UNEP-WCMC Technical Briefing Note

October, 2018

Green and blue carbon

The role of habitats in mitigating carbon emissions. Linking biodiversity management and climate change mitigation.

Key messages

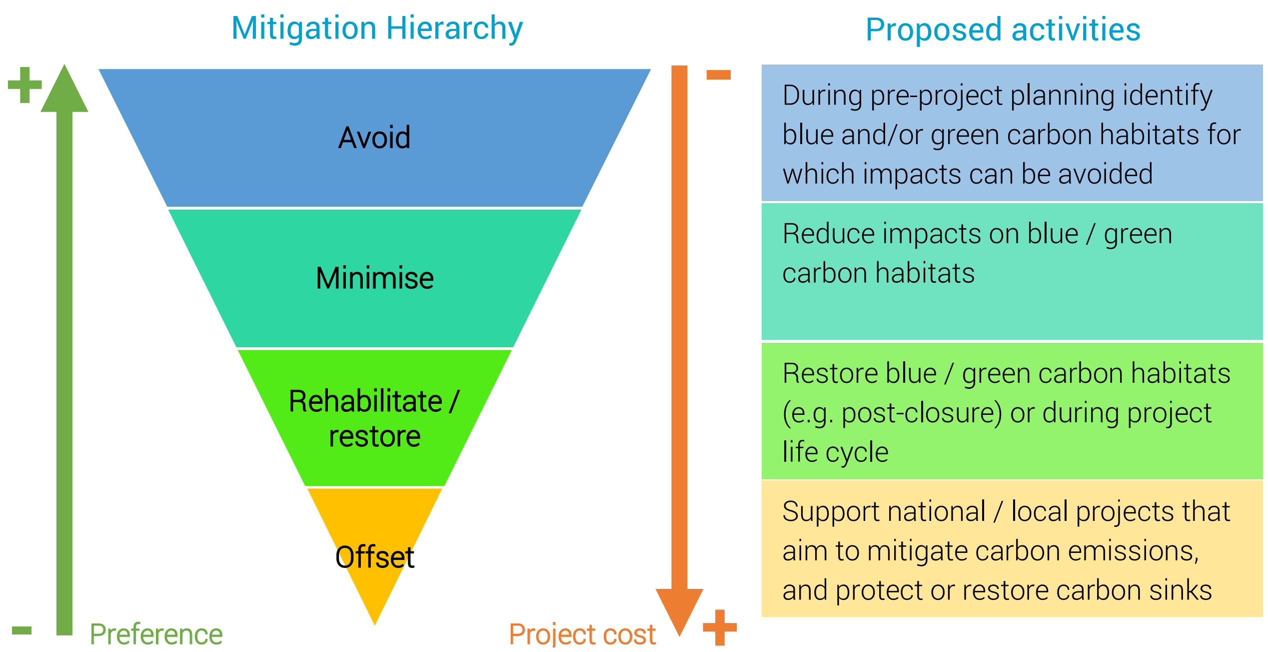
Climate change mitigation activities are essential for reaching global climate goals. Extractive industries, and the private sector more broadly, can play an important role in contributing to these goals.

Ecosystems in the terrestrial and marine realms have been recognised for their crucial roles in removing and storing carbon dioxide (CO_2) from the atmosphere. The health of biodiversity and ecosystems is closely linked to carbon sequestration and storage.

Ecosystem conservation, restoration and enhancement is embedded in the global carbon agenda, national emissions reduction strategies and actions plans, and the finance sector's investment standards. Some companies have successfully engaged with national climate change mitigation efforts, however activities have largely been limited to the agriculture and forestry sectors and relate mostly to carbon offsets or credits.

Important and intuitive links can be made between extractives companies' biodiversity impact mitigation practices and climate change mitigation. Developing management practices that conserve important biodiversity features, particularly in areas of high biodiversity, can contribute to effective ecosystem-based climate change mitigation.

Figure 1: Summary of potential activities that extractive companies can take to conserve green and blue carbon ecosystems along the steps of the mitigation hierarchy



Introduction

Reducing global greenhouse gas (GHG) emissions is a major focus of international climate change mitigation efforts (IPCC, 2014a). Global-scale action to address climate change and reduce CO_2 and other GHG emissions is coordinated under the United Nations Framework Convention on Climate Change (UNFCCC), which was formally established in 1992.

Most recently, the 2015 Paris Agreement, signed by 195 government Parties, set out clear and ambitious goals for countries to halt climate change to the extent possible, and adapt to its effects wherever necessary. The central objective is to maintain the increase in the global mean temperature to below 2°C compared to pre-industrial levels.

The private sector is recognized as key to achieving this objective. A number of actors have committed themselves to the direction set out by the Paris Agreement (e.g. Oil and Gas Climate Initiative, 2017). Reductions in GHG emissions at the necessary scale by any single sector, or company, will require efficiency improvements in all parts of the project life cycle, and the implementation of a broad range of mitigation strategies (Bourgouin, 2014).

This briefing note focusses on potential carbon gains associated with the conservation and enhancement of high carbon habitats by the extractive sector. It summarises the current state of knowledge on carbon sinks in both the terrestrial and marine realms (i.e. green and blue carbon, respectively), and provides an overview of key terms, datasets, tools and initiatives of relevance to extractive companies' decision making.

