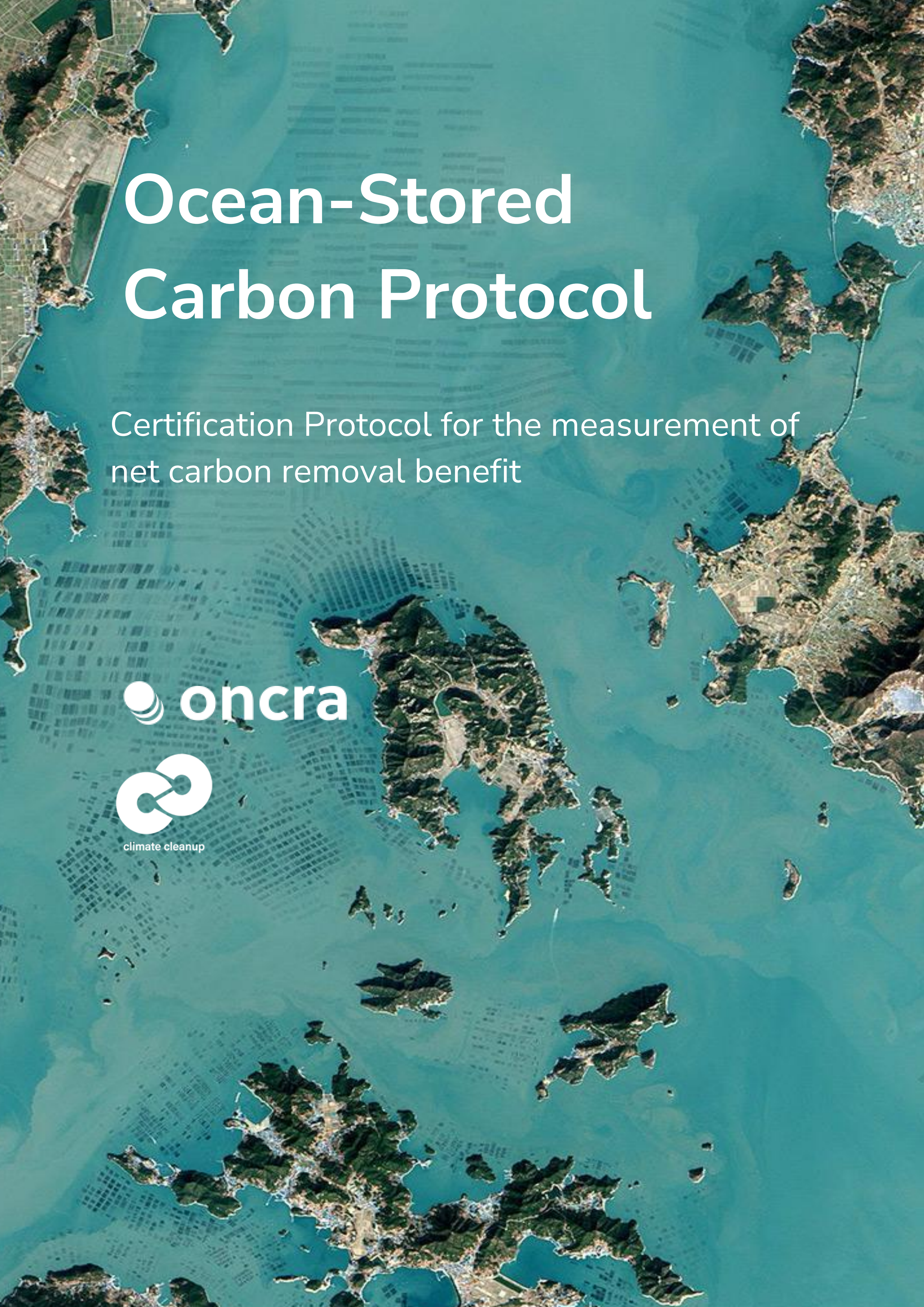

Ocean-Stored Carbon Protocol

Certification Protocol for the measurement of net carbon removal benefit

oncra

climate cleanup

About this document

This Certification Protocol describes the criteria to be met by operators or groups of operators (henceforth: Removers) of Ocean-Stored Carbon (OSC) projects, should they wish to receive Open Natural Carbon Removal Accounting (ONCRA) certification. This Certification Protocol includes the general requirements for projects and Removers (Section 1), the quantification used to determine the amount of biogenic carbon[1] stored in projects (Section 2), reporting and verification requirements (Section 3) and example calculations (Section 4).

