SUSTAINABLE STRATEGIES FOR CARBON MANAGEMENT IN COASTAL ZONES-ROLE FOR THE DREDGING SECTOR

P. van der Klis[1], P. Sansoglou[2] and F.J. Mink[3]

ABSTRACT

The paper discusses the linkage between carbon release from dredging operations and carbon sequestration in mangrove forests, salt marshes and sea grass fields from three angles.

1. Coastal ecosystems like mangrove forests play an essential role in protecting the coastline from erosion. At the same time they provide a host of ecosystem services that are important for the local population. The paper discusses in particular the capacity to sequester carbon (CO_2- ‘blue carbon’). Recent insight into the regional variation in carbon uptake is reviewed.

2. The potential for carbon uptake is important in view of the climate change problem, which is driven a.o. by excessive CO_2 production. The dredging sector can play an essential role in responsible management of these carbon sinks. For instance by providing alternative solutions in coastal development projects that minimise damage or even loss of existing mangrove forest, salt marshes, etc. On the other hand dredging can play a role in the afforestation/reforestation of mangrove forests and restoration of excessive nutrient-enriched salt marshes and thus stimulate both the local economies and the carbon uptake.

3. Dredging operations require considerable quantities of fuel hence equivalent release of CO_2. Obligatory carbon offsetting schemes have not yet been imposed on the maritime sector. Nevertheless dredging companies are aware of the impact on the environment and their responsibility in this respect. The paper reflects on the viability of such a scheme. The development of a business case requires cooperation with stakeholders on issues like risk sharing and political recognition.

Keywords: Dredging, Blue Carbon, Carbon Offsetting, Carbon Management, Building with Nature.

INTRODUCTION

The role of blue carbon in coastal biotopes and the potential for the dredging industry to enhance their functioning, was presented in a paper at the dredging conference WODCON 2013 (van der Klis 2013). The term ‘blue carbon’, while not a common term, simply refers to the carbon captured by the world's ocean and coastal ecosystems, more specifically it refers to the carbon sequestration capacity of coastal biotopes (Sifleet (2011) for detailed concept and policy implications). The 2013 paper took a top-down approach to blue carbon in the context of the global carbon cycles. The data used in such a global overview are necessarily averages and a broad uncertainty range applies to these data. The 2013 paper emphasised the potential for the dredging industry to play an important role in the management of blue carbon biotopes. It did, however, not present further detail on the variability of carbon uptake of the various biotopes. The current paper builds on this earlier work, but approaches the subject from a bottom-up perspective. This provides more detail on regional variation and species variability.

Considering the potential for carbon uptake by blue carbon biotopes, the current paper briefly discusses possible project management options for the dredging industry to reduce carbon releases and maintain or increase atmospheric carbon sequestration as part of a broader carbon strategy.

[1] Chairman Environment Committee EuDA, Tel.: +31 888 260000, www.european-dredging.eu, pieter.vanderklis@vanoord.com,

[2] Secretary General, European Dredging Association, 148 avenue Grandchamp, Brussels, B-1150, Belgium, Tel.: +32 2 6468183, Fax: +32 2 6466063, paris.sansoglou@euda.be, www.european-dredging.eu.

[3] Advisor to the EuDA Environment Committee, erik.mink@bilbo-ms.be

COASTAL ECOSYSTEMS, ECOSYSTEM SERVICES AND BLUE CARBON

Carbon Uptake

Three coastal biotopes are considered: mangrove forests, saltmarshes and seagrass beds. All three are important for coastal protection and provide a wide range of ecosystem services. These biotopes are also characterised by their capacity to absorb and store large amounts of carbon ('blue carbon'). The capacity to absorb atmospheric CO_2 is important in the context of climate policy. Mangrove forests are discussed in more detail compared to the other biotopes for two reasons: more data are available on the carbon balance of mangroves and they provide a wider variety of ecosystem services. Mangrove forests in particular play also an important role in supporting local communities as well as in providing natural barriers of coastal protection. Table 1 lists ecosystem services typically provided by these biotopes.

Table 1. Ecosystem services provided by 'blue carbon' biotopes.

Ecosystem services	**Mangrove forests**	**Salt marshes**	**Seagrass beds**
Ecological:			
-erosion protection	**V**	**V**	**V**
-barrier saline intrusion	**V**	**V**	
-bird colonies	**V**	**V**	
-carbon sequestration	**V**	**V**	**V**
-water purification	**V**	**V**	**V**
Economic:			
-nursery for fish	**V**	**V**	**V**
- habitat fish	**V**		**V**
-grow seafood	**V**	**V**	**V**
-bees/honey	**V**		
-construction material	**V**		
-fire wood	**V**		
- potential for trading CO_2 emission rights	**V**	**V**	**(v)**
Social:			
-plants for medicine	**V**		
-support local community ('commons')	**V**		
-bird watching		**V**	
-ecological/underwater 'tourism'	**(v)**	**V**	**V**

V: Yes; (v): maybe.

