CARBON OFFSETTING ? BLUE CARBON PROVIDES OPPORTUNITIES FOR THE DREDGING INDUSTRY

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Abstract: Coastal ecosystems with high carbon sequestration capacity disappear at a high rate, often causing the release of large amounts of stored carbon into the atmosphere.
This paper defines the different forms of carbon that play a role in the context of climate change. Of particular interest is 'blue carbon', which is the term used for carbon captured and stored by the oceans and the coastal ecosystems. The global carbon cycle and the role of carbon storage are summarised. This is necessary in order to understand the very significant role of blue carbon in climate change mitigation. The carbon storage capacity of coastal biotopes, (seagrass beds, mangrove forests, marshes, wetlands, etc.) is extremely high. The paper provides global scale estimates for the specific carbon uptake of each of these valuable biotopes, their loss rate during the past 50 years, as well as estimates for the areas remaining. Based on these data the paper warns against further loss of coastal ecosystems and pleads for habitat restoration where possible (United Nations Environment Programme).
The second part of the paper provides an estimate of the annual CO_2 emissions of the global dredging fleet and compares this figure with the area of coastal habitats necessary to sequester such an amount.
In the concluding section the paper explores the possible role of dredging-related activities in restoring coastal habitats in view of offsetting global CO_2 emissions of the dredging fleet.

Keywords: Blue Carbon, Coastal Ecosystems, Carbon Capture, Ecosystems Approach, Dredging

1. INTRODUCTION

Carbon is the 12th element in the Mendeleev periodic table but is THE element in chemistry typically associated with life (forms, structures and processes) on Earth. Carbon is essential to life because it is one of its building blocks and because it allows for the transfer of energy. Transfer of energy takes place through chemical reactions mirroring each other in either storing or releasing energy: in photosynthesis, chlorophyll-rich plants capture light from the sun and store it in carbon-rich organic compounds whereas in combustion the energy is liberated, releasing CO_2 (amongst other products).

Since the industrial revolution, carbon-based fossil fuels have been essential for our economic prosperity and human activities, but the burning of fossil fuels combined with deforestation have continuously released more greenhouse gases (GHGs) in the atmosphere and reduced the carbon capture capacities. Only with the development of nuclear power and the recently promoted solar and wind energy has the hegemony of carbon fossil fuels been broken. Nevertheless carbon still plays the major role in the energy transfers necessary for all human activities.

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The main reference for GHG and climate change knowledge and data is the Intergovernmental Panel on Climate Change (IPCC). In its Fourth Assessment Report (AR4) of 2007 the IPCC concluded that increased anthropogenic GHG concentrations are very likely to have caused most of the increase in global average temperatures since the mid-20th century.

Among the GHGs present in the atmosphere, including water vapour, methane and ozone, CO_2 is predominant and has been the focus of control and reduction by the policy makers around the world. Unsurprisingly, the CO_2 concentration is used as a reference for calculating the Global Warming Potential (including the other GHGs). As we will briefly describe in this paper, the majority of CO_2 in the atmosphere originates from natural processes.

Among the human activities, a major role is played by transport operations consuming vast amounts of energy and therefore identified as a main CO_2 emission source. Among the transport modes, shipping is the most environmentally friendly transport mode per ton km. Note however that CO_2 is the only GHG emitted in large quantities by maritime transport and that its contribution to the total anthropogenic CO_2 emissions is not negligible: around 3%. The dredging fleet emissions represent a small fraction of the total shipping emissions (0.6%). The paper investigates whether it is realistic for a sector like dredging to compensate for its CO_2 emissions by creating or restoring natural ‘carbon sinks’ in coastal zones.

The answer to this question requires a rudimentary understanding of the global carbon and CO_2 cycles including the particular role of coastal vegetation as carbon sink. This overview should help understand the importance of coastal ecosystems in the overall carbon cycle. The paper limits itself to the policy aspects of coastal ecosystems conservation, restoration and development in order to offset the CO_2 emissions from human activities such as dredging, without elaborating on other aspects of CO_2 in relation with climate change. It presents quantitative estimates of the carbon uptake and storage potential of specific biotopes viz. **salt marshes**, **mangrove forests** and **seagrass beds**. Clearly, the issues surrounding the global carbon cycle are very complex. Based on recent literature, the paper attempts to draw an up-to-date picture of the diverse carbon flows, their quantification of which is subject to debate as they include gradually decreasing, but still significant uncertainties.

