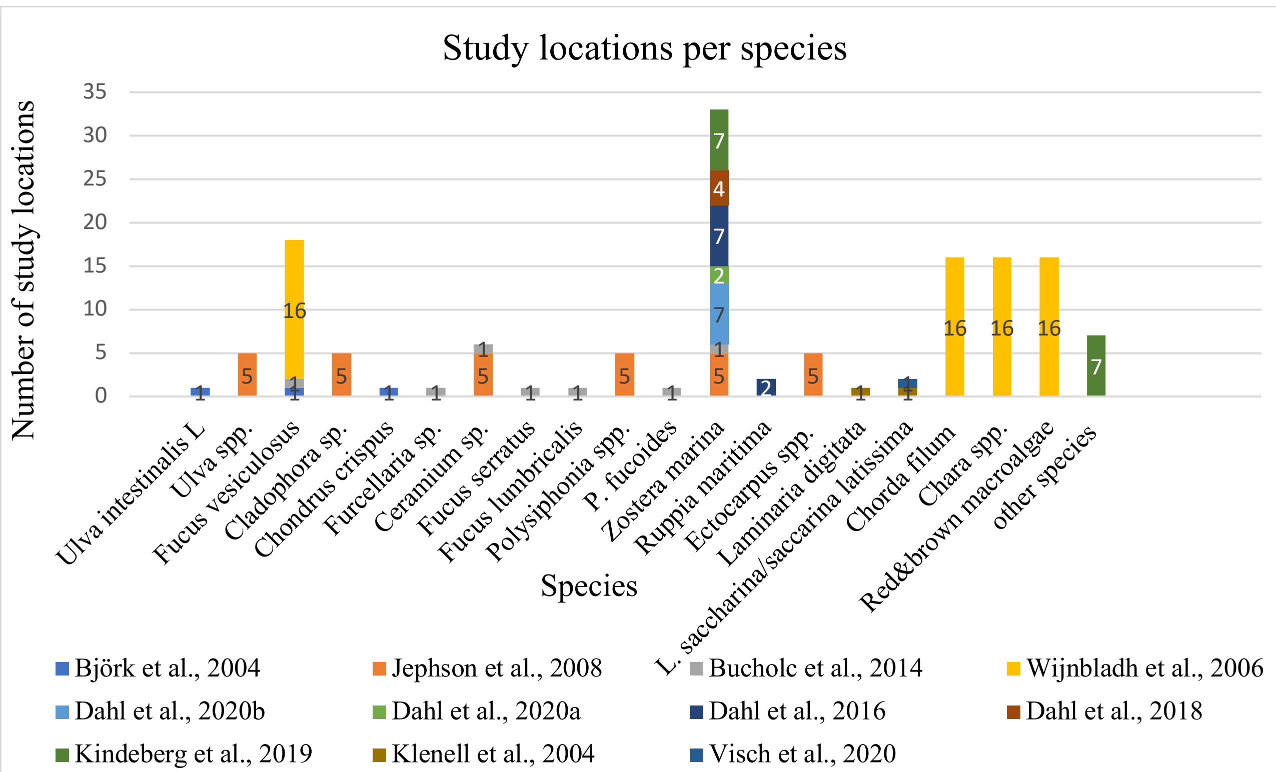


Figure 6: **Number of study locations per species.**

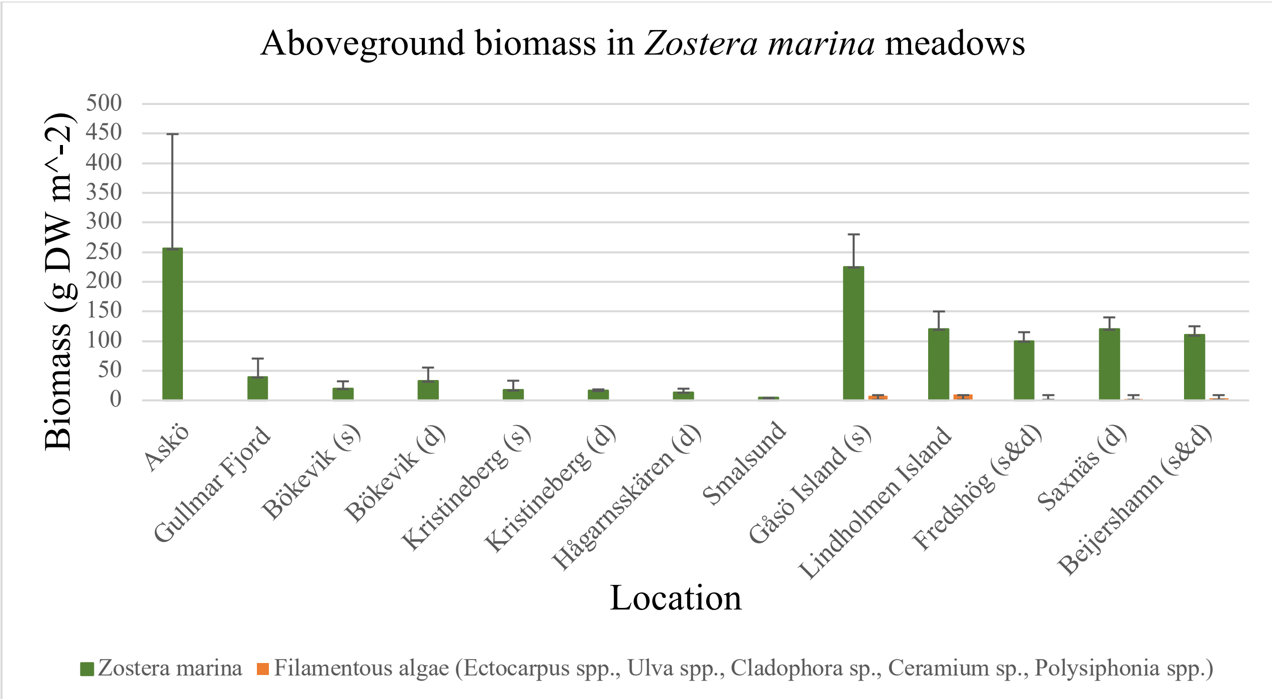


Figure 7: **Reported aboveground plant biomass in *Zostera marina* meadows.** *(Dahl et al., 2020a; Dahl et al., 2018; Dahl et al., 2016; Jephson et al., 2008). Shallow (s): < 2.5 meter, Deep (d): >2.5 meter.*

3.4 Reported Carbon Assets

The systematic literature review revealed carbon concentration in the different carbon pools of the coastal vegetated ecosystems. The reported assets of aboveground plant biomass and the included sedimentary carbon stocks (section 3.4.1) and those on seagrass belowground biomass and sedimentary carbon stocks (section 3.4.2) are all presented in the following sections.

3.4.1 Aboveground Carbon Stocks

Four publications report on aboveground carbon concentrations in the studied coastal vegetated ecosystems (*Table 3*). The units in which these studies reported the aboveground plant biomass (AGB) were given in g DW m^{-2} (Dahl et al., 2016; 2018; Jephson et al., 2008) and the carbon content of the aboveground seagrass biomass in percentage (Dahl et al., 2016). For comparability, the carbon stock was calculated using the conversion factor of 0.36 for seagrass meadows dominated by *Zostera marina* (Duarte, 1990; Postlethwaite et al., 2018). Species of the coastal vegetated ecosystems on which data was found in the systematic literature review were primarily for *Zostera marina* (*Table 3* and *Figure 6 and 7*), but also for filamentous algae, *Ectocarpus* spp., *Ulva* spp., *Cladophora* spp., *Ceramium* spp. and *Polysiphonia* spp. The majority of the data on aboveground carbon pools is for *Zostera marina* meadows. Data was found for the Swedish west and east coast on the aboveground carbon concentration, while clearly the majority is from studies on the west coast, particularly around the area of the Gullmar Fjord (58°15′N 11°26′E; *Figure 8*). The data compilation of the aboveground carbon pools demonstrates the availability of data in relation to location, species and which carbon pool the data is available for (*Table 3*). In terms of *Zostera marina* meadows, the highest reported aboveground seagrass biomass (255.7 ± 193.4 g DW m^{-2}; Dahl et al., 2016) has been reported from the east coast at Askö (*Table 3*; *Figure 9*). The highest reported carbon stock in the aboveground seagrass biomass (3965 ± 214 g C m^{-2}) is from a *Zostera* meadow at Getevik on the Swedish west coast (Dahl et al., 2020a).