This Certification Protocol is the result of a research project initiated and stewarded by the Climate Cleanup Foundation as part of its Ocean-Stored Carbon intervention programme. The development of this Certification Protocol was funded by the INNO-fonds project of WWF Netherlands. This Certification Protocol is aligned with the final proposal of the European Union Certification Framework for Carbon Removals[2] and the ONCRA Guidelines.

Version

This document represents version 3 (third draft) of the *Certification Protocol for Ocean-stored Carbon* published on 4 March 2024. This is a draft version of the final protocol, open for feedback. We kindly request that any feedback or remarks are sent to the lead author, Hajna Tijssen.

Authors

Climate Cleanup is a non-profit foundation and social enterprise funded by members and well-aligned partners. Our mission is to reverse climate change by removing 1500 gigaton CO_2 from the atmosphere with Nature-based Solutions. We do so by fostering systemic conditions for a regenerative economy that double nature. We are grateful to our members as without their support this work could not have been done. We express our gratitude to the INNO-fonds of the WWF for supporting the research project for this Certification Protocol.

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[1] Biogenic carbon: carbon that is stored in biological materials, such as plants and soils.

[2] A legislative proposal by the EU is being set up to include oceans in a certification framework for carbon removals, see: https://data.consilium.europa.eu/doc/document/ST-15629-2023-INIT/en/pdf

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1. General Activity Requirements

1.1 Eligible Carbon Removal Activities

Projects eligible for certification using this protocol must involve carbon removal activities that meet the following criteria:

- **Ocean-based removal**: ocean-based removal activities include interventions that (1) take place primarily in the ocean, which includes marine coastal regions and (2) extract CO_2 directly from the atmosphere, or from seawater indirectly leading to a reduction in atmospheric CO_2 (Aspen Institute, 2021). These removal activities are also known under the term *blue carbon* (Nelleman et al., 2009).
- **Nature-based solutions**: the carbon removal activity stores carbon by increasing nature. Nature-based Solutions are “actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature” (IUCN, 2016). For example, the restoration or conservation of mangroves, seagrasses or seaweed ecosystems are examples of nature-based solutions in coastal environments. These are collectively referred to as *coastal blue carbon*.
- **Long-term storage**: the carbon removal activity must aim at facilitating the long-term storage of biogenic carbon (Section 2.5).
- **Additional**: the carbon removal activity must be additional, in the sense that the money from carbon certificates should lead to extra carbon sequestration (Section 2.4).
- **Sustainability**: the project complies with the minimum sustainability criteria (Section 2.6).
- **Project stage**: the carbon removal activities can be in different stages:
    - The carbon has been sequestered: *Ex-post phase*, Technology Readiness Level (TRL) 9 (DOE, 2010).
    - Carbon sequestration is possible and happening: *Integration phase*, TRL 9.
    - Carbon sequestration is technically possible, but implementation at scale is uncertain: *Development phase*, TRL 5-8.
    - The technical implementation is uncertain: *Research phase*, TRL 1-4.

1.2 Eligible Removers

To be eligible for receiving certification on one or more of their projects, Removers must meet the following criteria:

a. At least one of the Removers of the project must have legal ownership and/or control over the design, execution and monitoring of the project. Legal ownership and/or control over these different project stages may be divided between Removers.

b. Right of usage of the land and/or permission to operate the OSC project. The Remover must have a proof of the right of usage of the land that the OSC (eco)system is present on and/or required permits or licences to operate the OSC project.

2. OSC metric

2.1 Description

The Ocean-Stored Carbon (OSC) metric calculates the amount of biogenic carbon stored in nature-based ocean projects. Nature-based ocean projects include, but are not limited to, mangrove, seaweed and seagrass ecosystems. The metric is based on equations to calculate the net amount of carbon stored in the (eco)system (Section 2.2). To make the calculations tangible, carbon calculations for example projects are presented for a mangrove ecosystem in Bonaire, a seagrass ecosystem and two seaweed methods (Section 4).