All three biotopes have in common that they are net 'consumers' of carbon. Sources of carbon are CO_2 in the atmosphere or dissolved in the sea. The bulk of the carbon is taken in via photosynthesis; excess carbon is either sequestered in the soil in the form of organic or inorganic carbon, or it is fixed by the growth of biomass. This particular feature was reviewed in our 2013 paper, where the authors presented a quantification of carbon uptake on the basis of global averages. The data used in the 2013 paper (van der Klis 2013) are the following:

Table 2. Estimate of global carbon uptake rates.

Biotope	**Rate carbon burial (sequestration) gC/m²/yr (Mg/ha/yr)**	**Estimated carbon uptake in biomass gC/m²/yr (Mg/ha/yr)**	**Total rate gC/m²/yr (sequestration + net biomass) (Mg/ha/yr)**
Seagrass	83 (0.83)	107 (1.07)	190 (1.90)
Saltmarsh	151 (1.51)	204 (2.04)	355 (3.55)
Mangroves	139 (1.39)	188 (1.88)	327 (3.27)

In the current paper two important elements are being revisited in more detail: updated global data for the three biotopes, and specifically for mangroves, and the variability of carbon uptake in mangrove forests by geographical zones. The goal is to provide a quantitative basis for developing carbon absorption and offsetting strategies.

The concept of carbon sequestration and management of blue carbon biotopes is fully compatible and consistent with the broader framework of ecosystem-based management of coastal zones and marine habitat. Specific project design guidelines and practical guidance for project implementation have been developed under the framework of Building with Nature[4] but are outside the scope of the current paper.

Binding Carbon: Uptake And Sequestration In Mangroves

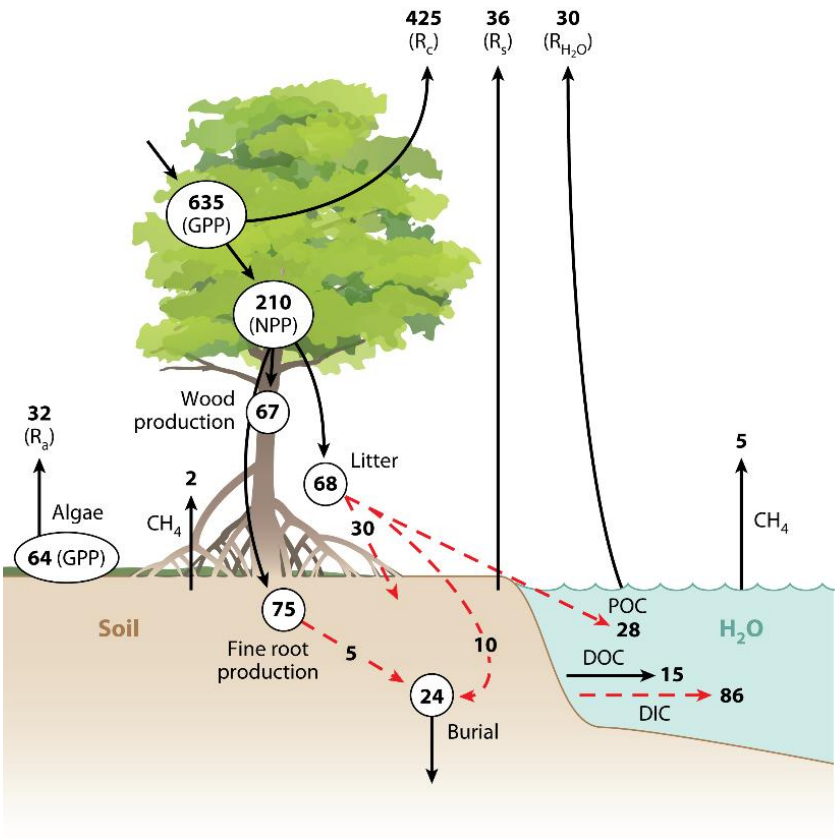
The question of carbon uptake and sequestration is complex. In order to grasp the issue, the case of mangrove forest is used as example. It is necessary to distinguish clearly between the carbon cycle associated with the growth of the trees, the formation of wood above ground, the extensive root system, the leaves and foliage (canopy) on the one hand, and the long term carbon storage in the form of sediment and organic material, captured by the root system (the net sequestration) on the other hand.

Existing mangrove forests stock enormous quantities of carbon in the soil. The process of accumulation can continue over many decades, even centuries, and the result is a layer of meters of soil enriched with carbon. These carbon layers are not exposed to oxygen and the carbon is thus isolated from the atmosphere.

The carbon cycle starts with the seeding of the mangrove trees. The carbon will initially produce growth: the mangroves develop an extensive root system, wood is formed and there is abundance of leaf growth (foliage, canopy).