The briefing note additionally explores the linkages between biodiversity and climate change mitigation. Biodiversity plays an essential role in maintaining natural processes and ecosystem services, and consequently balancing the carbon cycle. Biodiversity management practices that mitigate negative impacts on green and blue carbon habitats may deliver multiple benefits, and contribute to effective ecosystem-based climate change mitigation.

Context

Impact of land use change on carbon emissions

Net carbon emissions from land use change and ecosystem degradation were estimated at one Gigatonne of carbon (1 Gt C) per year between 1980 and 2009 (Ciais *et al.*, 2013). This is the second largest source of CO_2 emissions after the burning of fossil fuels (Ciais *et al.*, 2013), representing approximately 10% of the total anthropogenic carbon emissions.

Achieving the 2°C global temperature target will therefore rely on effective planning and implementation of measures to protect carbon stocks, in addition to reducing current CO_2 emissions from human activities (e.g. through developing new technologies).

The global carbon agenda

The conservation and restoration of carbon stocks is firmly established as a global priority and integrated into conservation and sustainable development agendas (Box 1).

The conservation of carbon stocks is embedded across the Paris agreement, the 2030 Agenda for Sustainable Development, and the Strategic Plan for Biodiversity adopted under the Convention on Biological Diversity (CBD).

In 2020, the Parties to the CBD are expected to adopt a new Strategic Plan for Biodiversity for 2021-2030, in which carbon stocks are expected to retain an important position.

Box 1: Global framework supporting the conservation and restoration of carbon stocks.

The **2015 Paris Agreement** commits Parties to "conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases" and, more specifically, the UNFCCC's Article 4.1 (d) lists "biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems" as important habitats for carbon sequestration.

Aichi Target 15 of the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011-2020 focuses on climate change mitigation and adaptation by enhancing biodiversity's contribution to carbon stocks, and conserving and restoring degraded ecosystems.

Sustainable Development Goal (SDG) 13 on 'Climate Action' shows commitment from governments to take action on climate (e.g. through the Nationally Determined Contributions) and puts mechanisms in place to report progress on the reduction of atmospheric CO_2 levels.

Sustainable Development Goals 14 and 15 ('Life below water' and 'Life on land') engage national action plans to enhance conservation and sustainable use of ecosystems that are important reservoirs of sequestered CO_2 (i.e. sinks).

How are financial lenders responding?

Major financial institutions are also adapting their investment policies and standards to favour projects that demonstrate net reductions in atmospheric GHG emissions, and that protect or enhance existing carbon sinks. For example, the World Bank stopped funding new coal projects in 2010, and recently committed to ending its funding for upstream oil and gas projects after 2019. In May 2018 insurance and asset management company Allianz stopped insuring "single coal-fired power plants and coal mines in operation or planning". Other finance companies have made similar announcements.

The International Finance Corporation's Performance Standard 3 (IFC PS3) on 'Resource Efficiency and Pollution Prevention' requires clients to reduce project-related GHG emissions through options such as "alternative project locations, adoption of renewable or low carbon energy sources, sustainable agricultural, forestry and livestock management practices, the reduction of fugitive emissions and the reduction of gas flaring" (IFC, 2012a).

Furthermore, the IFC's Performance Standard 6 on 'Biodiversity Conservation and Sustainable Management of Living Natural Resources' requires its clients to avoid impacting on ecosystem services, including carbon storage and sequestration (IFC, 2012b).

What has the private sector done to date?

As a result of these drivers, proactive and forward-thinking companies are aligning to, and engaging with this agenda.

> **Box 2: Key definitions**
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> **Carbon sink**: Mechanisms or entities that remove CO_2 from the atmosphere, including vegetation and soils (IPCC 2014b; UNFCCC 2009)
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> **Carbon stock**: The quantity of carbon stored in a carbon pool at a specified time (REDD Desk n.d. a).
>
> **Carbon pool**: A system that has the capacity to store or release carbon. The Marrakesh Accords recognise five main carbon pools or reservoirs in forests: above-ground biomass, below-ground biomass, dead wood, litter and soil organic matter (REDD Desk n.d. b).
>
> **Carbon sequestration**: The removal of carbon from the atmosphere into carbon sinks through physical or biological processes, such as photosynthesis (REDD Desk n.d. c).
>
> **Green carbon**: Commonly refers to carbon that is contained in living vegetation and soil in forest ecosystems of the terrestrial realm (Mackey et al., 2008).
>
> **Blue carbon**: Carbon stored in coastal and marine ecosystems, such as mangroves, tidal marshes and seagrass meadows (Murray et al. 2011).

Major multinational companies in the agriculture and forestry industries are, in particular, engaging with national emissions reduction programmes that aim to prevent GHG emissions from deforestation and forest degradation. The Olam Group has, for instance, collaborated with the Republic of Congo to support the development and implementation of the government's emissions reductions strategy.

To date the private sector's activities relating to carbon have focused either on developing new technologies for low-carbon production processes, or on reducing direct emissions (Bourgouin, 2014; Climate Action Network, 2013).

Despite their significant potential to contribute to meeting the 2°C global target, carbon sinks have received limited attention outside of the forestry and agriculture industries. Where they have been addressed, most activities have centred on carbon credits as incentives to reduce GHG emissions (e.g. through national carbon tax models or the Voluntary Carbon Market).