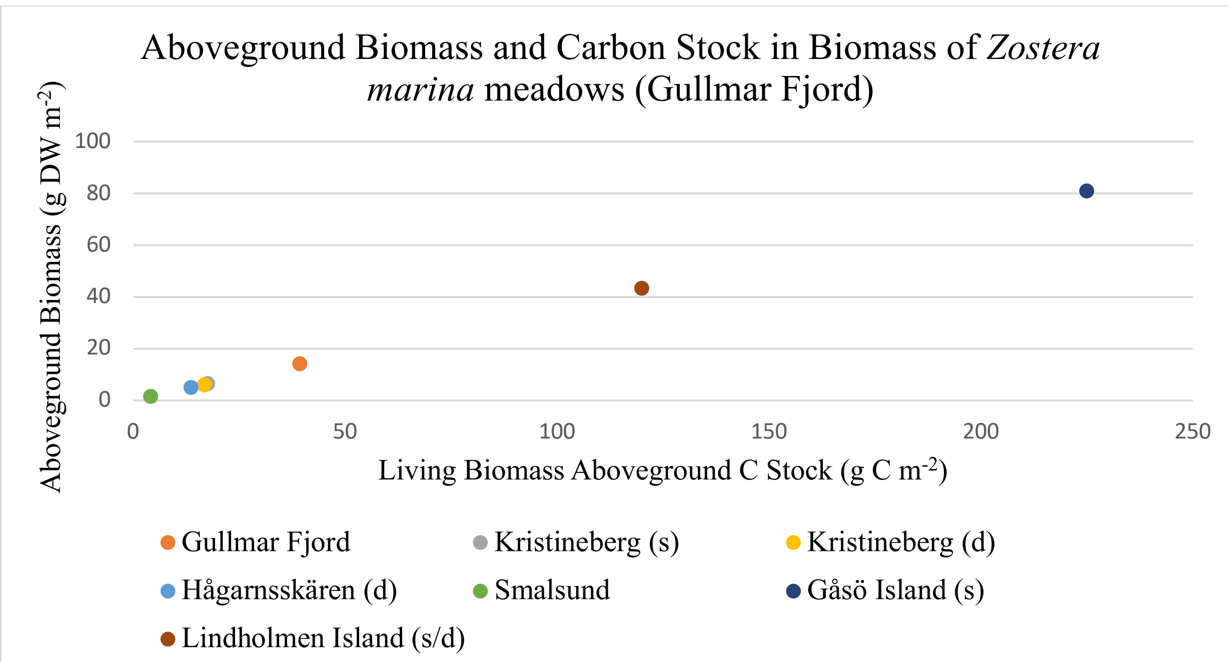


Figure 8: ***Aboveground seagrass biomass in relation to carbon stocks of the aboveground seagrass biomass at locations in the Gullmar Fjord at the west coast of Sweden****. Data from (Dahl et al., 2016; 2018; Jephson et al., 2008). Shallow (s): < 2.5 meter, Deep (d): >2.5 meter.*

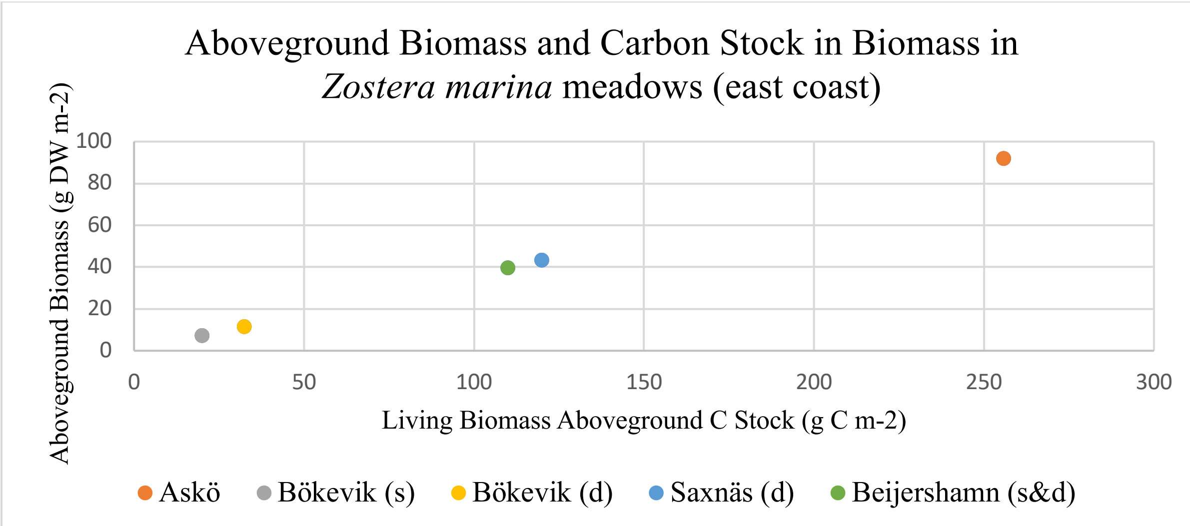


Figure 9: ***Aboveground seagrass biomass in relation to carbon stocks of aboveground seagrass biomass at locations at the east coast of Sweden. Saxnäs and Beijershamn are located in Kalmar sound at Öland.*** *Data from (Dahl et al., 2016; 2018; Jephson et al., 2008). Shallow (s): < 2.5 meter, Deep (d): >2.5 meter.*

Species	*Location deep: > 2.5m shallow: < 2.5m*	*N*	AG Biomass g DW m^{-2}	SD AGB	BG Biomass g DW m^{-2}	SD BGB	biomass C stock g C m^{-2}	SD AG C stock	AG biomass % C (% C org)	SD AGB %	Study ID
Zostera											
	Askö	3	255.7	193.4			92.052		37.2	2	Dahl et al., 2016
	Gullmar Fjord	2	39.4	31.1			14.184		38.8	0.7	Dahl et al., 2016
	Bökevik (s)	2	20	12.1622	36.35	31.7490	7.2	13.086			Dahl et al., 2018
	Bökevik (d)	8	32.4	22.8961	60.414286	39.7664	11.664	21.749 14286			Dahl et al., 2018
	Kristineberg (s)	2	17.55	15.6271	29.4	9.1923	6.318	10.584			Dahl et al., 2018
	Kristineberg (d)	2	16.75	1.76777	80	59.9626	6.03	28.8			Dahl et al., 2018
	Hågarnsskären (d)	4	13.675	6.02184	44.075	17.4329	4.923	15.867			Dahl et al., 2018
	Smalsund	1	4.1	0	58		1.476	20.88			Dahl et al., 2018
	Gåsö Island (s)	3	225	55			81				Jephson et al., 2008
	Lindholmen Island	5	120	30			43.2				Jephson et al., 2008
	Fredshög (s&d)	4	100	15			36				Jephson et al., 2008
	Saxnäs (d)	4	120	20			43.2				Jephson et al., 2008
	Beijershamn (s&d)	5	110	15			39.6				Jephson et al., 2008
Filamentous algae Ectocarpus spp. Ulva spp. Cladophora sp. Ceramium sp. Polysiphonia spp.											
	Gåsö Island (s)	3	8.2	1.3							Jephson et al., 2008
	Lindholmen Island	5	9.8	1.2							Jephson et al., 2008
	Fredshög (s&d)	4	0.7	0.1							Jephson et al., 2008
	Saxnäs (d)	4	2	0.7							Jephson et al., 2008
	Beijershamn (s&d)	5	3.8	1.5							Jephson et al., 2008

Table 3: **Data on aboveground carbon assets and above (AGB) and belowground (BGB) plant biomass. All data of aboveground carbon stocks (g C m^{-2}) have been converted from biomass using the conversion factor 0.36 for *Zostera marina*** (Duarte, 1990; Postlethwaite et al., 2018).

3.4.2 Belowground Carbon Content

Six studies have focused on carbon contents of sediments in *Zostera marina* meadows at different locations in Sweden, which are summarized in *Figures 10* and *11*. *Table 3* summarises the data that is available, including data on belowground seagrass biomass (see *Table 3*) (g DW m^{-2}; Dahl et al., 2018; *Table 3*), soil carbon content (in percentage; Dahl et al., 2020), soil organic carbon content (SOC) (in percentage; Dahl et al., 2018; Haamer, 1996; Jephson et al., 2008), soil carbon content (in g C m^{-2}; Dahl et al., 2016; 2020a), total organic carbon (TOC) of the sediment (in percentage; Dahl et al., 2020b)) and particulate organic matter (POC) (in percent; Kindeberg et al., 2019) (see also *Table 1* in Appendix I). The retrieved data for belowground carbon stocks is for *Zostera marina* meadows. Noteworthy is that the study by Haamer is for a fjord ecosystem, without detailed indication of the habitat building species (Haamer, 1996).

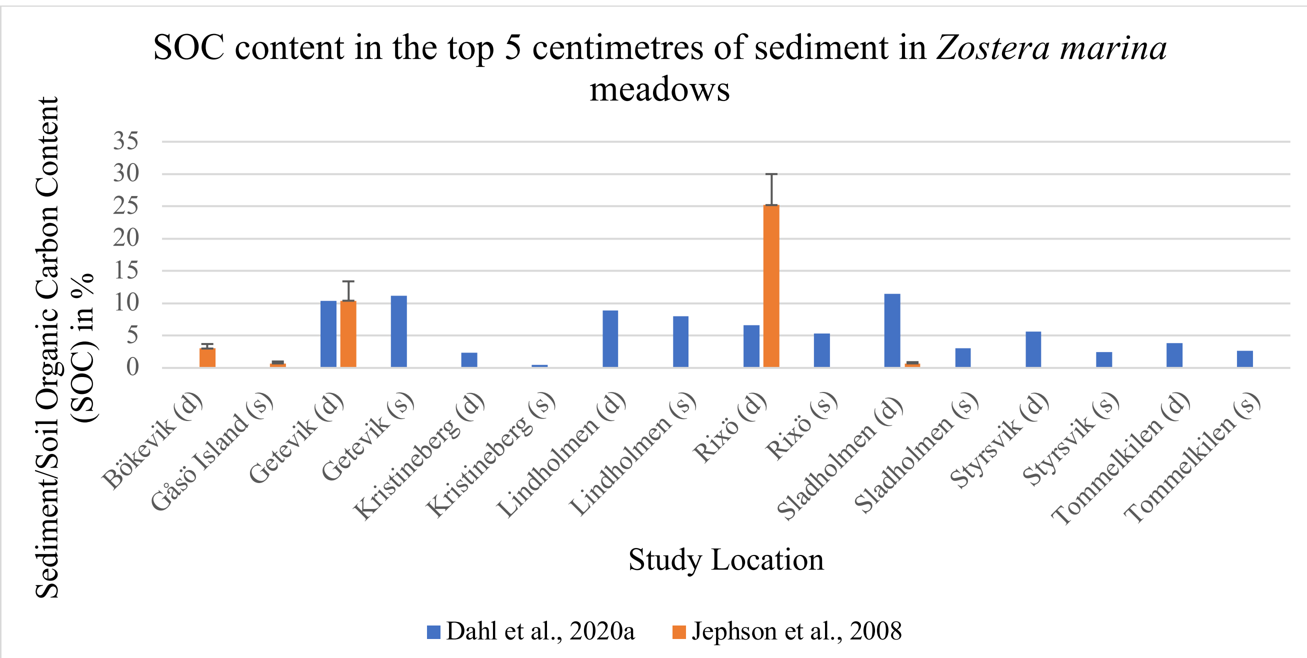


Figure 10: **Sediment organic carbon (SOC) content in the top five centimetres of sediment in *Zostera marina* meadows based on data from two relevant studies in Sweden.** *Shallow (s): < 2.5 meter, Deep (d): >2.5 meter.*