2. THE COLOURFUL LANGUAGE SURROUNDING CO_2

The debate on climate change and its consequences has placed the role of CO_2 and of carbon cycles in the limelight. The combustion of fossil fuels produces carbon-dioxide (CO_2), a stable gas reaching the upper atmosphere and remaining there for decades. The consequent increase of atmospheric CO_2 concentrations has been identified by the IPCC as the prime cause for the recent changes in the global climate. Combustion of fossil fuels forms one aspect of this, but essential parts of the carbon cycles result from biological and other natural processes, including carbon capture and long-term carbon storage processes known as ‘carbon sequestration’. The latter occurs in some biotopes of the oceans and the coastal zones and has been labelled by the UN as ‘**blue carbon**’ in reference to the seas and oceans where these processes take place.

Besides ‘blue’, the terminology on climate change and GHGs (Nelleman, 2009) includes many other colourful analogies:

For **carbon emissions**

Brown carbon: refers to the anthropogenic CO_2 emissions in gaseous form resulting from the combustion of fossil fuels usually released into the atmosphere for the purpose of electricity generation, heating, transport, industrial processes, etc.

Black carbon: is composed of particles resulting from incomplete combustion processes or impure composition of fuel, such as soot and dust (e.g. coal fuelled power stations, Heavy Fuel Oil burning by ships). These carbon particles have not oxidised and contribute to climate effects by changing the heat absorption characteristics (particularly noticeable in Polar Regions).

For **carbon capture and sequestration**

Green carbon: carbon removed by photosynthesis and stored in plant biomass and soils in forest land, plantations, agricultural and pasture land. Green carbon is the feedstock for biofuel.

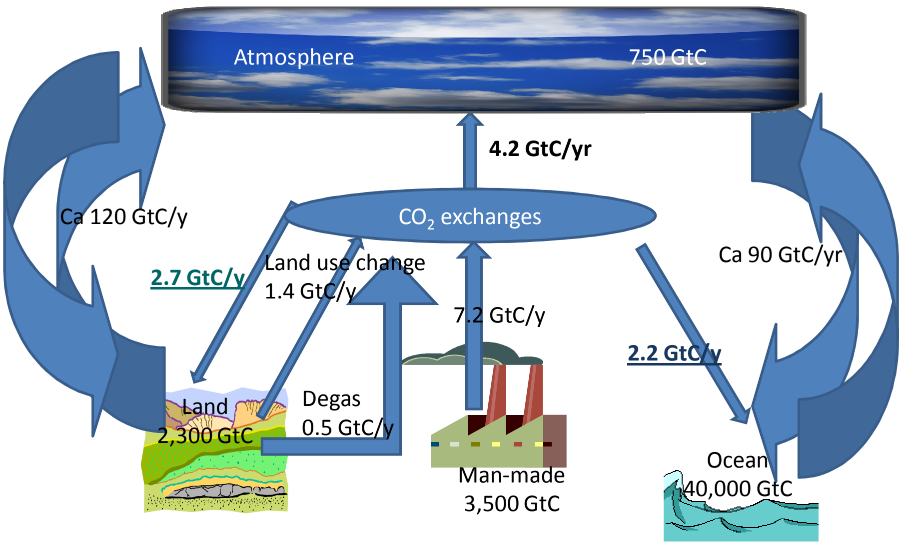
Blue carbon: similarly to green carbon, the carbon captured and stored by the world's oceans and coastal biotopes (mangroves, seagrasses, salt marshes, coral reefs, etc.) is named blue carbon.

The main significance of both green and blue carbons results from the capacity of their respective ecosystems to capture atmospheric CO_2 and to store the carbon for long periods of time: they are natural 'carbon sinks' with varying degrees of efficiency.