Carbon sinks and sequestration

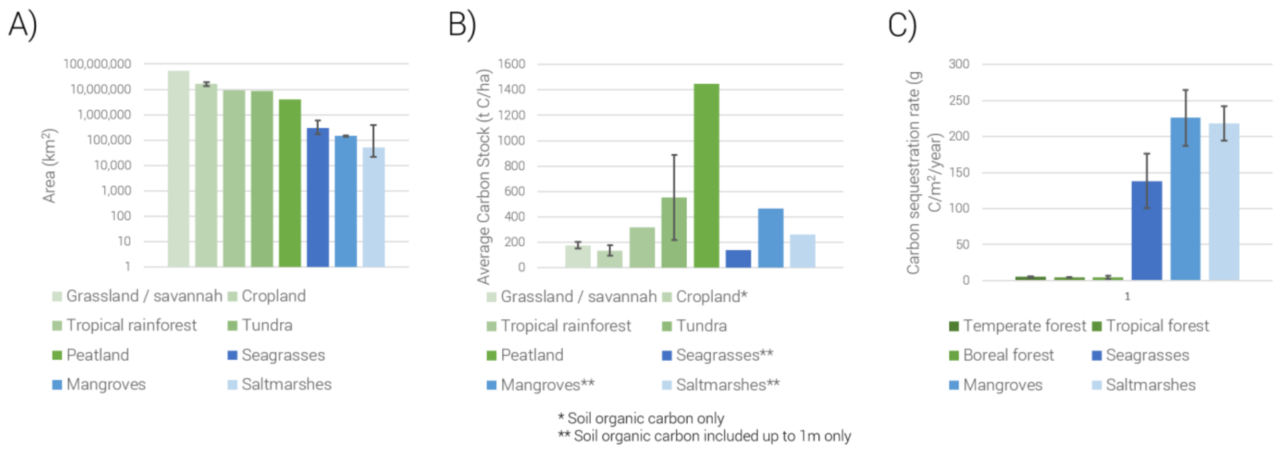
What is green and blue carbon?

The terms green and blue carbon are sometimes used to distinguish between carbon stored in the terrestrial and marine realms, respectively (Box 2).

While there is no formal definition of green carbon, the term is generally used to refer to carbon stored in forest ecosystems. In this briefing note, we extend this definition to include other terrestrial ecosystems. These include peatlands, grasslands and savannah, tundra, and croplands, which are increasingly being recognised for the important contributions they make to storage and removal of CO_2 from the atmosphere (Epple *et al.*, 2016; Figure 2).

Blue carbon commonly refers to carbon stored in coastal and marine

Figure 2: Variation among selected ecosystems important for terrestrial or blue carbon in: estimated total global area (A - note logarithmic scale); average carbon storage per area (B); and carbon sequestration rates (C). Error bars represent the range of estimates for A and B, and standard error for C. Sources: Epple et al 2016 for A and B; Mcleod et al 2011 for C



ecosystems. Current research efforts primarily focus on vegetated coastal ecosystems such as mangroves, seagrasses and saltmarshes (Howard *et al.*, 2017). Other coastal and marine ecosystem components have climate mitigation potential (e.g. kelp, coral, phytoplankton, and marine fauna). Jurisdictional issues and practical challenges in managing these systems however make it difficult to integrate them into climate mitigation frameworks. For example, blue carbon in the form of fish, whales and plankton, is present in Areas Beyond National Jurisdiction, which are notoriously difficult to manage.

Carbon storage in green and blue carbon habitats

Carbon dioxide is removed from the atmosphere, or 'sequestered', by plants through photosynthesis and stored in both their aboveground and belowground biomass (IPCC, 2006, Box 3). It may in turn be released into the atmosphere through land disturbance (e.g. due to fires, deforestation, or for coastal development, fish and shrimp ponds, agricultural fields; Denman *et al.*, 2007).

Terrestrial ecosystems as a whole store between 2,850 and 3,050 Gt C in living vegetation, dead plant matter, and the top 2m of their soils (Epple *et al.*, 2016). This is equivalent to between 3.4 and 3.6 times the amount of CO_2 contained in the atmosphere.

Mangroves, seagrasses and saltmarshes together store between 11-25 Gt C. There are further, poorly quantified, carbon stocks in other marine systems (Epple *et al.*, 2016).

The physical processes through which CO_2 is sequestered are similar for both green and blue carbon. However, there are differences in the rates at which carbon is accumulated, the amount of time for which CO_2 is stored, and the speed at which it is emitted due to disturbance in blue and green carbon.

For example, when degraded, green carbon ecosystems rapidly emit CO_2 into the atmosphere, whereas in blue carbon CO_2 may be reabsorbed by sediments. This is due to difference in the way carbon is sequestered – in green carbon, this occurs mainly in aboveground biomass, whereas in blue carbon it is sequestered and stored mainly in sediments.

State of knowledge on sequestration rates

A summary of knowledge on carbon by major terrestrial, marine and coastal ecosystems is provided in Annexes A and B. Sequestration rates are typically measured in grams of carbon per unit area (e.g. square metres or hectares) per year, and estimates vary from an average of 5.1 g C/m^2/year for temperate forests to 163 g C/m^2/year for mangroves (Mcleod *et al.*, 2011; Figure 2: B and C).