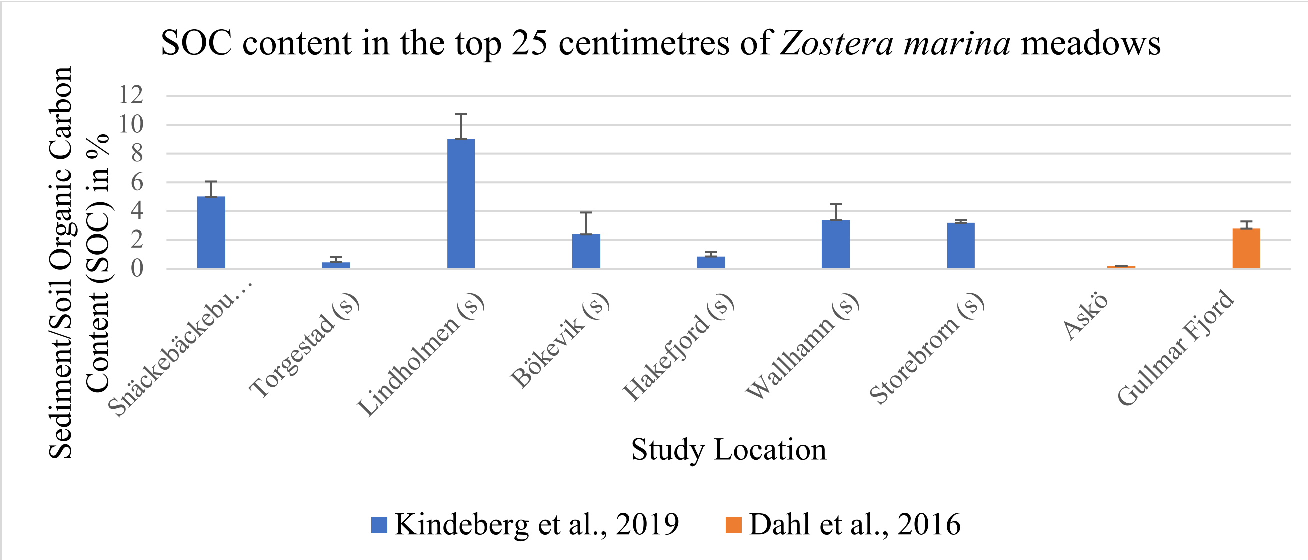


Figure 11: **Sediment organic carbon content in the top 25 centimetres in *Zostera marina* meadows based on data from two relevant studies in Sweden.** *Shallow (s): < 2.5 meter.*

The data in *Figure 10* and *Figure 11* depicts variation in sedimentary organic carbon content in *Zostera marina* meadows among different locations from four selected studies of the literature search; all four studies focused on the SOC content of the sediment below *Zostera marina* meadows. It is important to note that the sampling depth of the reported SOC content of the sediment or soil differs between the different studies and that the data has not been extrapolated to similar depths (*Figures 10 and 11*). Comparatively high is the SOC content in the top five centimetres of sediment at Rixö (SOC: 25 ± 5 %; Jephson et al., 2008). The study by Kindeberg and colleagues provides an extensive dataset on particulate organic carbon concentration of the first 25 centimetres (or even deeper in some locations, with a maximum of 37 centimetres depth) of sediment in *Zostera marina* meadows (Kindeberg et al., 2019).

3.4.3 Origin of Organic Carbon in *Zostera marina* Meadows

Two studies have analysed the stable isotope δ13C composition to determine the origin of the organic matter in the blue carbon habitats (Kindeberg et al., 2019; Visch et al., 2020) and one study has analysed the stable isotope composition in regard to the trophic structure in the sampled ecosystem (Jephson et al., 2008). By finding differences in accessibility of carbon in locations of different exposure level near Tjärnö, the study by Visch et al. (2020) concluded that there is a reduced access to organic carbon in more sheltered locations. The differences found in the stable isotope analysis of the blades of kelp were -23 ± 0.5‰ (dry weight per mille) for exposed locations to -21 ± 0.2‰ for sheltered locations (Visch et al., 2020). Isotope characteristics of δ13C between -20‰ to -10‰ are typically originating in organic matter derived from algae which can be seagrass associated (autochthonous organic carbon) and characteristics between -24‰ and -18‰ are typical for allochthonous organic carbon (Miyajima & Hamaguchi, 2019). Ratios from -12‰ to -5‰ are associated with sources from seagrasses, typically live or dead seagrass tissue of autochthonous organic carbon (Miyajima & Hamaguchi, 2019). By analysing the stable isotope composition to assess the contribution to POC in *Zostera marina* meadows, the study by Kindeberg et al. (2019) relates δ13C profiles which have a high POC to a decreased input of autochthonous organic matter over time (Kindeberg et al., 2019). This would lead to a shift towards a higher input of macroalgae and may contribute to explain the vanishing seagrass meadows at the Swedish west coast (Kindeberg et al., 2019).

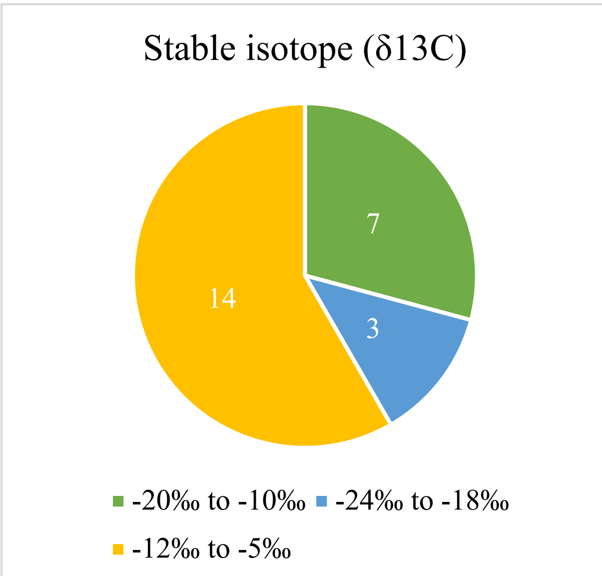


Figure 12: ***Stable isotopes reported in the publications.*** *Visch et al. (2020), three values, and Kindeberg et al. (2019), seven values for the sedimentary isotope composition and fourteen values for plant leaves and roots of seagrass.*

3.6 Results of Methane Emissions in Coastal Vegetated Ecosystems

No study concerning methane emissions from coastal vegetated ecosystems was found in the structured literature review. While the search string produced several publications about methane emissions, the absolute majority did not match the specific scope of this study as they concerned terrestrial mires or peatlands. Therefore, based on the focus and scope of this thesis, no results concerning either methane emissions from coastal vegetated ecosystems or coastal terrestrial mires were found. The results for methane will be further discussed in the discussion section 4.4.

3.7 Grey Literature Results

The Nordic Blue Carbon project (Nordisk Ministerråd og Nordisk Råd, 2021), funded by the Nordic Council of Ministers, sets out to create an inventory about blue carbon ecosystems, address knowledge gaps and provide a knowledge basis for blue carbon systems in the Nordic countries. The focus of the project is on the Norwegian carbon assets, but Danish, Swedish and Finnish data is presented as well. The report of the Nordic Blue Carbon project (Frigstad et al., 2020) is based on data from the responsible national environmental organisations and then modelled to show the spatial distribution and estimate carbon assets. The results do not distinguish between the Nordic countries, which leads to focus issues of this report. However, the estimates made in the report are important, so some of the key findings of the report which are presenting carbon assets were selected. The report concludes that, based on the contributed data by the different countries, which is processed by the model, that in the Nordic blue carbon ecosystems up to 3.9 million tonnes of carbon dioxide are stored (Frigstad et al., 2020). They found that spatially the largest contributing ecosystem in the Nordic countries are kelp forests (69%) followed by rockweed beds (19%) and seagrass meadows (12%) (Frigstad et al., 2020). The report does not only focus on a greater scope geographically by covering four countries but also covering a greater scope extending into the ocean down to deeper depths.

4. Discussion

Through the compilation of data on Swedish blue carbon habitats, both gaps in data and knowledge became visible, and highlights a need for future research. The systematic literature review in the current study clearly shows large gaps in knowledge concerning Swedish blue carbon assets, therefore, no estimation of the full potential of Sweden's blue carbon ecosystems can be made based on this data. Data concerning the carbon assets is too scarce and too limited spatially and geographically to attempt an estimation of the total stored blue carbon assets.

4.1 Literature

The relevant literature, determined through the systematic literature review, showed a variety in terms of types of studies among the different studies. This variation could be explained by multiple reasons; for example, the search string may have been too broad and created noise in the search results, the inclusion and exclusion criteria may have been too broad or the topic might be a too narrow one so only few publications are available. The decision to include some studies even though the focus of these was too broad was due to the scarcity of data for parts of the selected topic. For instance, the study by Jansson and Nohrstedt (2001) includes the whole area of Stockholm County without distinguishing between terrestrial coastal and terrestrial non-coastal environments; it is, however, the only study that is indicting Swedish coastal wetlands as potential carbon sinks. Furthermore, the only study that concerns methane emissions related to blue carbon habitats is the study by Nilsson et al. (2001), showing the distribution of mires across Sweden. The focus of this study is broad and does not allow for a differentiation between terrestrial coastal and non-coastal environments (further discussed in section 4.4). The third study with a broad focus is the one by Haamer (1996), which evaluates the improvement of water quality through mussel farming in a fjord ecosystem.