3. THE CARBON CYCLE

The global carbon cycle is composed of the aggregated carbon transfers between the atmosphere, the oceans, the land, the biomass and the human activities. Using the findings of IPCC (AR4, 2007), figure 1 presents an overview of the main carbon flows. This simplified representation, providing some aggregated data, can help put in perspective the relative contribution of blue carbon. There are many more specific sources and sinks of CO_2 on land and in the oceans and important differences between the various climate zones, which are not represented in the diagram.

Figure 1: Simplified global carbon cycle



Source: IPCC AR4 2007

The IPPC overall finding is that over half of the excess anthropogenic CO_2 remains in the atmosphere (causing increases in the CO_2 concentration), while the remainder returns to the biosphere and the oceans. This ratio has been fairly constant over the last few decades and, as a rule of thumb, one can consider that the landmass and ecosystems absorb roughly half of the net carbon uptake and the oceans and coastal shelves the other half[4]. The anthropogenic impact must be viewed against the background of large natural carbon cycles.

Another important finding is the essential distinction between long-term carbon storage and the short-term carbon uptake capacity. The uptake mechanisms function by binding of carbon through photosynthesis in plants and trees and by dissolving carbon-dioxides in the oceans. Long-term storage occurs only when the thus captured carbon is stored in the soil or sediments and to some extent in the deep ocean water mass.

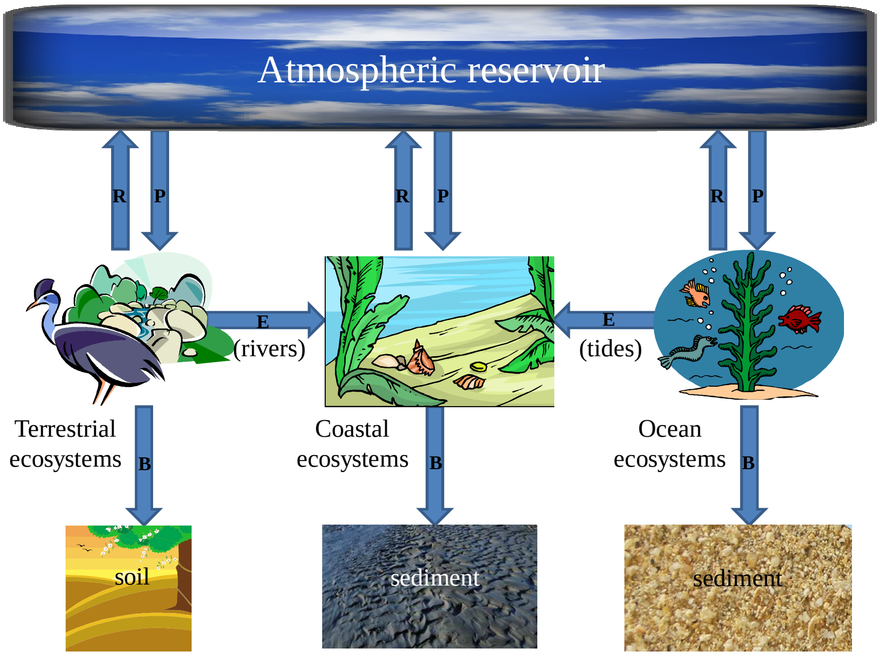
4. RELATIVE IMPORTANCE OF 'BLUE CARBON SINKS'

To provide an estimate of the relative contribution of blue carbon to the global carbon cycle, this section describes the carbon exchange mechanisms in coastal seas and the oceans.

The oceans take up carbon at a very slow pace by virtue of maintaining the equilibrium in CO_2 concentration with the atmosphere. Since the CO_2 concentration in the atmosphere is increasing, the oceans take up some of this carbon, which in turn leads to long-term acidification. Closer to land, the coastal ecosystems also capture more carbon than they emit, thanks to plants growth (mangroves, kelp forests, etc.). Several coastal biomes are effective filters for the carbon which flows into the coastal zone from rivers (sediments, nutrients) or from the oceans. Much of this excess carbon is stored in sediments along the coast. Figure 2 shows the general structure of the carbon cycles in the various zones.