A major limitation to current carbon stock estimates across terrestrial ecosystems arises from overlapping definitions and limited dataset sizes. For example, peatlands are often wrongly recognised as other ecosystem types, as such there may be issues with double-counting, or under-estimation due to currently unrecognised areas of peatland (Epple *et al.*, 2016; Tarnocai *et al.*, 2009).

Other factors contributing to uncertainty in estimates of carbon stocks and sequestration rates for green carbon include habitat age

Box 3: How is Carbon quantified?

A carbon stock is quantified by adding all relevant carbon pools within the investigated area, such as…

Type of carbon pool	**Aboveground biomass**, including living woody and herbaceous vegetation above the soil (e.g. stumps, stems, branches, seeds, and leaves), algae, and microbes living on plants.	**Belowground biomass** e.g. roots and rhizomes and dead plant tissues and soil organic matter (i.e. soil carbon).
	Carbon conservation projects may choose not to account for one or more carbon pools if they can prove that they will not significantly change the assessment results. The value is typically reported as megagrams of organic carbon (MgC) per hectare (ha) over a specified soil depth (Howard *et al.*, 2014b)	
Timeframe for carbon pool	**Short-term** pools e.g., prevailing less than 50 years, such as living biomass	**Long-term** pools e.g., prevailing for centuries or millennia, such as soil organic carbon

and species composition, local soil, climate and geological conditions (Tarnocai *et al.*, 2009; van Breugel *et al.*, 2011; Ahlström *et al.*, 2012).

Estimates of carbon sequestration rates for blue carbon have wide error margins due to limited data availability, especially in Africa, South America, and Southeast Asia (Howard *et al.*, 2014a). In most cases, values are generalised from the very limited data that are available. This introduces error as a variety of biotic (species) and abiotic (depth, temperature, sediment type, type of coastline – i.e. estuarine vs. exposed coast) factors exert a strong influence on carbon stocks, resulting in significant inter-habitat variability. For example, an 18-fold difference in organic carbon storage was found between two temperate seagrass species (Lavery *et al.*, 2013).

Sequestration and emissions in blue versus green carbon habitats

Blue carbon ecosystems are efficient at trapping organic carbon from both internal and external sources (e.g. plant and rock debris). For example, in seagrass meadows, an estimated 50% of carbon stored in soils can be from outside the ecosystem boundary (Kennedy *et al.*, 2010). As a result, these systems have rates of organic carbon accumulation per hectare estimated to be an order of magnitude greater than that of terrestrial forests (Figure 2). Therefore, their capacity to bury organic carbon for long term storage is comparable to forest ecosystems despite their much smaller total global area (Mcleod *et al.*, 2011).

Blue carbon ecosystems store a significantly higher proportion of their carbon stock in soils. These soils are saturated with water and oxygen-deprived meaning that carbon can continuously accrue. This results in soil organic carbon stocks ranging from 600 MgC/ha to 1,050 MgC/ha, depending on the coastal habitat, compared to less than 300 MgC/ha for terrestrial forest habitats (Ewers Lewis *et al.*, 2017).

When these systems are drained, and/or converted to other land uses, the carbon locked away can be released as CO_2 into the atmosphere and ocean, resulting in large contributions to climate change. For instance, due to widespread degradation from human activities and despite their relatively small global area (2% of that of tropical forests) the annual loss of blue carbon ecosystems results in substantial CO_2 emissions (0.15–1.02 billion tonnes of CO_2 per year), equivalent to 3–19% of carbon emissions from tropical deforestation globally, resulting in economic costs of USD 6–42 billion annually (Pendleton *et al.*, 2012).

Biodiversity levels and carbon stocks

Evidence suggests that higher levels of biodiversity and effective carbon sequestration and storage are interlinked (Epple *et al.*, 2016). Biodiversity likely contributes to carbon stocks in two ways:

- Firstly, by increasing the efficiency of carbon sequestration in ecosystems through increased net primary productivity (i.e. the balance between carbon sequestration through photosynthesis and respiration);
- Secondly, by increasing ecosystems' ability to recover from disturbance and degradation (Hicks *et al.*, 2014).

As a result, developing management practices that conserve important biodiversity features, particularly in areas of high biodiversity, will contribute to effective ecosystem-based climate change mitigation (Epple *et al.*, 2016).

What can extractives companies do?

Incorporate carbon sinks in environmental management practices

In addition to supporting projects, companies can incorporate carbon sink conservation into their existing environmental management practices. In the extractives industry, for example, this is applicable throughout each stage of the Mitigation Hierarchy (

Figure 1):

1. In the 'Avoidance' stage, during pre-project planning companies can identify carbon sinks for which impacts can be avoided (see Annex C on datasets and tools that can be used).
2. Activities in the 'Minimisation' stage can be targeted at carbon sinks to reduce the likelihood of green and blue carbon ecosystem degradation. For example an innovative solution to reduce impacts on mangroves would use removable jetties to access offshore infrastructure and enable pile driving, minimising the area of mangrove which would otherwise be degraded by building roads for heavy machinery access
3. 'Restoration' stage activities need to be compatible with both biodiversity and carbon values. As such they can target degraded green and blue carbon ecosystems that also have high levels of biodiversity.
4. Finally, offsets can take the form of support for national or local projects that aim to mitigate carbon emissions and protect or restore carbon sinks, where such activities exist close to operating locations.