4.2 Geographical Distribution

The geographical distribution of the data in Sweden (presented in *Figure 5*) indicates there is a clear lack of data concerning blue carbon or coastal carbon sink research in the Gulf of Bothnia. Most of the data found is accumulated at the coasts of Skagerrak, Kattegat and the Baltic Sea.

In general, the geographical distribution of the compiled data from Swedish coastal waters shows two data hotspots, one in the Gullmar Fjord on the west coast (58°15′N, 11°26′E) and one at Askö on the east coast (58°82′N, 17°65′E). At both locations marine research stations run by Swedish universities are located; the Kristineberg Marine Research station managed by the University of Gothenburg at the west coast (University of Gothenburg, 2021) and the Askö Laboratory which is part of the Stockholm University Baltic Sea Centre on the east coast (58°49.5'N, 17°39'E (Stockholms Universitet, 2020)). The data hotspots may be explained by the close proximity to the research stations and likely there are many other unexplored areas in the surrounding coastline that may function as hotspots for data considered in this study. A third major Swedish marine research station situated close to Koster marine national park, near the Norwegian border, is Tjärnö Marine Laboratory, which is also run by the University of Gothenburg (2021). A lack of studies on blue carbon from this area raises the question why there is not more research found about the coastal vegetated ecosystems in Koster national park close to the Tjärnö research station, as it is located at Swedens most species rich marine area. The only study found for the area around Tjärnö was the one by Visch et al. (2020) about potential locations for kelp aquaculture.

The current research from Swedish environments does not cover the majority of the coastal vegetated blue carbon ecosystems and there is a geographical bias towards a few areas. An extensive data set can be found in the databank of the Swedish Meteorological and Hydrological Institute, SMHI (2020). The datasets from SMHI cover long-term monitoring and specific surveys of Swedish seagrass meadows and other macrophyte habitats and include all types of relevant detailed data such as sampling location, areal cover, plant shoot length and plant biomass, etc. (SMHI, 2020). The databank SHARKweb hosted by SMHI is used to archive all types of important environmental data, of which spatial distribution of seagrass meadows is part; such spatial data is primarily caught in monitoring efforts and therefore not seen in research studies such as the literature from this review. Another conservation-oriented project also compiling a great deal of the spatial extent of Swedish seagrass meadows is the citizen science project SeagrassSpotter (Project Seagrass, 2021). The project aims to inspire citizens to engage in research about seagrass meadows and educate about this vulnerable ecosystem (Project Seagrass, 2021). On the website of SeagrassSpotter (Project Seagrass, 2021), maps indicating locations of seagrass meadows, including pictures of the seagrass species, can be found. There is, however, no indication visible of the extent or health of seagrass meadows nor any data regarding meadows' carbon storage potential. For this reason, the outcome of the SeagrassSpotter project was not included in the result section. It is, however, important to mention the great number of seagrass meadows along the Swedish coastline presented from this and other sources.

4.3 Carbon Assets

The compiled data on carbon assets in the different marine carbon pools shows knowledge gaps as the availability of comparable data is scarce. Therefore, it is difficult to determine which area is the most productive in trapping and storing carbon around the Swedish coasts. From the limited data found, the most productive area in terms of aboveground seagrass biomass is at Askö on the Swedish east coast (south of Stockholm). At the Swedish west coast, Gåsö, which is located just outside of the Gullmar Fjord, is the seagrass site with highest productivity of those reported in the literature. For belowground seagrass biomass, the highest levels are reported from the deeper part (about 4-meter depth) of a seagrass meadow near Kristineberg marine research station in the Gullmar Fjord. The highest amount of sedimentary carbon was found in the deeper part (about 4-meter depth) of a seagrass meadow at Tommekilen outside Lysekil on the west coast. The findings show that there is generally higher levels of sedimentary carbon in seagrass meadows at the Swedish west coast than at the east coast (Dahl, et al., 2016). Variation in sedimentary carbon storage suggests a strong influence of site-specific abiotic factors.

The availability of data is of high importance when managing coastal areas and the clear gaps in existing relevant data show that there is a great need for future research and monitoring efforts. Of particular importance is future research and reliable data collection and production concerning the distribution of shallow-water habitats along the coast. In addition, more data concerning coastal vegetated blue carbon ecosystems are needed; mainly reliable data on habitat building species such as macrophytes, kelp and rockweed would increase the knowledge of carbon assets. Further assessments of adjacent ecosystems and coastal interfaces would improve the knowledge of connectivity in relation to marine carbon (Asplund et al., 2021). Another aspect for future research is the need for long-term, continuous data to be able to monitor and track changes in the ecosystems.

By comparing the findings of this review with global data, a first viewpoint is the claim for more research that is mirrored on a global scale. A starting point is the call for more research covering all coastal vegetated ecosystems, including mangroves, salt marshes, seagrass meadows, kelp forests, rockweed and macroalgae (Hori et al., 2019; Pendelton et al., 2012). Further, long-term continuous monitoring of shallow-water environment is necessary to detect trends and changes of the ecosystems.

Globally, the yearly stored carbon in seagrass meadows is estimated to be between 27.4 and 44 carbon Tg per year. This estimate is for the species *Posidonia oceanica* (Nellemann et al., 2009), which is the largest seagrass in the world, thereby likely building up the most carbon-rich seagrass sediment worldwide. Another study by Bridgham (2014) estimated an annual carbon storage of 18 Tg per year for seagrass meadows and a carbon storage rate of 101 g m^{-2} per year (Bridgham, 2014). Globally reported values of 180 g C m^{-2} for belowground plant biomass in seagrass meadows (Siikamäki et al., 2012) is high in comparison to the highest number (92 g C m^{-2}; Dahl et al., 2016) found for Swedish seagrass meadows. The reported global levels of 38.9 g C m^{-2} for seagrass SOC (Siikamäki et al., 2012) are close to the values reported for POC of seagrass by Kindeberg et al. (2019).

An estimation of the stored carbon for the Nordic countries has been done in a report produced by the Nordic blue carbon project. Projects like the Nordic blue carbon project are important projects for increasing knowledge in the field but also for cross border ambitions as ecosystems span further than national borders. The report shows estimates of 79 g C m^{-2} for living plant biomass (above- and belowground merged) for seagrass meadows, 300 g C m^{-2} for rockweed and 670 g C m^{-2} for kelp forests (Frigstad et al., 2020). Scaled up, the report gives estimates from the nordic countries (Norway excluded); 10,990 km^2 of kelp forest is estimated to have a living plant biomass of 7363 Gg C; 5,556 km^2 of rockweed to contain 1667 Gg C and 2,611 km^2 of seagrass meadows are estimated to contain 206 Gg C (Frigstad et al., 2020). Further, for seagrass meadows, the sedimentary carbon stocks were estimated to 6,789 Gg C (Frigstad et al., 2020). These estimates cover multiple countries, while the distribution of the habitats per country is not indicated. The estimated carbon stocks in living seagrass biomass per square meter for seagrass meadows is on average more than twice as high compared to the data found through the literature review (see *Table 3*). Projects like the Nordic blue carbon project call for more actions, such as further filling in the existing knowledge gaps as well as calling for enhancing the resilience of the coastal vegetated ecosystems. Unfortunately, the project does not differentiate between the Nordic countries except for Norway, being the initiator of the project, and therefore specific data for Swedish environments is not available in the report. The Nordic blue carbon project have estimated that 69% of the blue carbon ecosystems in the Nordic countries are from kelp forests (46 % by Norwegian kelp forests; Frigstad et al., 2020). This high contribution by kelp forests might partly depend on that a high number of studies have been performed in Norway, where kelp is common, and a lack of knowledge from other Nordic countries (which may have higher contribution from other habitats to the long-term storage of blue carbon). Nevertheless, the majority of the studies found in the search of this thesis concerned seagrass meadows.

4.2.1 Sampling Methods for Sedimentary Carbon Assets

The methods used for the sediment sampling on belowground carbon assets were similar in the different studies. A hollow steel tube, also known as a corer in any length and diameter, were used to take the sediment samples in *Zostera marina* meadows. The length of corers were reported to vary little, from 50 centimetre (Dahl et al., 2016) to 60-centimetre in length (Dahl et al., 2020b), while the core diameter ranged from 4.5 centimetre (Jephson et al., 2008) to 8 centimetre (Dahl et al., 2020a). A 35 x 35-centimetre box corer was used by Jephson et al. (2008). All sediment samples were dried, and in the majority of studies, analyses were carried out using a CN (carbon nutrient) analyser (Dahl et al., 2018; 2020a; 2020b). In the study by Jephson et al. (2008), the LOI method (loss on ignition) was used to determine the carbon content of the sampled sediment. The only study not indicating the method used is the study by Haamer (1996). The study by Haamer (1996) neither indicates the depth at which samples were taken to determine the SOC content, nor is information about the species in the ecosystem available. An improvement would be a more standardised sampling process of sedimentary carbon assets, which would increase the comparability of different data sets and any doubts of variation between studies coming from the use of different methods would be erased. As for the method, standardised sampling depth would increase comparability of data on not only a national but also on a global scale. Such standards would make worldwide data more comparable.