D. Alongi (Alongi 2014) has compiled an extensive overview of the current knowledge on the carbon cycling and storage in mangrove forests. The review article synthesises a wealth of research on mangrove forests. Even though not all details of the carbon cycle are fully understood yet, enough data are available to construct an overall budget of the carbon flux through the mangrove ecosystem. Alongi has presented the results in his article in the form of a budget shown in Figure 1 where solid black arrows represent mean values based on numerous empirical data. Dashed red arrows represent either mean values estimated indirectly (by difference) or pathways suggested from the most recent literature. The budget assumes a global mangrove area of 138,000 km^2. The quantification in this budget is expressed in Tg C/yr and is done for the global averaged flows (estimates for total carbon flow through the mangrove forests around the globe). The abbreviations used in Figure 1 stand for: DIC, dissolved inorganic carbon; DOC, dissolved organic carbon; GPP, gross primary production; NPP, net primary production; POC, particulate organic carbon; R_a, algal respiration; R_c, canopy respiration; R_s, soil respiration; R_{H2O}, waterway respiration.

[4] Building with Nature is a partnership with Nature, integrating both physical and biological aspects of Nature into a project's design, EcoDynamic Design or Geo-Engineering (www.ecoshape.nl and www.vlaamsebaaien.com), and its implementation so that the project integrates more harmoniously and with less impact into Nature and preferably to Nature's benefits.



Alongi DM. 2014.
Annu. Rev. Mar. Sci. 6:195–219

Figure 1. Budget of the major pathways of carbon flow through the world's mangrove ecosystems (Alongi, D. M. (2014), Annual Review of Marine Sciences 2014/6 (p.195-219)).

There are still important uncertainties regarding the carbon budget: the estimate of the amount of carbon retained is the result of subtracting the total respiration from the gross primary production, while taking import and export into account. Moreover, the processes of photosynthesis and respiration are not constant, but vary with the time of the day. Nevertheless, in spite of large uncertainties, one can estimate the carbon flux and establish a carbon budget. In ecology the concept of net ecosystem production (NEP) has been defined as a first approximation to assess the carbon uptake. NEP represents the total amount of carbon that is retained in the mangrove ecosystem after all the respiration processes (canopy and secondary respiration) have been accounted for. One can argue that NEP is a measure for the total retention of carbon in the biotopes. It is, however, usually not yet equivalent to the net carbon storage in a particular ecosystem, because one also has to account for carbon import and export flows. When all this is done one finds the net ecosystem carbon budget (NECB) (Chapin, 2006). On the basis of the carbon budget in Figure 1 we have estimated a typical carbon budget as in Figure 2. The abbreviations used in Figure 2 stand for: GPP-gross primary production; NPP- net primary production; R_{can}- respiration of CO_2 via leafs; R_{sec}- respiration via secondary processes. The percentages referred to in Figure 2 give the estimate of carbon transported through the cycle. Our emphasis is on the carbon retained in the system, the net carbon uptake or net ecosystem carbon budget (NECB) which consists of two parts: one part of 4-5% is stored in long term (from several years to many decades) in roots and wood (biomass) and one other part of 3-4% is sequestered in the soil indefinitely (from decades to centuries). For ease of use the carbon flows are now expressed as percentages of the gross primary production. This assumes of course that the relative share of the carbon flow is constant throughout the cycle. Alongi (2014) presents the arguments for this assumption. It has indeed been found that the relative share of carbon flows is comparable between different climate zones and different species of mangroves, even though the magnitude varies significantly.

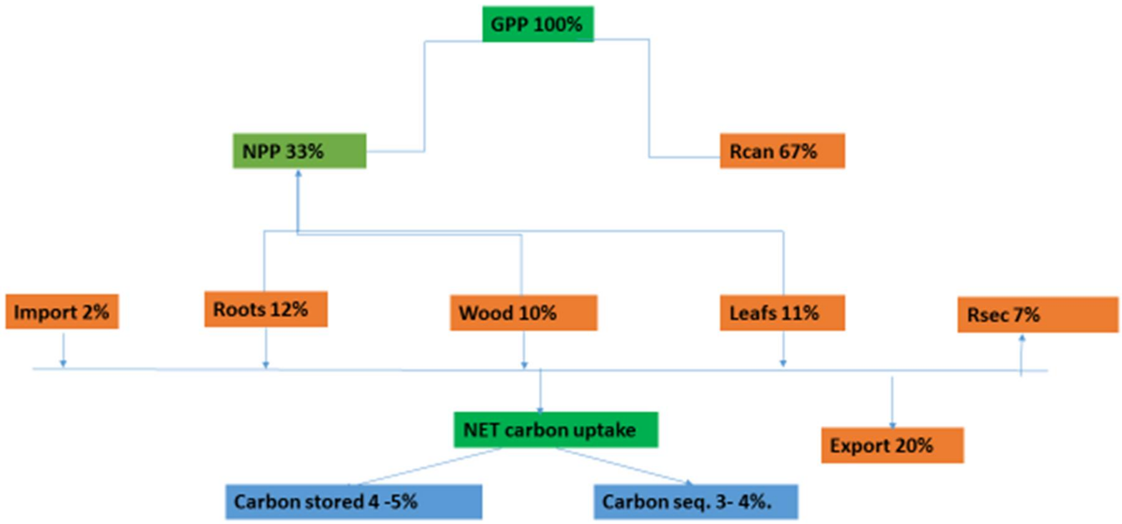


Figure 2. Simplified carbon cycle for mangrove forest.