Industry may see a shift in policy to include natural habitats within carbon mitigation strategies and an increased emphasis on REDD+ (**R**educing **E**missions from **D**eforestation and forest **D**egradation, **plus** conserving, sustainably managing and enhancing forest carbon stocks). Extractives companies could consider the positioning of their operations, conservation zones and offset sites in the context of carbon sequestration potential of habitats. This will require access to good data on the location of different carbon sink habitats and their carbon sequestration potential (see Annex C).

Ideally, extractives companies could develop more integrated, cross-disciplinary responses that link climate, water, biodiversity and ecosystems services, and social issues.

Different kinds of management activities will affect the size and stability of carbon sinks differently, and will need to take into account local conditions such as type and severity of threats, land use history, and social factors (Epple *et al.*, 2016).

Additionally, knowledge exchange between corporate climate and biodiversity divisions may enable a better understanding of the potential value of biodiversity and

> **Box 4: Global initiatives relating to green and blue carbon**
>
> **Green carbon**
>
> Climate Community & Biodiversity Alliance – http://www.climate-standards.org/
>
> Forest Carbon Partnership Facility – https://www.forestcarbonpartnership.org/
>
> Global Peatlands Initiative – https://www.globalpeatlands.org/
>
> High Carbon Stock Approach – http://highcarbonstock.org/
>
> New York Declaration on Forests – https://nydfglobalplatform.org/
>
> REDD+ – http://redd.unfccc.int/
>
> UN-REDD Programme – http://www.un-redd.org
>
> **Blue carbon**
>
> Friends of Ocean Action – https://www.weforum.org/press/2018/01/new-global-partnership-to-save-life-in-the-ocean-launched-at-the-world-economic-forum/
>
> High-level Panel on Sustainable Ocean Economy – https://www.regjeringen.no/en/aktuelt/norway-establishes-international-high-level-panel-on-sustainable-ocean-economy/id2587691/
>
> The Blue Carbon Initiative – http://thebluecarboninitiative.org/
>
> Mangroves for the Future – https://www.mangrovesforthefuture.org/

ecosystems services to climate mitigation and adaptation efforts.

Finally, extractives companies can already include carbon sink management, restoration or enhancement into carbon reporting such as WRI and WBCSD's Greenhouse Gas Protocol.

Engage with and support national strategies

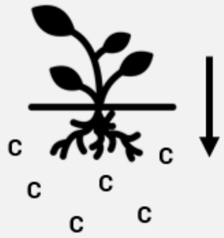
Governments have been encouraged to develop ecosystem-based mitigation measures to address climate change[1], in consultation with all relevant stakeholders across sectors and scales. This presents an opportunity for companies to be involved in planning, especially where they hold or manage land that either overlaps with or is adjacent to carbon-rich habitats. This will also help companies establish good working relationships with local stakeholders where these do not yet exist, and build upon existing relationships where they do.

Engage in global initiatives relating to green and blue carbon

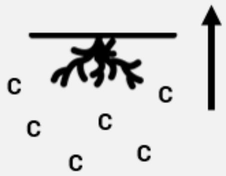
The private sector has the potential to demonstrate leadership in conservation of carbon-rich ecosystems where they operate. Due to the strong linkage between levels of biodiversity and carbon stocks, conserving carbon sinks would lead to co-benefits for biodiversity, ecosystem services, and the local communities that depend on them.

Box 5: Knowledge required to create a carbon inventory

1. The past and present **distribution** of coastal vegetated ecosystems linked to the human uses of the area.



2. The **current carbon stock** within the project area and **rate of carbon accrual**.



3. The **potential carbon emissions** that will result from expected or potential changes to the landscape.

Source: Howard et al. 2014. Icons (Noun Project): Ivan Colic, IYIKON

There are several initiatives that aim to achieve such multiple benefits, which focus on sustainable land management (Box 4). These initiatives have standards to demonstrate contributions for carbon sequestration and enhancement of carbon sinks.

For example, the UNFCCC has a well-established work programme for mitigating GHG emissions under REDD+, which focuses on forest ecosystems in developing countries.

There are multiple opportunities for the private sector to engage in REDD+ projects (Bernard *et al.*, 2012). Companies could play several roles, from funding projects to developing and implementing them, or advising and building capacity. Specifically, companies can help collect baseline data on carbon-rich habitats by developing carbon inventories (e.g. occurrence data for peatlands; Box 5), which can then be used to plan mitigation and adaptation measures that will benefit much wider stakeholder groups, as well as biodiversity and sustainable development.

Features included in REDD+ projects and blue carbon share a wide range of characteristics, and in the majority of countries, mangroves are considered forestland. As such, supporting coastal REDD+ projects would also contribute to blue carbon conservation. However, it is often not clear to what extent blue carbon environments are covered by a country's REDD+ policy framework (Herr *et al.*, 2017).