2.2 Formulas

The OSC is calculated from the amount of biogenic carbon stored in an ocean (eco)system: the Total (Eco)system Carbon (TEC) (Formula 1). The amount of biogenic carbon is assessed as the increase from the pre-project baseline (b) carbon amount. The target system (t) is the amount of carbon that is stored in the (eco)system at its capacity, which is what the carbon removal activity is aiming to attain. The permanence of the carbon storage is considered through the estimated duration of the storage (L) which is converted to match a 100-year equivalence (Section 2.5). As there can be emissions of greenhouse gasses during project activities, these project emissions (E) are subtracted from the carbon storage (Section 2.3). Consequently, the OSC represents the net amount of CO_2 equivalents (tCO_2e) that are kept out of the atmosphere and stored in the ocean carbon sink for a substantial period of time.

$$OSC = (TEC_t - TEC_b) * \frac{L}{100} - E \tag{1}$$

Symbol	Description	Unit
OSC	Ocean-stored Carbon	tCO_2e
TEC	Total (Eco)system Carbon	tCO_2
t	Target system (carbon stored in the capacity system)	tCO_2
b	Baseline (carbon stored at the year before project start)	tCO_2
L	Estimated duration of storage (max 100 years)	yr
E	Project emissions	tCO_2e

The total carbon stored in the (eco)system (TEC) is made up of two main components, the carbon stored in the biomass (BC) and the carbon stored in the sediment (SC; Formula 2). To arrive at the total amount, the BC and SC are multiplied by the area of the system.

$$TEC = (BC + SC) * A \tag{2}$$

Symbol	Description	Unit
TEC	Total (Eco)system Carbon	tCO_2
BC	Biomass Carbon	tCO_2/ha

SC	Sediment Carbon	tCO_2/ha
A	Area	ha

The biomass carbon (BC) is the total carbon stored in the plant material of the (eco)system. The biomass carbon is calculated from the carbon content, the percentage of carbon in the plant material, and the amount of biomass (Formula 3). As the water content is a fluctuating variable, the amount of dry weight is used to determine the amount of biomass. Dry weight is the weight of the plant after all its water content has been removed. In the case of ecosystems that are rooted in sediment, the biomass is the total of the aboveground and the belowground biomass (e.g. roots). A conversion from carbon to CO_2 is made in the calculation (44/12).

$$BC = C * B * (44/12) \tag{3}$$

Symbol	Description	Unit
BC	Biomass carbon	tCO_2/ha
C	Carbon content (biomass)	%C
B	Amount of biomass (dry weight)	tDW/ha

For (eco)systems that increase the amount of carbon in the sediment[3], the amount of sediment carbon is calculated (Formula 4). The carbon content is the amount of biogenic carbon per unit of sediment (g/kg) and is calculated from onsite soil samples or reference measurements. The depth, dry bulk density and other numbers in the formula are used to convert the carbon content to tonnes of CO_2 sequestration per hectare.

$$SC = C * D * DBD * (44/12)/10 \tag{4}$$

Symbol	Description	Unit
SC	Soil carbon	tCO_2/ha
C	Carbon content (soil)	C g/kg
D	Depth of sample	cm
DBD	Dry bulk density	g

2.3 Emissions and Accounting Boundaries

Emissions of CO_2 or other greenhouse gases (GHG) produced by OSC projects must be accounted for. For projects that have a larger sequestration than 100 thousand tCO_2e, emissions must be reported through a Life Cycle Assessment (LCA) with standardisation norms being adhered to (ISO 14040[4]). For projects with a smaller sequestration, an emission standard of 20% shall be applied.[5] In case that smaller or larger emissions are foreseen, calculations must justify this statement. The expected project emissions are subtracted from the amount of carbon sequestered

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[3] Mangroves and seagrass have been found to increase the SOC, while for seaweed this is dependent on the conditions of cultivation (e.g. if cultivated above sediment, current strength).

[4] Principles and framework for LCA, see: https://www.iso.org/standard/37456.html

[5] 20% standard based on Pareto Principle and emissions found to be below this standard (e.g. Thomas et al., 2020)

by the project (Formula 1). Furthermore, the starting point is that the first 12 years of carbon storage will be distributed as transition financing in the form of pre-purchase agreements.

The following accounting boundaries must be included in the calculation (Figure 1):

a. Planting stage: the GHG emissions during the seed creation (e.g. laboratory), the transport of materials, the planting of the OSC (eco)system and the possible removal of an already present (eco)system must all be included in the LCA.
b. Growing stage: the GHG emissions during the growing stage must also be accounted for, which include but are not limited to the transport of materials and people, maintenance and research of the (eco)system.
c. End of life stage: in case the OSC system is only present for a certain time period, emissions from decomposition (natural) and demolition (anthropogenic) must be included.