Unfortunately the carbon budget for salt marsh and seagrass is not available with the same amount of detail. One can observe, however, that neither of these biotopes stores carbon in biomass for very long periods of time. The focus is in both cases on the carbon sequestration.

Carbon Uptake Revised

Murray et al. (Murray 2011) provide updated estimates for the global total living biomass in the three types of ecosystems under review; these data can be scaled to find approximate rates of carbon retention in biomass for salt marshes and seagrass (see Table 3).). The estimates for carbon uptake rates and available area have been refined in comparison to the data in Table 2 above. The data have largely been compiled by D. Alongi in a recent review paper (ref. Alongi 2014, Duarte 2005, Duarte 2010, Sifleet 2011). The range specified for the total uptake is a reflection of the variability by species and geographical region.

The carbon burial rates cited in this table have slightly increased compared to earlier estimates; the estimated net carbon uptake in the biomass (NECB) has been refined.

Table 3. Recent estimates of global carbon uptake rates.

Biotope	Rate carbon burial (sequestration) gC/m²/yr - (MgC/ha/yr)	Estimated net carbon retention in biomass gC/m²/yr – (MgC/ha/yr)	Total rate gC/m²/yr (MgC/ha/yr) (NECB)
Seagrass	140 +/- 40 (1.4+/-0.4)	1-10 (0.01-0.1)	100-180 (1.0-1.8)
Saltmarsh	220 +/- 25 (2.2+/-0.25)	10-30 (0.1-0.3)	210-270 (2.1-2.7)
Mangroves	175+/- 25 (1.75+/-0.25)	150-400 (1.5-4.0)	300-600 (3.0-6.0)

Variability In Carbon Uptake Of Mangrove Forests

The carbon uptake rates in Table 3 provide the range of values. The mangrove forests in particular show significant differences in characteristics and carbon uptake, depending on the type of mangrove, the climate zone where the mangrove forest is situated, the age of the forest and the management practices. This results in a variation in carbon uptake rates that must be taken into consideration when defining CO_2 management strategies.

There are about 50 types of mangroves in the world. Among these the mangrove forests in South-East Asia (Indonesia, Philippines) grow the largest trees and are very dense (high volume of biomass per unit area) (Hutchison, 2014). Hence the carbon uptake is more important here than in other geographical regions such as in Western Africa (Senegal, Côte d'Ivoire, …) or the Southern USA, where the mangrove forest is dominated by smaller species which develop less biomass per ha, thus resulting in a lower carbon burial rate.

Field data suggest that the distribution of carbon throughout the cycle (the percentages in the budget) is not changing materially from one species to another. In fact very similar ratios of carbon uptake have also been found for tropical forests, indicating that comparable processes take place in tropical forest as in mangrove forest (Alongi 2014).

The **carbon uptake** is a function of the total biomass, in this context expressed as $MgCO_2eq/ha$. Data are available for the range of biomass per unit area. For mangroves it varies between approximately 240 and 560 $MgCO_2eq/ha$ (65 – 150 MgC/ha/yr). Expressed as percentages, this equals a range of 60% - 140% relative to the average of 400 $MgCO_2eq/ha$ (Murray 2011). It can be assumed that the biomass per ha is proportional to the gross primary production (GPP) and thus also a fair indication for the variability in carbon uptake. Carbon sequestration has a weaker link with the biomass and is not proportional; other factors play a role as well.

The data from Table 3 have been used in combination with the range of biomass as summarised by Murray et al (2011). This leads to the simplified model in **Figure 3** of the variability in carbon uptake.