Only a small number of countries explicitly mention blue carbon

[1] For further information see UNEP-WCMC (2018) Ecosystem-based Adaptation: Nature and its role in delivering resilience to climate change, UNEP-WCMC, Cambridge, UK. Available at: http://www.proteuspartners.org/resources/ecosystem-based-adaptation.pdf

ecosystems as part of their mitigation efforts. Progress has been made to include blue carbon in international and national policy mechanisms, for example, coastal wetlands are included in existing frameworks under the UNFCCC (e.g. Nationally Appropriate Mitigation Actions; REDD+; Land Use, Land-Use Change and Forestry [LULUCF] sectors), and related climate financing mechanisms (Herr *et al.*, 2017).

An analysis of the 163 submitted National Determined Contributions (NDCs) showed that 28 countries have included a reference to coastal wetlands in terms of mitigation (e.g. the Dominican Republic with its blue carbon "Nationally Appropriate Mitigation Actions"; Herr *et al.*, 2017). This creates opportunities for private investment by extractives companies that seek to engage, particularly those operating in coastal areas.

Governments and non-government institutions have started to link blue carbon interventions with conservation finance and payment-for-ecosystem services. Additionally, others are exploring new climate finance tools, such as results-based finance, blue bonds and debt-swap-for-nature agreements, to fast-track coastal management approaches.

Nevertheless, while the concept of blue carbon is increasingly being mainstreamed, fully implemented actions are still rare and often limited to modest mangrove restoration projects.

Data availability

Data sources are generally more diverse for green carbon than for blue carbon, due to historic interest in forest ecosystems.

There are several ongoing initiatives working towards improving the quality, accuracy and representativeness of datasets for both blue carbon and less well-mapped green carbon ecosystems (e.g. peatlands and tundra; Box 4).

A non-exhaustive list of commercially available datasets and tools that can be used to assess the spatial distribution of carbon-rich ecosystems is provided in Annex C.

Conclusion and Next Steps

Extractives companies are well aware of the importance of climate change mitigation to their business models. In turn climate change is the biggest global driver of biodiversity loss, making climate, biodiversity and the energy extractives sector fundamentally linked.

Many extractives companies already significantly reduce their potential impacts on biodiversity through mitigation activities.

However companies may experience difficulties in communicating their successes in mitigating biodiversity impacts without acknowledging the climate-biodiversity-energy link. Addressing carbon sinks alongside biodiversity mitigation is one way for companies to construct a more comprehensive approach within their environmental management activities.

There are many emerging opportunities for extractives companies to engage in climate change mitigation efforts.

Companies could focus their efforts on conserving, enhancing and restoring ecosystems and habitats recognised as important carbon sinks. This would achieve multiple benefits for climate change mitigation, local biodiversity, ecosystem services, and local communities, in addition to reputational and financial gains.

High levels of biodiversity and carbon sequestration are intrinsically related. Hence, biodiversity impact mitigation and ecosystem-based adaption activities targeted at areas of high biodiversity in blue and green carbon ecosystems will likely result in the highest benefits for nature, climate change, and all stakeholders involved.

In summary, it is likely that there will be alignment between carbon sink conservation and biodiversity impact mitigation in highly biodiverse ecosystems, resulting in positive results that can be communicated more confidently.

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Annex A – Summary of knowledge on carbon stocks in major terrestrial ecosystems (Green carbon)

Forests

The majority of research on carbon sequestration and potential climate change mitigation by terrestrial ecosystems to date has focused on forests. This is due mainly to deforestation and its contribution to global CO_2 emissions. Tropical rainforests alone cover approximately 9.4 million km^2 (Joosten, 2015), which is an area almost equivalent to the size of China. Average organic carbon stocks in these rainforests is 320 tonnes of carbon per hectare (t C/ha; Figure 2; Joosten, 2015). Temperate forests were estimated to cover over 6.8 million km^2 in 2015 (Keenan et al., 2015), with an average carbon stock of 60 t C/ha for temperate broadleaf / mixed forests and temperate conifer forests (Thurner *et al.*, 2014).

Global policy drivers and initiatives for forest conservation activities include among others, the UNFCCC's REDD+, the Bonn Challenge for 2020, which encourages private sector commitments to forest restoration, and the Global Partnership on Forest Landscape Restoration, and NDCs.

Peatlands

Peatlands cover only 3% of Earth's terrestrial area, but have an estimated average carbon stock of 1,450 t C/ha (Figure 2; Crump, 2017; Parish *et al.*, 2008), which is the second largest of any terrestrial ecosystem. As such, they represent a substantial carbon sink and have been gaining recognition for their importance and their threat levels. Approximately 15% of global peatland area is threatened by human activities, either through drainage or burning, and the resulting CO_2 emissions equate to approximately 5% of global carbon emissions (Epple *et al.*, 2016; Global Peatlands Initiative, n.d.; Joosten *et al.*, 2012). On a global level, activities related to peatland conservation are coordinated through the Global Peatlands Initiative. Most recently activities to support peatland conservation were strengthened through the Brazzaville Declaration on Peatlands on 22 March 2018 (Brazzaville Declaration, 2018). The Declaration, signed by the governments of the Republic of Congo, the Democratic Republic of Congo and the Republic of Indonesia, has a commitment that specifically focuses on working with the African Development Bank to secure more investments that are in line with conservation and sustainable development, and encourage private-public sector partnerships. Similar commitments are to be expected in other peatland-rich areas, such as Asia and South America.