4.4 Methane

When coastal vegetated ecosystems are lost or degraded, they can turn into emitters of greenhouse gases, including methane (Duarte et al., 2013). There is research about coastal carbon sinks being contributors to atmospheric GHGs (Chmura et al., 2003; George et al., 2020; Lyimo et al., 2018; Oreska et al., 2020), but the field of research is not very widely spread and common. The potential emissions of methane from coastal vegetated ecosystems are part of the process and important to remember when talking about these ecosystems as natural climate mitigation options (Duarte et al., 2013; Oreska et al., 2020). For this reason, methane was included in the search string. The ability of degraded blue carbon habitats releasing methane to the atmosphere amplifies the need for policies to manage and protect coastal vegetated ecosystems (Oreska et al., 2020). For this thesis, two search terms, in the same search block as the terms for carbon, were included in the search string. There were a number of publications about methane emissions being released from ecosystems that are carbon sinks in Sweden. However, all of these articles were about terrestrial non-coastal ecosystems, especially about Swedish peatlands or mires and mainly in northern Sweden. The majority of the studies concerning methane emissions from peatlands have been about the Abisko Stordalen mire or the Degerö Stormyr mire (see for example: Granberg et al., 2001; Jackowicz-Korczyński et al., 2010; Robroek et al., 2014). This finding highlights the gap in knowledge and data for Swedish coastal vegetated ecosystems and their potential methane emissions. The gap of knowledge concerning methane emissions from coastal vegetated ecosystems in Sweden is line with the global findings, as scientific papers presenting emissions from coastal vegetated ecosystems are generally lacking and there is a need for measurements of CH_4 fluxes (Al-Haj & Fulweiler, 2020; Pendelton et al., 2012).

The search for studies on terrestrial coastal mires, including their possible methane emissions, resulted in only one relevant study (Nilsson et al., 2001). The study by Nilsson et al. (2001) provides an overview of Swedish mires and their methane emissions, the results are presented in the form of national maps. The scale and focus of that study, however, seems too wide to be able to differentiate between terrestrial coastal and terrestrial non-coastal mires. Due to the impossible differentiation of data the study becomes unusable for the scope of this review, while the study is relevant to illustrate maps of nationwide mires and their methane emissions.

4.5 Coastal Wetlands

Terrestrial coastal wetlands were included in the spatial scope of the search, although the result of the search showed that there was little or no data available on this blue carbon habitat. The data and publications found concerned terrestrial non-coastal wetlands, which were out of the spatial scope whether using the definition by NOAA fisheries (NOAA Fisheries, 2021). As pointed out earlier (section 3.1.3 and 4.1), the study by Jansson and Nohrstedt (2001) about natural carbon sinks in the Stockholm County, however, indicated no differentiation location wise between coastal and terrestrial wetlands. “The Swedish Wetland Survey” (Gunnarsson & Löfroth, 2014) is an extensive survey of Sweden’s terrestrial wetlands. The category of shore wetlands includes marine wetlands and characterizes them by being vegetated with salt resistant vegetation and either constantly or temporarily flooded (Gunnarsson & Löfroth, 2014). According to the report, there were 90 ha of marine submerged vegetation at eight sites (*Zostera marina*) and 49 coastal lagoons extending over an area of 400 ha (Gunnarsson & Löfroth, 2014). Furthermore, the report also addressed 185 coastal marsh sites covering 2,400 ha as well as 537 coastal wet meadows over 9,600 ha and 68 swamp forest sites (400 ha) (Gunnarsson & Löfroth, 2014). The finding that the focus of carbon storing wetlands in Sweden is on terrestrial mires or peatlands mirrors the finding on a global scale (Chmura et al., 2003). On a global scale, coastal wetlands as mangrove swamps and salt marshes account together for at least 44.6 Tg C yr^{-1} (Chmura et al., 2003).

4.6 Science-Policy Interface

Managing coastal vegetated ecosystems is important to maintain essential ecosystem services provided by these ecosystems. For creating knowledge based and data-driven management decisions, connections between policy on different levels and science are needed. On the global level, the Intergovernmental Panel on Climate Change (IPCC) is a global platform providing and creating rooms for discussion, exchange, information and interdisciplinary research. The Paris Agreement binds signatory states, like Sweden, to submit the Nationally Determined Contributions (NDCs) every five years (United Nations, 2015), which allows for adapted efforts towards conservation of ecosystems. Research and strategies are decided on a national, regional and local level. Policy-science interfaces would allow for coastal management and regional organisations to develop strategies for coastal areas to reduce pressures on vegetated coastal ecosystems based on knowledge, research and data. Environmental factors (biotic and abiotic) human pressures are commonly site-specific and therefore site-specific assessments and management plans are needed.

5. Conclusion

This systematic literature review highlights the geographical distribution and carbon assets of blue carbon systems in Sweden based on the currently available data. Through the compilation of data, strength and variability of carbon stocks in Swedish seagrass (*Zostera marina*) meadows was shown in relation to trophic interactions (Jephson et al., 2008), seasonal dynamics (Dahl et al., 2020a), hydrodynamics (Dahl et al., 2020b), sediment properties (Dahl et al. 2016) and other environmental factors. The influence of the various environmental factors is depicted in the carbon capacity of an ecosystem and reflected in the variability of the carbon assets at the different locations. Reported assets of other blue carbon systems, such as macroalgae, rockweed and kelp forests, are missing for Swedish coastal environments. Data from Swedish blue carbon systems is currently limited and the potential for carbon sequestration mostly an estimation based on site-specific knowledge. This emphasises the need for more data on carbon storage and sequestration in coastal vegetated marine and terrestrial ecosystems to understand the carbon sink function, carbon storage potential and climate change mitigation capacity of Swedish coastal blue carbon habitats. More available data on a regional and global level can provide a scientific base for policy decisions to further balance human development and thriving ecosystems in coastal areas.

Literature Cited

Agawin, N. & Duarte, C. (2002). Evidence of direct particle trapping by a tropical seagrass meadow. *Estuaries, 25*, 1205-1209.

Al-Haj, A. & Fulweiler, R. (2020). A synthesis of methane emissions from shallow vegetated coastal ecosystems. *Global Change Biology, 26*(5), 2988-3005.

Alongi, D. (2012). Carbon sequestration in mangrove forests. *Carbon Management, 3*(3), 313-322.

Asplund, M., Dahl, M., Ismail, R., Arias-Ortiz, A., Deyanova, D., Franco, J., et al. (2021). Dynamics and fate of blue carbon in a mangrove-seagrass seascape: influence of landscape configuration and land-use change. *Landscape Ecol*.

Avnimelech, Y., Ritvo, G., Meijer, L. & Kochba, M. (2001). Water content, organic carbon and dry bulk density in flooded sediments. *Aquac Eng, 25*, 25-33.

Baden, S. & Pihl, L. (1984). Abundance, biomass and production of mobile epibenthic fauna in *Zostera marina* (L.) meadows, western Sweden. *Ophelia, 23*, 65-90.

Baden, S., Gullström, M., Lundén, B., Pihl, L. & Rosenberg, R. (2003). Vanishing Seagrass (*Zostera marina*, L.) in Swedish Coastal Waters. *AMBIO*.

Barbier, E., Hacker, S., Kennedy, C., Koch, E., Stier, A. & Silliman, B. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monoographs, 81*(2), 169-193.

Beer, S., Björk, M. & Beardall, J. (2014). Mechanisms of Photosynthesis, and Carbon Acquisition in Marine Plants. In S. Beer, M. Björk & J. Beardall, *Photosynthesis in the Marine Environment.* Hoboken: John Wiley & Sons, Incorporated.

Bekkby, T. & Moy, F. (2011). Developing spatial models of sugar kelp (*Saccharina latissima*) potential distribution under natural conditions and areas of its disappearance in Skagerrak. *Estuarine, Coastal and Shelf Science, 95*, 477-483.

Belgrano, A. (2018). Biodiversity and Ecosystem Services in Nordic coastal ecosystems- an IPBES-like assessment. *1. General overview. TemaNord 2018:536*.

Bindoff, N., Cheung, W., Kairo, J., Arístegui, J., Guinder, V., Hallberg, R., et al. (2019). *Changing Ocean. Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* IPCC. [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]: In press.

Björk, M., Axelsson, L. & Beer, S. (2004). Why is *Ulva intestinalis* the only macroalga inhabiting isolated rockpools along the Swedish Atlantic coasta? *Marine Ecology Progress Series, 284*, 109-116.

Boström, C., Baden, S., Bockelmann, A., Dromph, K., Fredriksen, S. & Gustafsson, C.E. (2014). Distribution, Structure and Function of Nordic Eelgrass (*Zostera marina*) Ecosystems: Implications for Coastal Management. *Aquat Conserv Mar Freshw Ecosyst, 24*, 410-434.

Bridgham, S. (2014). Carbon dynamics and ecosystem processes. In D. Batzer, R. Sharitz, & S. Bridgham. *Ecology of freshwater and estuarine wetlands* (pp. 277-309). Berkley: University of California Press.

Bucholc, K., Szymczak-Żyła, M., Lubecki, L., Zamojska, A., Hapter, P., Tjernström, E. & Kowalewska, G. (2014). Nutrient content in macrophyta collected from southern Baltic Sea beaches in relation to eutrophication and biogas production. *Science of the Total Environment, 473-474*, 298-307.

Chmura, G., Anisfeld, S., Cahoon, D. & Lynch, J. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles, 17*(4).

Clarivate. (2021). *Web of Science*. Retrieved April 2021, from http://apps.webofknowledge.com.ezproxy.ub.gu.se/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=C6wE2oa8OqheokQGbye&preferencesSaved=

Cole, S. & Moksnes, P.-O. (2016). Valuing Multiple Eelgrass Ecosystem Services in Sweden: Fish Production and Uptake of Carbon and Nitrogen. *Frontiers in Marine Science*(2:121).

Dahl, M., Asplund, M., Björk, M., Deyanova, D., Infantes, E., Isaeus, M., et al. (2020). The influence of hydrodynamic exposure on carbon storage and nutrient retention in eelgrass (*Zostera marina* L.) meadows on the Swedish Skagerrak coast. *Scientific Reports, 10:13666*.

Dahl, M., Asplund, M., Deyanova, D., Franco, J., Koliji, A., Infantes, E., et al. (2020). High Seasonal Variability in Sediment Carbon Stocks of Cold-Temperate Seagrass Meadows. *Journal of Geophysical Research: Biogeosciences*(125).