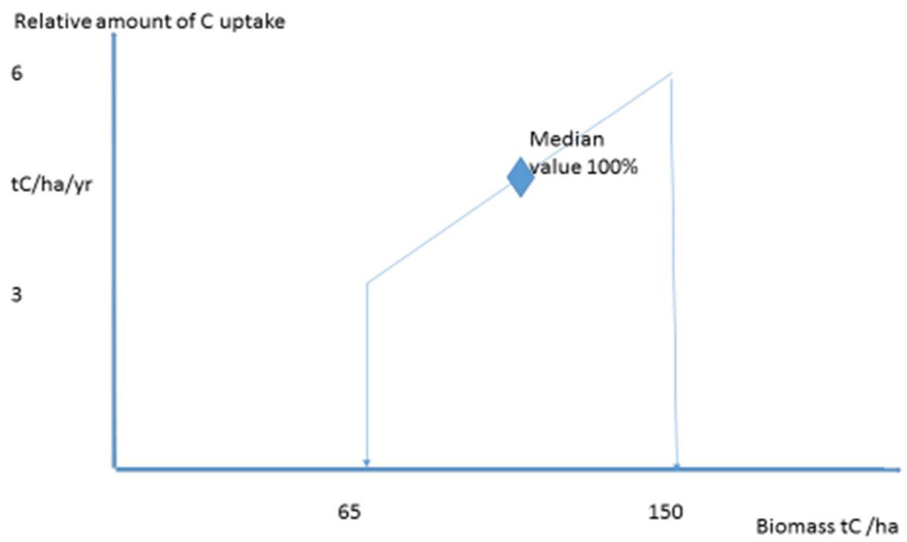


Figure 3. Net carbon uptake as a function of biomass. The biomass varies a.o. in function of latitude. The highest biomass per unit area is found in tropical zones.

A second important variable is **the age** of the mangrove forest. Especially in the case of reforestation projects, the initial carbon uptake is relatively low, but will gradually increase over a period of some 20 years before levelling off. This element needs to be taken into account when planning reforestation projects for mangroves. Individual mangrove trees have a lifetime up to 80 year. Mangrove forests, once replanted, renew themselves continually and can remain effective carbon sinks for centuries.

With the above data for carbon uptake and sequestration and their variability, one can assess (dredging) projects in terms of carbon uptake and carbon loss. Two case studies of how these data can be used are included in **Appendix I**. One case concerns optimisation of a dredging project in a mangrove forest environment and another case policy options for management of a coastline formed by saltmarshes.

ROLE OF DREDGING INDUSTRY IN THE MANAGEMENT OF COASTAL BIOTOPES

Mangrove and saltmarsh biotopes are of particular interest to the dredging industry as they combine coastal protection features with net carbon uptake. The coastal protection is realised by forming coastal barriers that absorb wave and tidal energy. Their net carbon absorption (blue carbon) plays a significant role in the global CO_2 budget.

Considering the importance of climate issues and in view of the capabilities of the industry, the priorities of mangrove and saltmarsh 'management' can be stated as follows:

- the first priority is to manage existing mangrove forests and protect them from further large scale destruction. The industry can contribute to prevent this destruction by proposing (alternative) project designs that avoid the destruction of existing habitats.

- secondly, carbon restoration options should be considered and integrated in the project design: rebuilding carbon storage 'capacity' by replanting of mangrove forest and restoring or creating saltmarshes where possible. Replanting mangroves on sites where old forests have grown before is certainly a good strategy: the sooner the better, as it should prevent the subsoil layers to be exposed to oxygen and thus prevent CO_2 release.

- the third strategy aims at providing (carbon uptake) compensation in cases where the removal of mangroves or saltmarshes cannot be avoided. This can be done by replanting mangroves in a nearby zone or by recreating salt marsh at a suitable location. It is nevertheless emphasised that it takes years before ‘new’ mangroves or saltmarshes have matured. A form of ‘overcompensation’ may be necessary in these cases.

Reduction And Compensation Of CO_2 Emissions

The review of carbon sequestration by blue carbon biotopes has been undertaken in view of climate policy developments. The dredging fleet, although small in comparison with the total maritime fleet, consumes a significant amount of fuel annually and thus produces considerable quantities of CO_2, the greenhouse gas (GHG) of concern. Statistics published by the European Dredging Association suggest that the European owned dredging fleet alone produces annually roughly between 2.8-3.4 million tons (Mg) of CO_2 per year (0.75-0.95 mill. MgC/yr) (EuDA, 2014). The release of GHG by the shipping sector is currently not regulated, but policy initiatives are underway that may change this situation (Conclusions of COP 21 under the Kyoto protocol, IMO, EU,….). In addition, corporate performance in the areas of environmental and social responsibility receives much attention. Several dredging companies are already publishing their efforts in the domain of corporate social responsibility (CSR). There is increasing pressure to seek reduction or compensation for CO_2 emissions from dredging operations.

Carbon Management Strategies

When dredging contractors seek to manage their CO_2 emissions one can distinguish between four different options. These are, however, not mutually exclusive and combinations are conceivable. The Table 4 summarises the options.

Table 4. Carbon Management options.

	Investment based	Operational
Strategy at company/project level	(1) Invest in fleet efficiency or alternative fuels	(2) Project-based: offset loss of mangroves/salt marsh/seagrass (replant).
Strategy/Policy at sector/intersector level	(3) Up-front investment in large plantations	(4) Carbon trading: buy CO_2 certificates to compensate for project or fleet emissions

Fleet Efficiency (1)

Modernising the fleet with efficient engines and upscaling the size of dredging vessels will result in lower CO_2 emissions per unit work done. The overall effect on emissions can be substantial, but significant emissions remain unavoidable as long as fuel from hydrocarbons is used. Alternative fuels are also under consideration. This management option is not discussed in detail in the current paper.