[4] Remember that there are still major quantification uncertainties. It has nevertheless been found that the estimates of carbon flows by different methods tend to get closer and that uncertainty reduces (Dolman *et al.* 2010).

Figure 2: Conceptual diagram of the three major compartments of the biosphere that influence the global carbon cycle.



P= production, R= respiration; E= exchange; B= burial.

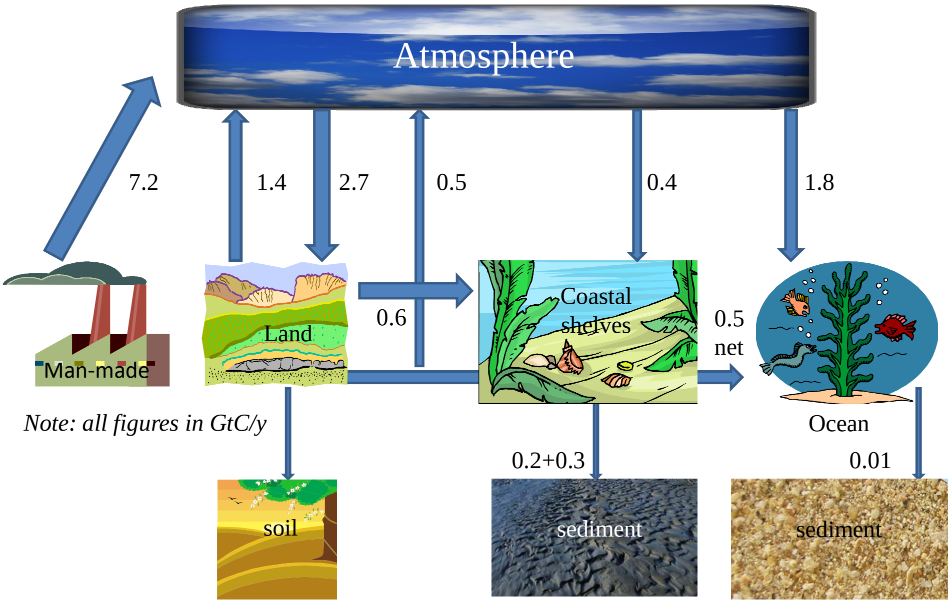
Source: Twilley, 1992

It is important to highlight which flows effectively contribute to the long-term carbon storage. The growth processes in the ecosystems are based on the uptake of nutrients and atmospheric CO_2 resulting in the **gross primary and secondary productions** (respectively plants and animal growth). Besides these, there are other mass flows that contribute to the total carbon balance. First there is the input of sediments and nutrients from the rivers and run-offs from the land mass, resulting typically in a small net export of sediments to the coastal zones. Then there will also be a significant amount of burial underneath the respective biotopes, consisting of organic detritus and sediments rich of organic carbon. The net result of the various processes constitutes the **net carbon uptake**.

The flows between the land mass, the coastal sea shelves and the oceans have been studied extensively. For a long time it was thought that the vegetation in the coastal zones was a net producer of CO_2. Only recently, since about 1990, have field measurements led to the conclusion that these blue ecosystems absorb a significant amount of inert and organic carbon. This question is treated in-depth in an overview of recent scientific literature and available data by Chen *et al.* (2009).

Figure 3 syntheses the findings of Chen *et al.* with slight adaptations. The detailed mechanisms of carbon flows in marine ecosystems are much more complex than can be shown in a mass balance at the global scale. There are important variations between coastal regions, between climate zones (tropical, subtropical, temperate, boreal) and between the different seas and oceans. The balance presented here reflects recent understanding: it highlights the relative importance of the coastal zones in carbon uptake. The CO_2 uptake by the coastal shelves represents up to 25% of the total uptake by the oceans, even though the surface is only 7% of the oceans.

Figure 3: Net CO_2 and Carbon flows in coastal shelves and oceans.



Source: adapted Chen et al. (2009)

When applying Chen's findings to coastal ecosystems, it appears that the most effective carbon sinks share some common features:

- they develop on **soft substrates** (sandy or muddy bottoms);
- they have a **large capacity to filter and retain sediments**;
- the bottom layers of sediments are anoxic, thus **avoiding the oxidation of the stored carbon** (which would produce CO_2).