Dahl, M., Deyanova, D., Gütschow, S., Asplund, M., Lyimo, L., Karamfilov, V., et al. (2016). Sediment Properties as Important Predictors of Carbon Storage in *Zostera marina* Meadows: A Comparison of Four European Areas. *PLoS ONE, 11*.

Dahl, M., Infantes, E., Clevesjö, R., Linderholm, H., Björk, M. & Gullström, M. (2018). Increased current flow enhances the risk of organic carbon loss from *Zostera marina* sediments: Insights from a flume experiment. *Limnology and Oceanography, 63*, 2793-2805.

de Coninck, H. E. (2018). Chapter 4: Strengthening and implementing the global response. In: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global. *In Press.*

Duarte, C. (1990). Seagrass nutrient content. *Mar Ecol Prog Ser, 67*, 201-207.

Duarte, C. & Krause-Jensen, D. (2017). Export from Seagrass Meadows Contributes to Marine Carbon Sequestration. *frontiers in Marine Science, 4:13*.

Duarte, C., Losada, I., Hendriks, I., Mazarrasa, I. & Marbà, N. (2013, November). The role of coastal plant communities for climate change mitigation and adaptation. *nature climate change, 3*.

Duarte, C., Marbà, N., Gacia, E., Fourqurean, J., Beggins, J., Barrón, C. & Apostolaki, E. (2010, December). Seagrass community metaboism: Assessing the carbon capacity of seagrass meadows. *Global Biogeochemical Cycles, 24*(4).

Elsevier B.V. (2021). *Scopus*. Retrieved April 2021, from https://www.scopus.com/home.uri

European Comission. (2020). *Update of the NDC of the European Union and its Member States.* Berlin: European Union.

eurostat. (2020). *eurostst Your key to European statistics*. Retrieved from GISCO: Geographical Information and Maps : https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

FAO. (2014). *The State of World Fisheries and Aquaculture.* Rome: Food and Agriculture Organization of the United Nations.

Fonseca, M. (1989). Sediment stabilization by *Halophila* decipiens in comparison to other seagrasses. *Estuar Coast Shelf Sci, 29*, 501-507.

Fourqurean, J., Duarte, C., Kennedy, H., Marbà, N., Holmer, M., Mateo, M., et al. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nat Geosci, 5*, 505-509.

Frigstad, H., Gundersen, H., Andersen, G., Borgersen, G., Kvile, K., Krause-Jensen, D., et al. (2020). *Blue Carbon- climate adaptation, CO_2 uptake and sequestration of carbon in Nordic blue forests.* Norwegian Environment Agency.

Gacia, E. & Duarte, C. (2001). Sediment retention by a Mediterranean *Posidonia oceanica* meadow: the balance between deposition and resuspension. *Estuar Coast Shelf Sci, 52*, 505-514.

Garpe, K. (2011). *Ecosystem Services provided by the Baltic Sea and Skagerrak.* Swedish Agency for Marine and Water Management.

George, R., Gullström, M., Mtolera, M., Lyimo, T. & Björk, M. (2020). Methane emissions and sulfide levels increase in tropical seagrass sediments during temperature stress: a mesocosm erxperiment. *Ecology and Evolution, 10*, 1917-1928.

Google. (2021). *Google Scholar*. Retrieved from https://scholar.google.com/

Gothenburg University. (2021). *Gothenburg University Library*. Retrieved from Supersearch: https://www.ub.gu.se/en

Granberg, G., Sundh, I., Svensson, B. & Nilsson, M. (2001). Effects of temperature, and nitrogen and sulfur deposition, on methane emission from a boreal mire. *Ecology*, 1982-1998.

Guiry, M. (2021). *The Seaweed Site: information on marine algae*. Retrieved April 2021, from *Saccharina latissima* (Linnaeus) J.V. Lamouroux: https://www.seaweed.ie/descriptions/Saccharina_latissima.php

Gullström, M., Baden, S. & Lindegarth, M. (2012). Spatial patterns and environmental correlates in leaf-associated epifaunal assemblages of temperate seagrass (*Zostera marina*) meadows. *Marine Biology*.

Gullström, M., Lyimo, L., Dahl, M., Samuelsson, G., Eggertsen, M., Anderberg, E., et al. (2018). Blue Carbon Storage in Tropical Seagrass Meadows Relates to Carbonate Stock Dynamics, Plant-Sediment Processes, and Landscape Context: Insights from the Western Indian Ocean. *Ecosystems, 21*, 551-566.

Gunnarsson, U. & Löfroth, M. (2014). *The Swedish Wetland Survey. Compiled Excerpts From The National Final Report.* Stockholm: Naturvårdsverket.

Haamer, J. (1996, August). Improving Water Quality in a Eutrophied Fjord System with Mussel Farming. *Ambio, 25*, 356-362.

Harley, C., Hughes, A., Hultgren, K., Miner, B., Sorte, C., Thornber, C., et al. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters, 9*(2), 228-241.

Heckwolf, M., Peterson, A., Jänes, H., Horne, P., Künne, J., Liversage, K., et al. (2021). From ecosystems to socio-economic benefits: A systematic review of coastal ecosystem services in the Baltic Sea. *Science of The Total Environment, 755*.

HELCOM. (2013). *HELCOM Red List Macrophytes Expert Group.*

Hendirks, I., Sintes, T., Bouma, T. & Duarte C.M. (2008). Experimental assessment and modeling evaluation of the effects of the seagrass Posidonia oceanica on flow and particle trapping. *Mar Ecol Prog Ser, 356*, 163-173.

Hendriks, I., Sintes, T., Bouma, T. & Duarte, C. (2008). Experimental assessment and modelin evaluation of the effects of the seagrass Posidonia oceanica on flow and particle trapping. *Mar Ecol Prog Ser, 356*, 163-173.

Herr, D. & Pidgeon, E. (2016). Coastal Blue Carbon Ecosystems. Opportunities for Nationally Determined Contributions. Policy Brief. *IUCN and Arlington*.

Herr, D., Pidgeon, E. & Laffoley, D. (2012). Blue Carbon, Policy Framework: Based on the Discussion of the International Blue, Carbon Policy Working Group. 39 pp.

Inoue, T. (2019). Carbon Sequestration in Mangroves. In T. Kuwae & M. Hori, *Blue Carbon in Shallow Coastal Ecosystems* (pp. 73-99). Singapore: Springer Nature Singapore Pte Ltd.

IPCC. (2019). *Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* IPCC, [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Jackowicz-Korczyński, M., Christensen, T., Bäckstrand, K., Crill, P., Friborg, T., Mastepanov, M. & Ström, L. (2010). Annual cycle of methane emission from a subarctic peatland. *Journal of Geophisical Research - Biogeosciences, 115*(G2).

Jackson, E., Langmead, O., Beaumont, N., Potts, T, & Hattam, C. (2012). *Seagrass Ecosystems Interactions with Social and Economic Systems.*

Jankowska, E., Michel, L., Zaborska, A., & Włodarska-Kowalczuk, M. (2016). Sediment carbon sink in low density temperate eelgrass meadows (Baltic Sea). *Journal of Geophysical Research: Biogeosciences, 121*, 1-17.

Jansson, Å. & Nohrstedt, P. (2001). Carbon sinks and human freshwater dependence in Stockholm County. *Ecological Economics, 39*, 361-370.

Jephson, T., Nyström, P., Moksnes, P.-O. & Baden, S. (2008). Trophic interactions in *Zostera marina* beds along the Swedish coast. *Marine Ecology Progress Series, 369*, 63-76.

Jesson, J., Matheson, L. & Lacey, F. (2011). Doing Your Literature Review. Traditional and Systematic Techniques. *Journal of Social Research & Policy*, 192 pp.

Kennedy, H., Beggins, J., Duarte, C., Fourqurean, J., Holmer, M., Marbà, N. & Middelburg, J. (2010). Seagrass sediments as a global carbon sink: isotopic constraints. *Glob Biogeochem Cycles, 24*, 1-8.

Kindeberg, T., Röhr, E., Moksnes, P.-O., Boström, C. & Holmer, M. (2019). *The Royal Society Publishing.* Retrieved from https://rs.figshare.com/articles/dataset/Raw_Data_from_Variation_of_carbon_contents_in_eelgrass_i_Zostera_marina_i_sediments_implied_from_depth_profiles/8262305?backTo=/collections/Supplementary_material_from_Variation_of_carbon_contents_in_eelgrass_i_Zos

Kindeberg, T., Röhr, E., Moksnes, P.-O., Boström, C. & Holmer, M. (2019). Variation of carbon contents in eelgrass (*Zostera marina*) sediments implied from depth profiles. *Biology Letters*(15).

Klenell, M., Snoeijs, P. & Pedersén, M. (2004). Active carbon uptake in *Laminaria digitata* and *L. saccharina* (*Phaeophyta*) is driven by a proton pump in the plasma membrane. *Hydrobiologia*(514), 41-53.

Krause-Jensen, D. & Duarte, C. (2016). Substantial role of macroalgae in marine carbon sequestration. *nature geoscience, 9*, 737-742.

Krause-Jensen, D., Lavery, P., Serrano, O., Marbà, N., Masque, P. & Duarte, C. (2018). Sequestration of macroalgae carbon: the elephant in the Blue Carbon room. *Biology Letters, 14*.

Krause-Jensen, D., Sejr, M., Bruhn, A., Rasmussen, M., Christensen, P., Hansen, J., et al. (2019). Deep penetration of kelps offshore along the west coast of Greenland. *Frontiers in Marine Science, 6*(375).

Kuawae, T., Bayne, C. & Hori, M. (2019). Blue Carbon: Characteristics of the Ocean's Sequestration and Storage Ability of Carbon Dioxide. In T. Kuwae & M. Hori, *Blue Carbon in Shallow Coastal Ecosystems* (pp. 1-33). Singapore: Springer Nature Singapore Pte Ltd.