Data for peatlands are relatively poor, as such building this knowledge base is a major focus at the national-level in regions that have substantial peat coverage (e.g. large parts of South America and tropical Asia). There is no globally consistent, high-resolution map of peatland occurrence and existing datasets (e.g. SWAMP) have particular issues with: 1) higher altitude peatlands; 2) distinguishing between peat and non-peat wetlands; and 3) small peatlands in tropical areas situated along coastlines, rivers, lakes, and floodplains.

Grassland and savannah

In their natural state grasslands and savannah cover close to 25% of the Earth's terrestrial area (Figure 2; Epple *et al.*, 2016), with an average carbon stock estimated at between 150-200 t C/ha depending on climate and soil properties, 80% of which is stored in soil (Epple *et al.*, 2016; Grace *et al.*, 2006; Ciais *et al.*, 2011). The carbon stocks in grasslands and savannah are mainly affected by agriculture, grazing by animals, and variations in fire and climate conditions (Epple *et al.*, 2016). It is estimated that grassland restoration could contribute up to 45 million tonnes of carbon sequestration per year (Conant and Paustian, 2002).

Tundra

Tundra ecosystems are mostly located in the northern hemisphere and cover close to 10% of Earth's land surface, with an average carbon stock ranging from 218 to 890 t C/ha (Figure 2; Joosten, 2015; Epple *et al.*, 2016). The main characteristics of tundra ecosystems are their peat-forming vegetation, but they mostly store carbon stocks in their soils, particularly layers of soil that remain permanently frozen (i.e. 'permafrost'). Together with boreal forests, they are the largest terrestrial organic carbon sink, containing at least 1,700 Gigatonnes of carbon (Gt C; Epple *et al.*, 2016). However, there is increasing concern that tundra ecosystems will become a significant source of carbon emissions due to climate change and increased human interference as permafrost layers release carbon when they melt or when disturbed and degraded (Epple *et al.*, 2016; Koven *et al.*, 2011). Existing anthropogenic threats arise mainly from extractive industries (i.e. fossil fuel and mineral extraction), which could worsen if the size and frequency of such activities increase in the future.

The distribution of carbon in tundra ecosystems is thought to be uneven, but is still relatively poorly understood (Ciais *et al.*, 2013; Tarnocai *et al.*, 2009). Since halting and/or reversing permafrost thawing is unfeasible, there are currently no major international initiatives to conserve tundra ecosystems. However, public and private sector actors can ensure they plan effectively to avoid degrading these ecosystems when developing new activities.

Cropland

Agricultural lands, or croplands, cover approximately 13% of the Earth's surface with an average soil carbon stock varying from 95-177 t C/ha (Figure 2; Eglin *et al.*, 2011; FAO, 2014; Verchot, 2014). The majority of croplands are currently located in former forests and grasslands. The carbon sink function of croplands is highly variable and dependent on local climate and geological conditions, as well as management practices (Epple *et al.*, 2016). Croplands are crucial for global food security, but they generally lead to decreases in carbon stocks, particularly if they are from converted natural or semi-natural habitats (Epple *et al.*, 2016).

The extent of croplands has been well-documented, particularly by the United Nations Food and Agricultural Organization (FAO) and maps of cropland extent are relatively accurate (see for example the Global Croplands web application).

Annex B – Summary of knowledge on carbon stocks in major marine and coastal ecosystems (blue carbon)

Mangroves

In general mangroves are relatively well mapped and so is their annual rate of loss (Howard *et al.*, 2014a). It is estimated that mangroves cover approximately 14.5 Million hectares, or 145,000 km^2 (Pendleton *et al.*, 2012), with an average carbon stock of 466.5 t C/ha (Siikamäki *et al.*, 2012). Mangroves store the majority of their carbon stock in soil, with averages at 319.0 t C/ha, rather than their biomass, which averages at 147.5 t C/ha (Siikamäki *et al.*, 2012). Estimates of carbon stocks in mangroves vary greatly between regions of the globe, with the highest reported estimate at 1,023 t C/ha in the Indo-Pacific region (Donato *et al.*, 2011). Carbon sequestration rates in mangroves are estimated at 2.26 t C/ha/year (Mcleod *et al.*, 2011).

Seagrasses

Seagrass meadows remain predominantly un-surveyed. The most data-scarce regions for seagrasses data include Southeast Asia, eastern and western South America and the west coast of Africa (Howard *et al.*, 2014a). Recent global estimates indicate that seagrasses cover approximately 30 Million hectares, or 300,000 km^2 (Pendleton *et al.*, 2012). Seagrasses store on average 140 t C/ha (Murray *et al.*, 2011) and their carbon sequestration rates are estimated at an average of 1.38 t C/ha/year (Mcleod *et al.*, 2011).

Saltmarshes

Saltmarshes, similar to seagrasses, still have major data gaps on distribution, particularly in Russia and South America (Mcowen *et al.*, 2017). Saltmarshes cover an estimated 5.1 Million hectares, or 51,000 km^2 (Pendleton *et al.*, 2012), with an average carbon stock of 260 t C/ha (Murray *et al.*, 2011). Carbon sequestration rates by saltmarshes are estimated to be on average 2.18 t C/ha/year (Mcleod *et al.*, 2011).