These marine ecosystems include principally mangrove forests, salt marshes and seagrass meadows. They all fix, store and bury the carbon from excess production and in addition capture large quantities of river or marine sediments that are already rich in organic carbon. These carbon deposits constitute the essence of the contribution of 'blue carbon' to the global carbon cycle. Other biomes on coastal shelves (kelp forests, coral reefs) are less effective because they are situated on hard substrate and therefore do not capture sediments.

5. BRIEF DESCRIPTION OF THE MOST EFFECTIVE BLUE CARBON SINKS (LAFFOLEY, 2009)

Tidal Salt Marshes.

Salt marshes have probably the highest carbon sequestration contribution of all ecosystems. The primary production (essentially above and below ground growth of vascular plants) and the secondary production (fish, seafood) also lead to the release of some CO_2 by respiration. But the overall result is nevertheless a very high **net carbon sequestration rate**. Moreover, the carbon sequestration capacity remains effective, because the sediment layer that is rich in organic and inorganic carbon continues to increase. One may find carbon-rich sediment layers of 10 meters and more. This carbon is stored almost indefinitely and is not available for oxidation and release to the atmosphere.

Mangrove Forests.

Similarly, the mangrove forests have a high primary productivity (both the mangrove trees and the complex root system). The figure 4 below illustrates this: the mangrove forests have the highest carbon sequestration rates, but the surface area of the salt marshes is greater and therefore the absolute contribution of mangrove forests at the global scale is a bit lower (cf. table 5). The bulk of the carbon uptake takes place through the capture and burial of carbon-rich sediments and also via the net growth of biomass during the development stage. Mangrove forests are particularly productive in the tropical zones.

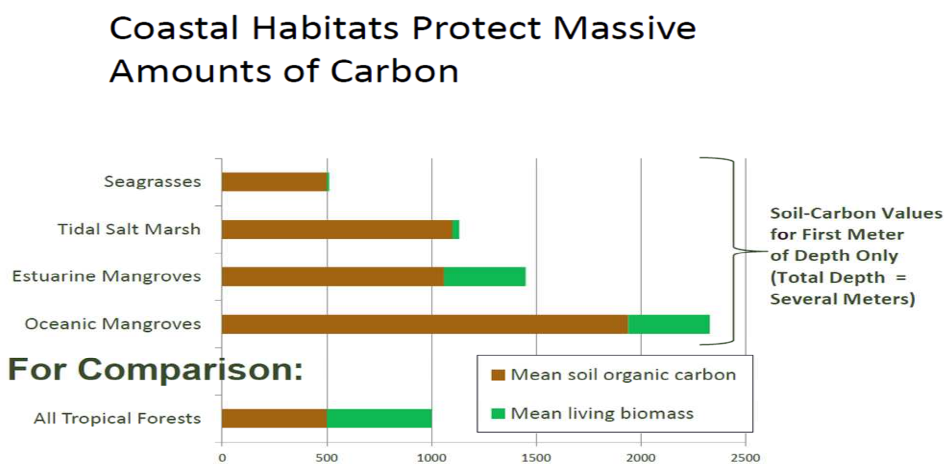
Seagrass Meadows

Seagrasses are marine flowering plants, occuring in many different varieties. Seagrass meadows are very productive ecosystems. The seagrass leaves degrade slowly and, through their roots and rhizomes, seagrasses deposit large amounts of carbon, part of which is mineralised. The growth and renewal of seagrass is relatively fast and therefore the amount of carbon stored in the living biomass is small (cf. figure 4 below). In addition, depending on the location and the specific marine environment, seagrass meadows capture also large amounts of sediments. Carbon-rich layers of more than 10 meters underneath seagrass beds are possible. The contribution of seagrass beds is more significant in the temperate climate zones.