Laffoley, D. D. & Grimsditch, G. (2009). The Management of Natural Coastal Carbon Sinks.

Lasserson, T., Thomas, J., & Higgins, J. (2021). Starting a review. In J. Higgins, J. Thomas, J. Chandler, M. Cumpston, T. Li, M. Page, & V. Welch, *Cochrane Handbook for Systematic Reviews of Interventions* (Vol. Version 6.2). Cochrane.

Lyimo, L., Gullström, M., Lyimo, T., Deyanova, D., Dahl, M., Hamisi, M., & Björk, M. (2018). Shading and simulated grazing increase the sulphide pool and methane emission in a tropical seagrass meadow. *Marine Pollution Bulletin, 134*, 89-93.

Möller, I. (2019). Applying Uncertain Science to Nature-Based Coastal Protection: Lessons from Shallow Wetland-Dominated Shores. *Frontiers in Environmental Science, 7*.

Mcleod, E., Chmura, G., Bouillon, S., Salm, R., Björk, M., Duarte, C., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Front Ecol Environ, 9*(10), 552-560.

Mendeley. (2020). Mendeley Reference Manager.

Miyajima, T. & Hamaguchi, M. (2019). Carbon Sequestration in Sediment as an Ecosystem Function of Seagrass Meadows. In T. Kuawe & M. Hori, *Blue Carbon in Shallow Coastal Ecosystems* (pp. 33-71). Singapore: Springer Nature Singapore Pte Ltd.

Miyajima, T., Hori, M., Hamaguchi, M., Shimabukuro, H. & Yoshida, G. (2017). Geophysical constraints for organic carbon sequestration capacity of *Zostera marina* seagrass meadows and surrounding habitats. *Limnol Oceanogr, 62*, 954-972.

Miyajima, T., Yamano, H., & Iizumi, H. (1998). Accumulation and transport of seagrass-derived organic matter in reef flat sediment of Green Island, Great Barrier Reef. *Mar Ecol Prog Ser, 175*, 251-259.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., et al. (2015). Preferred Reporting Items for Systematic Review and meta-Analysis Protocols (PRISMA-P). *Systematic Reviews*(4).

Naturvårdsverket. (2018). *Biodiversity and ecosystem services in Nordic coastal ecosystems - an IPBES-like assessment. Summary for policymakers.* Bromma: Swedish Enviornmental Protection Agency.

Nellemann, C., Corcoran, E., Duarte, C., Valde's, L. & De Young, C. E. (2009). *Blue carbon - The role of healthy oceans in binding carbon.* GRID-Arendal.

Nilsson, M., Mikkelä, C., Sundh, I., Granberg, G., Svensson, B.H. & Ranneby, B. (2001). Methane emissions from Swedish mires: National and regional budgets and dependence on mire vegetation. *Journal of Geophysical Research, 106*(18), 847-860.

NOAA Fisheries. (2021). *NOAA Fisheries*. Retrieved April 2021, from https://www.fisheries.noaa.gov/national/habitat-conservation/coastal-wetlands-too-valuable-lose

Nordisk Ministerråd og Nordisk Råd. (2021). *Nordic Blue Carbon*. Retrieved from https://nordicbluecarbon.no/

Nyqvist, A., André, C., Gullström, M., Pihl Baden, S. & Åberg, P. (2009). Dynamics of Seagrass Meadows on the Swedish Skagerrak Coast. *AMBIO, 38*(2), 85-88.

Omstedt, A. & Axell, L.B. (2003). Modeling the variations of salinity and temperature in the large Gulfs of the Baltic Sea. *Continental Shelf Research*, 265-294.

Oreska, M.P., McGlathery, K.J., Aoki, L.R., Berger, A.C., Berg, P. & Mullins, L. (2020). The greenhouse gas offset potential from seegras restoration. *Scientific Reports, 10:7325*.

Pendelton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S., et al. (2012). Estimating Global "Blue Carbon" Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLOS ONE*.

Postlethwaite, V., McGowan, A., Kohfeld, K. & Robinson, C. (2018). Low blue carbon storage in eelgrass (*Zostera marina*) meadows on the Pacific Coast of Canada. *PLOS one, 13*(6).

Project Seagrass. (2021). *SeagrassSpotter*. Retrieved May 2021, from https://seagrassspotter.org/

Röhr, M.E., Holmer, M., Baum, J.K., Björk, M., Boyer, K., Chin, D., et al. (2018). Blue Carbon Storage Capacity of Temperate Eelgrass (*Zostera marina*) Meadows. *Global Biogeochemical Cycles*, 1457-1475.

Rönnbäck, P., Kautsky, N., Pihl, L., Troell, M., Söderqvist, T. & Wennhage, H. (2007). Ecosystem Goods and Services from Swedish Coastal Habitats: Identification, Valuation, and Implications of Ecosystem Shifts. *Ambio, 36*(7), 534 ff.

Reynolds, P.L., Stachowicz, J.J., Hovel, K., Boström, C., Boyer, K., Cusson, M., et al. (2018). Latitude, temperature, and habitat complexity predict predation pressure in eelgrass beds across the Northern Hemisphere. *Ecology, 99*(1), 29-35.

Riemann, B., Carstensen, J., Dahl, K., Fossing, H., Hansen, J., Jakobsen, H., et al. (2016). Recovery of Danish coastal ecosystems after reductions in nutrient loading: a holistic ecosystem approach. *Estuaries and Coasts, 39*(1), 82-97.

Robroek, B., Generó, M.M., Wubs, J., Zajac, K., et al. (2014, June 30). Microclimatological consequences for plant and microbial composition in *Sphagnum*-dominated peatlands. *Boreal Environment Research, 19*, 195-208.

Schöpfel, J. (2010). *Towards a Prague Definition of Grey Literature. Twelfth International Conference on Grey Literature: Transparency in Grey Literature. Grey Tech Approaches to High Tech Issues.* Prague.

Siikamäki, J., Sanchirico, J., McLaughlin, D. & Morris, D. (2012). *Blue carbon: global options for reducing emissions from the degradation and development of coastal ecosystems.* Retrieved May 2021, from rff: https://media.rff.org/archive/files/sharepoint/WorkImages/Download/RFF-Rpt-2012-BlueCarbon_final_web.pdf

Smale, D., Burrows, M., Moore, P., O'Connor, N. & Hawkins, S. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. *Ecology and Evolution, 3*(11), 4016-4038.

SMHI. (2020). *SHARKweb*. Retrieved May 2021, from https://sharkweb.smhi.se/hamta-data/

Spalding, M.D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L.Z., Shepard, C.C. & Beck, M.W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management, 90*, 50-57.

Stockholms Universitet. (2020, March). *Baltic Sea Centre*. Retrieved April 2021, from Askö Laboratory - a centre for marine research: https://www.su.se/ostersjocentrum/english/ask%C3%B6-laboratory/about-the-field-station

Suess, E. (1973). Interaction of organic compounds with calcium carbonate - II. Organo-carbonate association in recent sediments. *Geochim Cosmochim Acta, 37*, 2435-2447.

Sundquist, E. (1985). Geological perspectives on carbon dioxide and the carbon cycle. In E. Sundquist & W. Broecker, *The carbon cycle and atmospheric CO_2: natural variations from archean to present.* (Vol. 32, pp. 5-59). American Geophysical Union.: Geophysical monograph series, .

Suzuki, A. & Kawahata, H. (2004). Reef water CO_2 system and carbon production of coral reefs: topographic control of system-level performance. In Shiyomi M. et al. (eds), *Global environmental change in the ocean and on land.* (pp. 229-248). Tokyo: TERRAPUB.

Swedish Environmental Protection Agency. (2018). *Sweden's Environmental Objectives - An Introduction.* Swedish Environmental Protection Agency.

Temmermann, S., Meire, P., Bouma, T., Herman, P., Ysebaert, T. & De Vriend, H. (2013). Ecosystem-based coastal defence in face of global change. *Nature, 504*, 79-83.

Tokoro, T., Watanabe, K., Tada, K. & Kuwae, T. (2019). Air-Water CO_2 Flux in Shallow Coastal Waters: Theory, Methods, and Empirical Studies. In T. Kuwae, & M. Hori, *Blue Carbon in Shallow Coastal Ecosystems* (pp. 153-184). Springer Nature Singapore Pte Ltd.

UMCES. (2021). *University of Maryland, Center for Environmental Science, Integration and Application Network*. Retrieved May 2021, from Media Library: https://ian.umces.edu/

UNEP. (2017). *The Emissions Gap Report.* Nairobi: United Nations Environment Programme.

United Nations. (2015). Paris Agreement. Paris: United Nations.

University of Gothenburg. (2021). *University of Gothenburg*. Retrieved April 2021, from Tjärnö Marine Laboratory: https://www.gu.se/en/tjarno

University of Gothenburg . (2021). *University of Gothenburg* . Retrieved from Kristineberg Marine Research Station : https://www.gu.se/en/kristineberg

Visch, W., Nylund, G. M. & Pavia, H. (2020). Growth and biofouling in kelp aquaculture (*Saccharina latissima*): the effect of location and wave exposure. *Journal of Applied Phycology, 32*, 3199-3209.

Wanninkhof, R. (1992). Relationship between wind-speed and gas-exchange over the ocean. *J Geophys Res, 97*, 7373-7382.

Ward , L., Kemp, W. & Boynton, W. (1984). The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. *Mar Geol, 59*, 85-103.

Watanabe, A., Kayanne, H., Hata, H., Kudo, S., Nozaki, K., Kato, K., et al. (2006). Analysis of the seawater CO_2 system in the barrier reef-lagoon system of Palau using total alkalinity-dissolved inorganic carbon diagrams. *Limnology and Oceanography, 51*(4), 1614-1628.