Projects With Compensation (2)

Many clients specify already the obligation to replace/restore/replant blue carbon biotopes for those projects where it is unavoidable to destroy such biotopes. Case studies are available for projects where coral has been replaced, mangroves replanted or saltmarshes recreated elsewhere. Two pilot projects are implemented by the ‘Building with Nature programme of The Netherlands: a mangrove restoration project in Indonesia and a saltmarsh creation project in The Netherlands (Ecoshape 2016).

This management option to provide compensation in the form of new habitat may ensure that no net loss of carbon uptake capacity takes place. As explained above for the case of mangrove re-planting, it will take years, even decades, before the carbon uptake capacity is back to previous levels; the project must be implemented on the basis of in-depth understanding of the issues.

Large-Scale Re-Planting (3)

This approach consists of planting or replanting large areas of mangroves in order to benefit during many years from the carbon sequestration capability of the plantation.

To be fair: there are several drawbacks to this approach. Firstly, the area required to compensate for the total European dredging fleet has been estimated at between 2,500 and 3,000 km² (Van der Klis 2013). In order to have access to such a large area for longer periods, one would need to cooperate at government level. Secondly, the carbon sequestration capacity develops slowly over the years, but is not 'operational' from the start. Thirdly, the cost will be very high and individual contractors will not be in a position to opt for this solution on their own.

Carbon Trading (4)

Formal mechanisms to pay for avoided emissions or enhancement of *blue carbon* isotopes do not yet exist, but some instruments are emerging. Under the Kyoto protocol (1997) developed nations were allowed to organise the trade in emission rights between themselves in order to meet the commitments to reduce CO_2 emissions.

For developing countries the 'clean development mechanism' (CDM) was created. This allowed the developing countries to voluntarily undertake GHG reduction projects and to generate marketable emission credits that can be sold to developed countries. The CDM defined a number of options. For tropical forests this included the so-called REDD+ (reduced emissions from deforestation and degradation) programme and the A/F action plan (afforestation/reforestation).

In order to organise the trade in emission rights, the market had to be structured. In the European Union this was realised via an emission trading system (ETS) for certified emission rights. The legislation defined the trading rules and should in principle result in a market price for CO_2 emissions. The ETS has not been a great success thus far for reasons that are beyond the scope of the paper.

In countries that did not sign the Kyoto protocol (e.g. USA), a number of regional trading systems have been developed. An example is provided by California (Bill 2006- started trading 2013).

Moreover, not all industry sectors are yet covered by the Kyoto protocol (aviation, maritime shipping, …). For sectors currently not covered by trading rules, carbon trading is possible on a voluntary basis. The Table 5 illustrates the current range of trading programmes. The range in carbon prices is indicative only.

Table 5. Overview of carbon trading mechanisms.

Carbon Market Programme	Regulatory/ Voluntary	Remarks	Range of carbon price (euro/MgCO_2)
Kyoto reduction goals (global)	Regulatory	Certified Emission Rights (CERs) can be used for compliance with Kyoto commitments	Approx. 20
EU- ETS (regional)	Regulatory	EU market mechanism to comply with Kyoto (cap and trade) (industry, power generation, ...)	8 - 25
Regional Initiatives (ex. California,…)	Regulatory	Regulatory initiatives (cap and trade)	8-12
Voluntary Carbon Offsets	Voluntary	Companies, individuals, events, buy emission certificates directly or via carbon traders	8-20

DREDGING AND CARBON OFFSETS

On balance it is found that a combination of management options appears to be realistic to achieve a net reduction in CO_2 emissions. Like any other CO_2 emitting industry, the dredging industry needs to establish a long term strategy at company/sector/intersector level to address the issue. The strategy could include mandatory or voluntary carbon trading schemes. Voluntary carbon markets do exist already, but the traded volume is still limited. A voluntary carbon market can certainly be structured on the basis of managing and replanting mangrove forests. There are also opportunities in various parts of the world to cooperate directly with regional mangrove restoration programmes. Case studies have been identified for regions in East-Africa (Gutman, 2003), (Jindal, 2008), West-Africa (Oceanium, 2015) and Vietnam (Vietnamnet, 2013) where mangrove forest restoration is practiced.

CONCLUSIONS

'Blue carbon' biotopes (such as mangrove forest, salt marsh and seagrass) feature important net carbon uptake properties. They play an essential role in carbon management strategies of coastal areas and should be considered and integrated in CO_2 emissions offsetting strategies industrial coastal sectors, such as dredging. Maritime sectors should join forces through intersectoral carbon management strategies to increase their impact on atmospheric carbon reduction, working on reducing emissions and increasing carbon sequestration.