Figure 4 presents the synthesis of these observations in the form of an overall comparison of the carbon pools in the different ecosystems under consideration. The carbon storage capacity of the tropical forests is presented for comparison (Sifleet, 2011). The data are provided as the specific contribution in tons of carbon per hectare. In order to better understand their contribution, it is important to distinguish between:

- Carbon stored in living biomass
- Carbon buried in the seabed in carbon-rich soil

Figure 4: Global averages for carbon stored (soil organic carbon in top layers and living biomass) in major coastal habitats (tropical forests included for comparison).



Source: Nicholas Institute for Environmental Protection, Research Report NI-R 11-04.

6. ABSOLUTE IMPORTANCE OF 'BLUE CARBON SINKS'

When combining the above-mentioned carbon capture rates and effective areas, one can appreciate the absolute significance of each of these ecosystems. The data in figure 4 cover the estimates of carbon stored on a global scale. These can be converted into global estimates for carbon pools per biotope by taking the surface area into account (see table 5). The rates represent the averages of mature ecosystems across many different climate zones. The storage capacity also depends on the thickness of the sediment layers, the size of which is quite uncertain. Finally the surface area still intact is a rough guess, in particular for the seagrass beds. The overall uncertainty associated with these values remains high, between 30%- 50%.

Table 5: Estimation of the annual carbon storage by the 3 'blue carbon' ecosystems

Biotope	Estimated surface M km²	Soil organic carbon gC/m²	Total GtC Stored	Living biomass gC/m²	Total GtC living
Seagrass	0.33 (0.6)	13,600	4.5	negligible	--
Saltmarsh	0.4 (0.8)	30,000	12.0	3,000	1.2
Mangroves	0.17 (0.3)	44,000 (avg)	7.5	13,000	2.2
TOTAL			**~ 24.0**		**~ 3.5**

Source: adapted Chen et al. (2009)

In table 6, two relevant rates of carbon capture are presented: the **total carbon uptake rate** (derived from the mass balance for the ecosystem) and the **burial rate** (representing the bulk of long-term carbon capture, using the depositions rates by Duarte *et al.*, 2005). The numbers are mean estimated values and the numbers in brackets are upper estimates. The estimates for the total carbon uptake (in the last column) have been scaled pro rata and are only presented here in order to develop a rough estimate of the carbon sequestration capacity of restored coastal habitats. The total carbon uptake rates combine the long-term carbon deposition via burial and the shorter term carbon binding in the biomass.

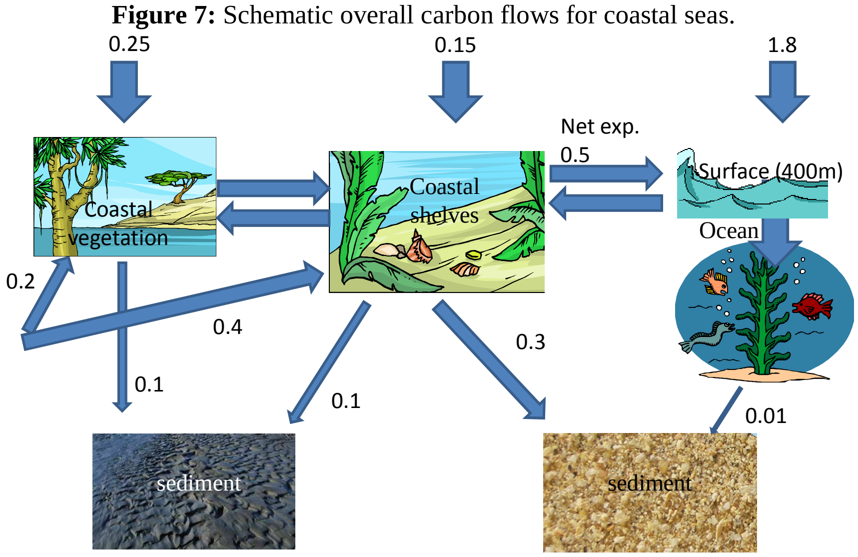
Table 6: Estimation of the CO_2 capture and carbon uptake rates by the 3 blue carbon ecosystems