Waycott, M., Duarte, C.M., Carruthers, T.J., Orth, R.J., Dennison, W.C., Olyarnik, S., et al. (2009). Accelerating loss of seagrasses across the globe threatesn coastal ecosystems. *PNAS, 106*(30), 12377-12381.

Wijnbladh, E., Jönsson, B. & Kumblad, L. (2006). Marine Ecosystem Modeling Beyond the Box: Using GIS to Study Carbon Fluxes in a Coastal Ecosystem. *Ambio, 35*(8).

Appendix

I. *Table 1*: Data on belowground carbon stocks

Species	Location	N	Sediment depth in cm	% C org (SOC)	SD Organic C content	Soil org C stock (SOC) g C m^{-2}	SD Soil org C stock	TOC %	SD TOC	POC % plant biomass	POC % plant biomass SD	study ID	Comments
Zostera													
	Getevik (d)	18	0-25			3965	214					Dahl et al., 2020a	TOC
	Getevik (s)	18	0-25			3465	154					Dahl et al., 2020a	TOC
	Kristineberg (d)	18	0-25			2712	146					Dahl et al., 2020a	TOC
	Kristineberg (s)	18	0-25			1053	108					Dahl et al., 2020a	TOC
	Getevik (d)		0-25	10.3947		947.41568						Dahl et al., 2020b	
	Lindholmen (d)		0-25	8.9135		1815.355						Dahl et al., 2020b	
	Rixö (d)		0-25	6.6159		3152.9406						Dahl et al., 2020b	
	Sladholmen (d)		0-25	11.47395		1979.3647						Dahl et al., 2020b	
	Styrsvik (d)		0-25	5.5802		3018.5643						Dahl et al., 2020b	
	Tommelkilen (d)		0-25	3.8729		3334.4839						Dahl et al., 2020b	
	Kristineberg (d)		0-25	2.3111		1533.9194						Dahl et al., 2020b	
	Getevik (s)		0-25	11.2051		670.4141						Dahl et al., 2020b	
	Lindholmen (s)		0-25	7.9731		2479.9902						Dahl et al., 2020b	
	Rixö (s)		0-25	5.3317		3088.1402						Dahl et al., 2020b	

	Sladholmen (s)		0-25	3.042		2650.3874						Dahl et al., 2020b
	Styrsvik (s)		0-25	2.451		2438.3611						Dahl et al., 2020b
	Tommelkilen (s)		0-25	2.6092		2653.6337						Dahl et al., 2020b
	Kristineberg (s)		0-25	0.4417		554.0988						Dahl et al., 2020b
	Getevik (d)	18	0-25					9.7	0.1			Dahl et al., 2020a
	Getevik (s)	18	0-25					9.9	0.25			Dahl et al., 2020a
	Kristineberg (d)	18	0-25					2.2	0.18			Dahl et al., 2020a
	Kristineberg (s)	18	0-25					0.3	0.02			Dahl et al., 2020a
	Askö	18	0-25	0.2	0.1	533.3333	230.9401					Dahl et al., 2016
	Gullmar Fjord	12	0-25	2.85	2.192	3500	1555.6349					Dahl et al., 2016
	Bökevik (s)	2	0- 4-16	1.25	0.6363							Dahl et al., 2018
	Bökevik (d)	7	0- 4-16	1.5904	1.5904							Dahl et al., 2018
	Kristineberg (s)	2	0- 4-16	0.3	0							Dahl et al., 2018
	Kristineberg (d)	2	0- 4-16	1.45	0.0707							Dahl et al., 2018
	Hågarnsskären (d)	4	0- 4-16	1.875	1.808							Dahl et al., 2018
	Smalsund	1	0- 4-16	4								Dahl et al., 2018
	Kalvo-Borgile-Koljo fjord			6								Haamer, 1996
	Gåsö Island (s)	3	0-5	10.4	3							Jephson et al., 2008
	Lindholmen Island (s/d)	5	0-5	25.2	4.8							Jephson et al., 2008
	Fredshög (s&d)	4	0-5	0.7	0.3							Jephson et al., 2008
	Saxnäs (d)	4	0-5	0.7	0.2							Jephson et al., 2008

	Beijershamn (s&d)	5	0-5	3	0.7							Jephson et al., 2008	
	Snäckebäcke bukten (s)	15	0-25	5.00	1.06							Kindeberg et al., 2019	POC
	Torgestad (s)	15	0-25	0.46	0.34							Kindeberg et al., 2019	POC
	Lindholmen (s)	15	0-25	9.02	1.73							Kindeberg et al., 2019	POC
	Bökevik (s)	15	0-25	2.39	1.52							Kindeberg et al., 2019	POC
	Hakefjord (s)	15	0-25	0.85	0.31							Kindeberg et al., 2019	POC
	Wallhamn (s)	15	0-25	3.38	1.11							Kindeberg et al., 2019	POC
	Storebrorn (s)	15	0-25	3.18	0.21							Kindeberg et al., 2019	POC
	Snäckebäcke bukten (s)	3								35.59	1.06	Kindeberg et al., 2019	
	Torgestad (s)	3								36.37	2.17	Kindeberg et al., 2019	
	Lindholmen (s)	3								36.05	0.64	Kindeberg et al., 2019	
	Bökevik (s)	3								37.09	0.15	Kindeberg et al., 2019	
	Hakefjord (s)	3								36.94	1.12	Kindeberg et al., 2019	
	Wallhamn (s)	3								34.95	5.23	Kindeberg et al., 2019	
	Storebrorn (s)	3								27.04	20.15	Kindeberg et al., 2019	

II. *Table 2*: List of study locations

Location	Latitude DD	Longitude DD	Study ID
Kristineberg	58.2585617	11.38930778	Björk et al., 2004
Skåre, Trelleborg	55.37785108	13.05194545	Bucholc et al., 2014
Getevik	58.2738889	11.50527778	Dahl et al., 2020b
Sladholmen	58.34149163	11.36673103	Dahl et al., 2020b

Lindholmen	58.32323025	11.38055177	Dahl et al., 2020b
Kristineberg	58.2486111	11.44833333	Dahl et al., 2020b
Rixö	58.36930933	11.46156451	Dahl et al., 2020b
Styrsvik	58.39745758	11.38492551	Dahl et al., 2020b
Tommekilen	58.349324	11.449403	Dahl et al., 2020b
Getevik	58.2738889	11.50527778	Dahl et al., 2020a
Kristineberg	58.2486111	11.44833333	Dahl et al., 2020a
Askö	58.82882694	17.64496523	Dahl et al., 2016
Torö	58.8038889	17.79222222	Dahl et al., 2016
Torö	58.8058333	17.79194444	Dahl et al., 2016
Långskär	58.8	17.68	Dahl et al., 2016
Storsand	58.8072222	17.69444444	Dahl et al., 2016
Godahoppsudeen	58.8025	17.70666667	Dahl et al., 2016
Gullmar Fjord	58.25	11.43333333	Dahl et al., 2016
Finnsbo	58.2986111	11.49277778	Dahl et al., 2016
Kristineberg	58.2480556	11.4475	Dahl et al., 2016
Rödberget	58.2516667	11.465	Dahl et al., 2016
Bökevik	58.2666667	11.46666667	Dahl et al., 2018
Hågarnsskären	58.2666667	11.46666667	Dahl et al., 2018
Kristineberg	58.2666667	11.46666667	Dahl et al., 2018
Smalsund	58.2666667	11.46666667	Dahl et al., 2018
Kalvo-Borgile-Koljo Fjord	58.2373	11.571864	Haamer, 1996
Stockholm county	59.3333333	18.16666667	(Jansson & Nohrstedt, 2001)
Gåsö Island	58.23278093	11.40867607	Jephson et al., 2008
Lindholmen Island	58.32285445	11.38064004	Jephson et al., 2008
Fredshög	55.41801029	13.04846505	Jephson et al., 2008
Saxnäs	56.686754	16.476546	Jephson et al., 2008

Beijershamn	56.6034664	16.39676082	Jephson et al., 2008
Snäckebäckebukten	58.36	11.56	Kindeberg et al., 2019
Torgestadt	58.34	11.55	Kindeberg et al., 2019
Lindholmen	58.26	11.48	Kindeberg et al., 2019
Bökevik	58.25	11.45	Kindeberg et al., 2019
Hakefjord	58.04	11.8	Kindeberg et al., 2019
Wallhamn	58.01	11.71	Kindeberg et al., 2019
Storebrorn	57.89	11.66	Kindeberg et al., 2019
Tjärnö	58.87606839	11.15383387	Visch et al., 2020
Bornholmsfjärden	57.424888	16.656183	Wijnbladh et al., 2006
Eköfjärden	57.404428	16.65499	Wijnbladh et al., 2006
Talleskärsfjärden	57.387579	16.655517	Wijnbladh et al., 2006
Fläsköfjärden	57.39581	16.644594	Wijnbladh et al., 2006
Mjältnatefjärden	57.440373	16.681365	Wijnbladh et al., 2006
Sketuddsfjärden	57.43857413	16.6708415	Wijnbladh et al., 2006
Långvarpsfjärden	57.44914	16.690659	Wijnbladh et al., 2006
Hamnefjärden	57.43141	16.678013	Wijnbladh et al., 2006
Ävrö Coastal	57.421909	16.702074	Wijnbladh et al., 2006
Finngrundsfjärden	57.397875	16.668325	Wijnbladh et al., 2006
Granholmsfjärden	57.440453	16.642809	Wijnbladh et al., 2006
Kalvholmsfjärden	57.446931	16.673696	Wijnbladh et al., 2006
S Getbergsfjärden	57.434206	16.694371	Wijnbladh et al., 2006
N Getbergsfjärden	57.433807	16.687966	Wijnbladh et al., 2006
Djupesund	57.449197	16.685144	Wijnbladh et al., 2006
Y Kråkefjärden	57.453513	16.71523	Wijnbladh et al., 2006