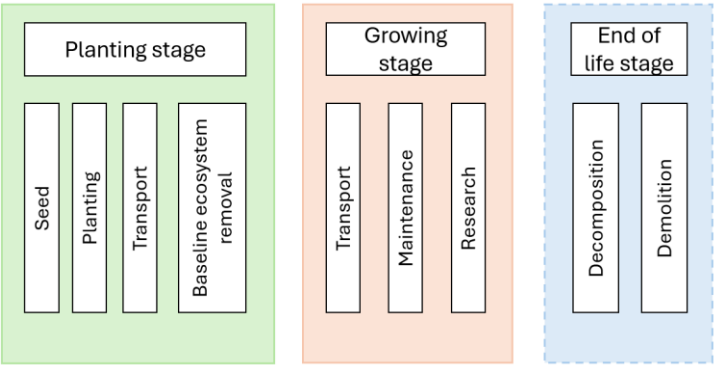

Figure 1. LCA calculation accounting boundaries for OSC projects.

2.4 Additionality

To be eligible for certification, the project shall comply with the following **additionality** criteria:

a. The project has a net carbon removal benefit above the baseline carbon.
b. The carbon removal associated with the project shall not be double counted. This means that no two certificates are issued for the same tonne of CO_2e removed. Removers shall be held liable for any occurrence of double counting. Three types of double counting shall be checked:
    i. Removers shall not certify the net carbon removal benefit of their product under any other carbon removal certification scheme.
    ii. Removers shall ensure that the ocean carbon removal accounted for are not claimed anywhere in their supply chains. If the carbon removals have already been claimed, these removals shall be excluded from the quantification of the OSC.

    iii. Once the certificate rights are sold to a third party, Removers shall refrain from claiming the quantified net carbon removal benefit, using it as a substantiation of climate neutrality claims, or including it in their carbon accounting, unless the relevant purchase agreement(s) explicitly state(s) that the buyer refrains from these claims.

c. The revenue from carbon certificates should lead to carbon sequestration. The Remover must declare that they use the revenue from the transition financing for carbon removal. The removal pathway or project should not cover climate mitigation measures that are included in the National Determined Contributions (NDC) of the country where the removal is effectuated.

d. A duty of accountability must be provided by the Remover, which shows that the transition finance provided for the carbon removal is a significant component of the business case of the project.

2.5 Permanence

Permanence describes the time that carbon is stored before it is returned to the atmosphere. Within the carbon removal calculations (Section 2.1), the permanence is considered. ONCRA uses a 100-year permanence basis, which is the benchmark generally used for a project to be considered permanent. From projects that have a shorter term storage, the carbon storage will be discounted to match the 100-year timeframe. For example, a project with an expected permanence of 70 years will receive 70% (70/100) of the certificates. If the permanence is longer than 100 years, the full amount of credits will be allocated. The permanence shall be determined by research on the carbon permanence of the carbon removal activities, as well as on expected local, regional, and global management and policy developments.

A buffer pool will be adhered to (Holding Pool), to offer buyers security about the permanence of the project. The Holding Pool is dependent on the project phase: 0% for *Ex-post*, 20% for *Integration*, 35% for *Development* and 50% for *Research* projects (ONCRA guidelines). Furthermore, to ensure the permanence of the carbon storage, continuous monitoring must be applied, with measurements being performed every three years for coastal projects and every year for offshore projects (flow-based projects).

2.6 Sustainability

To comply with the minimum **sustainability** requirements of this Certification Protocol, Removers shall comply with the following criteria for environmental and social impact:

a. The project shall have at least a neutral ("No Net Harm" principle; ICROA, 2023) impact on the following six sustainability objectives:

    i. Protection and restoration of biodiversity and ecosystems.
    ii. Climate change mitigation beyond the net carbon removal benefit as quantified according to Formula 1.
    iii. Climate change adaptation (e.g. coastal protection, erosion prevention).
    iv. Sustainable use and protection of water and marine resources (e.g. ocean acidification prevention, water quality improvement).
    v. Increasing social benefits and equality (e.g. job creation, involvement of local community).
    vi. Pollution prevention and control (e.g. no plastic waste).

b. To provide evidence of the compliance with the sustainability objectives of criterion (a), Removers need to deliver an Environmental Impact Assessment (EIA). The EIA must be updated at least once every three years.

c. Removers may report on any additional benefits generated by the project beyond the minimum sustainability requirements. These co-benefits need to be communicated transparently, concisely and clearly by the Remover to ONCRA.