Biotope	deposition rate (organic-rich sediments) g C/m²/yr	Estimated surface M km²	Total carbon burial rate Gt C/yr	Estimated total carbon uptake rates Gt C/yr	Estimated annual capture of atmospheric CO_2 per restored km^2 t CO_2-eq/km^2 /yr
Seagrass	83	0.33 (0.60)	0.027 (0.05)	0.060	700
Saltmarsh	151	0.40 (0.80)	0.060 (0.12)	0.140	1300
Mangroves	139	0.17 (0.30)	0.024 (0.04)	0.055	1200
TOTAL			**0.11 (0.21)**	**0.25**	

Source: adapted Chen et al. (2009)

Based on these estimates, the total global burial rate of organic carbon in the three coastal biotopes considered amounts to at least 0.11 Gt C/yr, with an upper bound of 0.21 Gt C/yr. The carbon balance (figure 7) assumes indeed 0.11Gt C/yr as final burial rate from coastal vegetation to sediments. The flows suggested by Chen have been reflected in the carbon balance of the coastal seas in figure 7. The resulting picture is an overall (atmospheric) carbon uptake rate for coastal vegetation of some **0.25 Gt C/yr or 0.92 Gt CO_2-eq/yr**. Details of the carbon exchange rate between the coastal vegetation and the shelf seas are not available though.

Figure 7: Schematic overall carbon flows for coastal seas.



Source: adapted Chen et al. (2009)

7. HOW COULD THIS BE RELEVANT TO THE DREDGING SECTOR?

From the discussion in this paper it has become apparent that salt marshes, mangrove forests, seagrass beds, but also coastal wetlands, peat marshes and estuaries play an essential role in balancing carbon flows. These coastal biotopes have been estimated to disappear globally at rates between 0.5 and 2.0% per year (Ten Brink, 2012). The total growth area that has disappeared at a global scale during the 20th century is estimated at some 50% for each of the three biotopes. With an approach such as Building with Nature (or Working with Nature), further degradation and loss of valuable coastal ecosystems could be reduced or avoided (by integrating nature into the project's design and thereby by better integrating the project in nature) and - if possible - even restoration or further development may be considered. Moreover it is essential to initiate programmes targeting the restoration of coastal marshland and mangrove forests around the world.

"*There are two primary mechanisms to reduce GHG emissions in a landscape with ongoing loss of coastal wetlands and near-shore marine ecosystems:*

1) *conserving historically sequestered pools of carbon; and*
2) *restoring and rebuilding degraded carbon pools.*

The rate at which carbon is lost from disturbed coastal wetlands is typically much greater than the rate at which it can be restored. Therefore, when planning to manage carbon stocks, it is more effective to prevent carbon-bearing soils from being disturbed than to begin a process of restoration." (Worldbank, 2011).

Conservation policies can be developed at different political levels. The initiatives can be generated at international level through focused programmes of measures and implemented at national or regional level. The details are beyond the scope of this paper. It is however within its scope to compare and to contrast the carbon sequestration capacity of these biotopes with the carbon emissions of the shipping fleet in general and the dredging fleet in particular.

The IMO has estimated that the world shipping fleet produces about 1.1 Gton of CO_2 per year (IMO 2009). This number is likely to increase further in the future according to the demand for seaborne trade. It should be appreciated that the contribution of the shipping fleet to the total CO_2 emissions caused by human activities is not negligible (roughly 2-3%). The world dredging fleet represents about 0.6% of the world shipping fleet in tonnage, and its emissions contribution is just above 0.6% as a consequence of the heavy work done by these vessels in addition to the transport. Within the European Dredging Association a CO_2 Working Group has studied these issues since a number of years in view of defining suitable policies to reduce the impact of emissions. Data have been collected for the annual consumption of fuel on board dredging vessels (Heavy Fuel Oil and Marine Gas Oil). The global emissions for the *fleet owned by EuDA members* for 2008/2011 is in the range of 3.2 – 3.4 million ton of CO_2 (0.001 Gt C/yr). The contribution of the global dredging fleet covering all vessels has been estimated at 7.7 Mton CO_2.