Issues common across for mangroves, seagrasses and saltmarshes

Areal extent of vegetated coastal ecosystems and their rate of loss is not uniform across the globe. Unfortunately, limited data are available in the scientific literature on the carbon sequestration and storage rates for blue carbon particularly in Africa, South America, and Southeast Asia (Howard *et al.*, 2014a) and therefore, values are typically generalised from a very limited data set. This introduces error as a variety of biotic (species) and abiotic (depth, temperature, sediment type, type of coastline – i.e. estuarine vs. exposed coast) factors exert a strong influence on carbon stocks, resulting in significant inter-habitat variability. For example, an 18-fold difference in organic carbon storage was found between two temperate seagrass species (Lavery *et al.*, 2013).

A further limitation is that whilst belowground carbon pools are usually the largest pool in vegetated coastal ecosystems, (between 50% to over 90% of the total ecosystem carbon stock of mangroves, and 98% for seagrass and saltmarsh), they are the least studied (Howard *et al.*, 2014a). This is likely due to the recent recognition of the significance of belowground soil carbon in these systems as an important source of carbon globally, and logistical challenges in assessing it. Furthermore, below-ground carbon storage is difficult to quantify — there is a need to consider variable deposition rates through time, transformation, and erosion dynamics associated with fluctuating sea levels and episodic disturbances.

Since the main pool in blue carbon ecosystems is found in the soil or sediment the proportion of CO_2 emitted after disturbance is less certain than in green carbon. While the Intergovernmental Panel on Climate Change (IPCC) Wetlands Supplement provides emissions factors for soil carbon for project activities, a lack of empirical data means that many environmental hazards and activities are not covered (Lovelock *et al.*, 2017). Furthermore, as the top 30 cm of soil are generally considered the most susceptible to land-use change in upland forests, IPCC protocols standardise loss to 1 m in the soil. However, disturbances in coastal ecosystems can alter soil conditions (e.g. drainage and oxidation) to much greater depths (Lovelock *et al.*, 2017).

Level of scientific understanding varies between the different ecosystems and geographic regions. Generally speaking the largest contributions to uncertainty in emissions from degraded or converted ecosystems stems from the wide ranges of global area and conversion rates. Uncertainty is relatively high for saltmarsh systems largely due to limited information on spatial extent (accounting for 30% of total uncertainty) – however, a newly published global saltmarsh map (available at: WCMC.io/WCMC_027) should reduce this. For mangroves, global area is better quantified, but uncertainty in habitat conversion rates is substantial and has the largest influence on total emissions estimates (18%). For seagrasses, the range in conversion rate is the most important influence on total uncertainty (14%) (Pendleton *et al.*, 2012).

Annex C – Data availability

Table 1: Overview of open access datasets and tools that are available for commercial use. Please note this list is non-exhaustive and access cannot be guaranteed.

Ecosystem	Resource type	Resource name and description	Link
Green carbon			
Forests	Tool	Global Forest Watch – provides visual data on forest change, land use, and biodiversity	https://www.globalforestwatch.org/map
Forests	Dataset	Forest carbon regional data for northern temperate forests	https://onlinelibrary.wiley.com/doi/full/10.1111/geb.12125 http://biomasar.org/index.php?id=71
Forests, Grasslands / Savannah	Dataset	New IPCC Tier-1 Global Biomass Carbon Map for the Year 2000 – Provides data for forests, grasslands, and shrublands	http://cdiac.ess-dive.lbl.gov/epubs/ndp/global_carbon/carbon_documentation#datafiles
Croplands	Tool	Global Croplands – provides visual and downloadable data on cropland extent	https://croplands.org/app/map?lat=0.17578&lng=0&zoom=2
Peatlands	Dataset	The Sustainable Wetlands Adaption and Mitigation Program (SWAMP) Tropical and Subtropical Histosol Distribution – provides distribution data for peat soils ('histosols')	https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00029
Peatlands	Dataset	Detailed map of peatlands in Europe, with downloadable files	http://mires-and-peat.net/pages/volumes/map19/map1922.php
Multiple – soils	Dataset	Joint Research Centre of the European Commission – Global Soil Organic Carbon Estimates	https://esdac.jrc.ec.europa.eu/content/global-soil-organic-carbon-estimates
Multiple – soils	Dataset	European Commission Soil Organic Carbon Estimates for Europe	https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-soc-projections-europe
Multiple – soils	Dataset	SoilsGrids – provides soil carbon estimates for Europe	https://soilgrids.org/#!/?layer=TAXNWRB_250m&vector=1
Multiple – soils	Dataset	AfricaSoils.net – provides soil carbon estimates for Africa and links to soil organic carbon datasets at varying scales	http://africasoils.net/services/data/soil-databases/

Ecosystem	Resource type	Resource name and description	Link
Blue carbon			
Mangroves	Dataset	Global distribution of Mangroves USGS – shows the global distribution of mangrove forests, derived from earth observation satellite imagery	WCMC.io/WCMC_010
Seagrasses	Dataset	Global distribution of Seagrasses – provides data on the global distribution of seagrasses	WCMC.io/WCMC_013_014
Saltmarshes	Dataset	Global Distribution of Saltmarshes – provides best available data on distribution of saltmarshes globally	WCMC.io/WCMC_027

Citation: UNEP-WCMC (2018), Green and blue carbon. The role of habitats in reducing carbon emissions. Linking biodiversity management and climate change mitigation. UNEP-WCMC, Cambridge, UK.

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