The paper presents recent data on carbon uptake capacity with a focus on mangrove forests. These data provide a basis for assessing the 'carbon impact' of a project as demonstrated in the examples in the Appendix I.

It is imperative that further destruction of blue carbon biotopes be halted. Dredging contractors can play an important role in proposing alternative project solutions and in providing compensation for losses of such biotopes.

Accounting for the cost of carbon emissions ('internalising external costs') can lead to further optimisation of dredging projects, in particular those that impact mangrove forests and salt marshes.

The paper outlines the options for 'carbon management' that are available to dredging contractors. In order to adopt effective management strategies towards carbon neutrality, a combination of policy measures will be most effective. They cover operational aspects as well as investment decisions.

The paper sketches the possibility to participate in voluntary carbon offset markets. Voluntary compensation based on replanting of mangrove forest appears to be an attractive opportunity for the dredging sector.

The dredging industry would welcome the opportunity to support -and participate in- large scale restoration projects of blue carbon biotopes, and this in cooperation with major stakeholders (international development organisations, national or regional authorities, project developers).

APPENDIX I

In the following we illustrate the 'blue carbon' implication by discussing of two theoretical and simplified projects involving marine construction. These cases also demonstrate that, with the available carbon uptake data, the costs of carbon emissions can be taken into consideration in the decision process. Optimisation of project design highlights the importance of protecting carbon sinks and carbon stocks.

Case A.

Option I: A port is situated in an estuary, some 20 km upstream from the coastline. The waterway is on both sides bordered by extensive mangrove forest. The river meanders strongly between the port and the coast, thus making the navigational access difficult. The current navigational depth allows ships with a draught of 8m to enter port. The port authority has foreseen to construct a new direct access channel of 15 km length and a width of 150m in parallel to the river. It cuts through a mangrove forest. Depth of the channel at low tide would be 9m. The material that is to be dredged would be placed at sea. For this option some 15 million m^3 needs to be dredged and disposed of.

Option II: A contractor proposes an alternative solution by which the port entry via the river is maintained in part and can be deepened to 10 m over a stretch of 16 km; the access is completed by a shorter channel of 3 km length and 150 m width. In addition the contractor proposes to build an artificial island near the mouth of the estuary and use the material to be dredged from the channel as fill. As the dredged mangrove-material-rich soil is not sufficiently stable for construction a dyke or bund has to be constructed around the site to retain the material. The material from the river bed is sandy and suitable for construction of a dyke. Once completed, this island can be replanted with mangroves.

Table 6. Comparison of alternative projects for port development.

	Option I	Option II
Mangrove area removed	300 ha	60 ha
Volume of material to be dredged (river bed)	-	7,200,000 m³
Volume of material to be dredged (mangrove soil) m³	15,000,000 m³	3,000,000m³
Surface area artificial island (new mangrove plantation)	-	60 ha

For this, admittedly theoretical, project one can now estimate the impact on the carbon balance, calculated as carbon emissions, as well as in carbon uptake and stored carbon.

Direct emissions: for the dredging and disposing of some 15 million m³, a typical number for CO_2 emissions would be 2kg CO_2/m³ (this figure[5] is based on a smaller type dredger and a disposal location at an average distance of around 10nm). The total CO_2 emission resulting from the project equals 30,000 tCO_2 (+/- 8,200 MgC).

For Option II the figure is approximately 10,000 tCO_2 (2,730 MgC)

Carbon release and uptake from mangroves:

The port location is assumed to be somewhere in West-Africa and the corresponding rates for carbon in mangrove soil are:

- carbon uptake: 3.0 MgC/ha/yr (scaled from Table 3)
- carbon stored: 200 MgC/ha in top 1m (scaled from data in van der Klis 2013, Table 1).

It is assumed that only carbon stored in the top 1m will gradually be released when removed from its original location (half-life 5 yrs, a release of 100 tC/ha is postulated). There is more carbon stored in deeper layers, but in this project that material will in both cases be isolated from atmospheric exposure and the carbon will thus remain in the soil.

Table 7. Project comparison in view of climate policy.

	Option I	Eqv. carbon 'cost'	Option II	Eqv. carbon 'cost'	Difference in C 'cost' impact (euro)
Carbon emitted by dredgers	8,200 MgC	246,000	2,730 MgC	81,900	164,100
Carbon 'lost' (long term exposure to atmosphere)	30,000 MgC	900,000	6,000 MgC	180,000	720,000
Carbon uptake capacity removed	900 MgC/yr (300 ha)	27,000 euro/yr	180 Mg /yr (60 ha)	5,400	21,600
Carbon uptake capacity planted as compensation	-		(long term) 180 MgC/yr		(21,600)

[5] The number is based on confidential data administered by the European Dredging Association. The number provides an order of magnitude, but no precision is suggested here.

The carbon ‘costs’ are usually not accounted for in such projects as they are considered to be ‘external costs’. However, the relevance of the carbon flux and carbon storage can be illustrated by internalising these costs. We use a low carbon ‘price’ of 30 euro/MgC (equals +/-8 euro/tCO_2) (see Table 7).