Different international measures to reduce CO_2 emissions are under consideration in the context of climate change policies. Measures for the global shipping fleet are being developed in particular within IMO, the International Maritime Organization. Technical and Operational Measures (Energy Efficiency Design Index and Ship Energy Efficiency Management Plan) have been approved (for 70% of the world tonnage) while Market-Based Measures, such as the international levy fund, are still discussed.

When all possibilities of reducing emissions have been exhausted or when the growth in global seaborne trade would more than compensate the reduction of emissions, another approach to the problem could be to increase the CO_2 capture from the atmosphere, by utilising either natural or man-made processes. In this paper, we have described the capacity and effectiveness of marine ecosystems in capturing CO_2. Therefore we will focus our conclusion on the creation, development or restoration of natural blue carbon sinks.

In the light of the data summarised above in the paper for the carbon sequestration capacity of coastal ecosystems and in view of the specific activities of the dredging sector in coastal zones, the following key question can be raised: **how realistic is it for the dredging fleet to compensate for its emissions ?**

One could think of the restoration and development of coastal biotopes that have been totally or partially lost in recent years. For the European-owned dredging fleet this would mean compensating for the emissions of about 0.001 Gt C/yr. In order to calculate the equivalent surface area that needs to be (re-)developed one needs the specific numbers for the rate of carbon uptake per biotope. These rates have been estimated above (table 6). With these carbon uptake rates the annual compensation areas for total emissions of the European dredging fleet (0.001 Gt C/yr) translate into:

- ✓ 2,700 km² of salt marshes; or
- ✓ 2,500 km² of mangrove forests; or
- ✓ 4,600 km² of seagrass beds; or
- ✓ combinations of these.

These estimates give ball-park figures only valid for mature ecosystems. Newly planted mangrove forests would take years before attaining their full potential of carbon sequestration.

Nevertheless, from these estimates, it is clear that CO_2 emissions offsetting can only be considered in cooperation between sectors, stakeholders and their respective governments. The complete compensation for its CO_2 emissions would be out of reach for the dredging sector on its own. Therefore sectors should consider spreading their efforts among each other and over time in a long-term sustainability strategy. Any significant offsetting, however, will only be possible if such a process would receive **clear political recognition and support** through Market Based Measures (e.g. exemption from or discounts in payment of CO_2 levies or taxes). In line with the Building with Nature philosophy, we have also touched upon the possibility for governments and coastal authorities to consider adding the development or restoration of salt marshes (inside Europe) and mangrove forest (outside Europe) when dealing with significant dredging projects. Moreover, one should realise that coastal ecosystems are not only important as carbon sinks: they also produce many valuable **ecosystem services** that are of great social and economic importance. This can make coastal ecosystem restoration projects economically feasible without charging a single sector with the costs. The dredging industry can play the role of blue carbon facilitator through the enhancement, restoration and development of coastal biotopes, but in order to be effective more research is needed.

8. CONCLUSIONS AND RECOMMENDATIONS

In this paper, we have demonstrated that

- "blue carbon" ecosystems play a significant role in the global carbon cycles and represent important carbon sinks;
- the coastal biotopes of salt marshes, mangrove forests and seagrass beds disappear at an alarming rate and their enhancement, restoration or development ought to be better integrated in the coastal development projects (using approaches such as Building with Nature);
- conservation, restoration and development of these ecosystems are not only important in relation with the carbon cycles, but also because it will enable them to keep on providing a range of valuable other services.

Policy makers should consider that

- the initiatives for restoration and re-building need to be co-ordinated at international level and implemented by national or regional authorities;
- from the above-mentioned estimates of CO_2 and carbon uptake rates, offsetting of (part of) the CO_2 emissions by the dredging fleet by restoring 'blue carbon' biotopes should be considered in cooperation with other sectors, stakeholders and national governments;
- this will require political recognition and support, as well as a fair way of risk sharing among parties involved;
- research activities that improve the understanding of the technical and ecological possibilities and limitations of, and the optimal conditions for, such ecosystem restoration programmes are needed;

- the dredging sector at large can and should play an important role in implementing programmes for the restoration and development of the blue carbon biotopes, but cannot solve this problem on its own.

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