The first conclusion is that dredging companies have the capability to contribute to sustainable management of the environment in sensitive coastal regions in a significant manner by optimising project design.

The second observation is that by internalising the external costs of carbon, the economic perspective of dredging projects changes, but the carbon costs remain small compared to the overall project costs.

The third observation is that in this example, in order to compensate for direct CO_2 emissions from the dredgers only, an area of at least 900 – 1,350 ha of mangrove forest needs to be replanted. This provides an indication of the scale of the task.

Case B.

A coastal region in Europe has a wide zone of salt marshes along the coastline. The saltmarsh is exposed to erosion and retreats annually with 4m over a length of 10 km, if nothing is done. This is considered as not being sustainable and a project is defined to construct an underwater berm at a distance of some 100 m in front of the coastline. The berm is designed to absorb most of the wave energy and thus reduce the erosion rate with 90%. Again one can compare the situation before and after constructing the berm.

The following data are used for carbon storage and uptake in salt marshes:

- carbon uptake rate: 250 gC/m² (2.5 MgC/ha) (the similarity with the mangrove data is incidental; the mangrove case was for a sub-tropical region with lower carbon rates. The salt marsh case is in a zone where the rates are relatively high. See data in Table 3).

- carbon stored in saltmarsh: 0.03 tC/m³. (half-life 5 yrs; we assume 0.015 tC/m³ lost)

Table 8. Comparison coastal retreat of salt marshes.

	do-nothing Option	Carbon ‘lost’	Berm protection Option	Carbon ‘lost’
Area lost per year	4 ha	10 MgC/yr as uptake rate	0.4 ha	1 MgC/yr as uptake rate
Volume lost per year	80,000 m³	1,200 MgC/yr	8,000 m³	120 MgC/yr

Again, when internalising the carbon costs, one remarks that in this example the carbon ‘lost’ is dominating. The assumption about which share of the carbon will be oxidised and released to the atmosphere is therefore critical. As there are no specific data available on this aspect, we assume that half of the amount of carbon stored will be oxidised. The carbon ‘cost’ of the eroding saltmarsh is then 36,000 euro/yr. These costs are obviously not sufficient to compensate for the cost of constructing an underwater berm. In practice many authorities opt for the retreating coastline in those cases where there is no infrastructure under threat. It is not to be assessed how CO_2 awareness and associated cost comparison would influence such decision.

REFERENCES

Alongi, D. M. (2014). “Carbon cycling and storage in mangrove forests” *Annual Review of Marine Sciences 2014/6* (p.195-219).

Chapin, F.S. and co-authors (2006). “Reconciling Carbon-cycle Concepts, Terminology and Methods.” *Ecosystems (2006) issue 6*, (p. 1041-1050).

Duarte, C., Middelburg, J., Caraco, N. (2005). “Major role of marine vegetation on the oceanic carbon cycle.” *Biogeosciences 2*, 1-8.

Duarte, C. et al. (2010). “Seagrass community metabolism: assessing the carbon sink capacity of seagrass meadows.” *Global Biogeochemical Cycles 24*.

Ecoshape (2016): www.ecoshape.nl

EuDA (2014). European Dredging Association Annual Report 2014 (www.european-dredging.eu).

Gutman, P. (ed.) (2003). “From Goodwill to Payments for Environmental Services: A Survey of Financing Options for Sustainable Natural Resource Management in Developing Countries.” *World Wide Fund for Nature (WWF) - 2003*.

Hutchison, J., Manica, A., Swetnam, R., Balmford, A., Spalding, M. (2014). “Predicting Global Patterns in Mangrove Forest Biomass” *Conservation Letters, vol. 7, Issue 3* (p. 233-240).

Jindal, R., Swallow, B., Kerr, J. (2008). “Forestry-based carbon sequestration projects in Africa: Potential benefits and challenges” *Natural Resources Forum 32 (2008),* 116–130.

Murray, B., Pendleton, L., Jenkins, W. A., Sifleet, S. (2011). “Green Payments for Blue Carbon: Economic Incentives for Protecting Threatened Coastal Habitats.” *Nicholas Institute Report R 11-04*.

(2015). *Oceanium*, http://www.oceaniumdakar.org/Le-reboisement-du-rhizophora.html?lang=en

Sifleet, S., Pendleton, L., Murray, B. (2011). “State of Science on Coastal Blue Carbon.” *Nicholas Institute Report R 11-06*.

van der Klis, P., Sansoglou, P., Mink, F.J. (2013). “Carbon Offsetting ? Blue Carbon provides Opportunities for the Dredging Industry.” *Proceedings World Dredging Conference XX, June 2013*.

Vietnamnet (2013): http://english.vietnamnet.vn/fms/special-reports/57987/revival-of-mangrove-forests.html