3. Measurement, Reporting and Verification

3.1 Measurement

When submitting a project for certification following the OSC Certification Protocol, Removers shall ensure that the following data is measured (when relevant to the OSC (eco)system):

- SOC content: the amount of sediment organic carbon measured in the (eco)system.
- Biomass carbon content: the percentage of carbon in the biomass.
- Biomass amount: the amount of biomass in the (eco)system measured in dry weight.
- The surface area of the project to be certified.
- The permanence of the storage: calculation of the duration of the carbon storage.
- Environmental Impact Assessment: proof of adherence with the minimum sustainability requirements through an EIA (Section 2.6).

When certain measurements are not available, data from scientific literature can be used. This data must be: location relevant (from the same or similar species, geological location and environmental condition) and time relevant (from within the last 10 years).

3.2 Reporting

When submitting a project for certification, Removers shall ensure the following information is reported and provided to ONCRA:

- Description of the project: including geolocation, country, size, project phase (Ex-post, Integration, Development, Research).
- Carbon calculation data: data required to calculate the carbon storage as specified in Section 3.1. The quantification of the carbon stored in the ocean project must happen every three years for coastal projects, while every year for offshore projects (flow-based projects).
- Right of usage: a proof of the right of usage of the land that the OSC (eco)system is present on and/or required permits or licences to operate the OSC project (e.g. environmental permit, aquaculture permit, business license). If materials are released in international waters (e.g. seaweed) it needs to be in line with international regimes and standards (e.g. EU and/or International Maritime Organization (IMO)).
- Signed contract of liability for double-counting and monitoring risk of reversal for the duration of the monitoring period, with a frequency equal to the quantification frequency.
- Eligibility of Removers: description of organisations involved including legal information, roles in the project and people involved. In case of grouped projects, a written and signed agreement on liability and beneficiaries is required.

3.3 Verification

Projects must seek verification from an independent verification body (IVB) in compliance with the following criteria:

a. Verification by the IVB must include the calculations on the amount of (expected) carbon storage, the baseline carbon, the amount of emissions (LCA calculations) and risks of the project.
b. After verification, Removers must provide ONCRA with a verification report signed by the IVB, that clearly states which documents and data the IVB has verified
c. If an IVB rejects the project verification request, written justification must be provided. After rejection by an IVB, Removers must re-submit their project to ONCRA for validation. After rejection by an IVB, Removers may re-submit their project up to two times
d. Once a verification report is delivered and accepted by ONCRA, Removers shall receive ONCRA certification.

3.4 Re-validation and Re-verification

For the purposes of mitigating risk of reversal, Removers shall comply with the following criteria regarding re-validation and re-verification:

a. Projects labelled as *Research credit* may request to be relabelled to *Development credit* when the carbon sequestration has been found to be technically possible. Or projects may request to be relabelled as *Ex-post* credits when onsite measurements have been performed, the amount of carbon sequestration is recalculated with the metric and the carbon has been sequestered.
b. Projects labelled as *Developments credit* may request to be relabelled as *Integration credit* once research has found that implementation at scale is possible. Or projects may request to be relabelled as *Ex-post* credits when onsite measurements have been performed, the amount of carbon sequestration is recalculated with the metric and the carbon has been sequestered.
c. Projects labelled as *Integration credit* may request to be relabelled as *Ex-post* credit when onsite measurements have been performed, the amount of carbon sequestration is recalculated with the metric and the carbon has been sequestered.

4. Example Calculations

In the following subchapters several example carbon calculations are presented for different ocean (eco)systems. These calculations have been set up with the help of Removers in the Climate Cleanup Network.

4.1.1 Mangroves Bonaire – Potential of Restoration

Mangroves have been found to provide many ecosystem services, including coastal protection, habitat for biodiverse systems and carbon sequestration. Mangroves have been shown to have high rates of productivity and carbon storage, as well as to be globally significant carbon stocks, accounting for 14% of carbon sequestration by the global ocean (Alongi, 2012; Breithaupt & Steinmuller, 2022).

In the southeastern part of Bonaire, an island in the Dutch Caribbean, mangroves are present within a shallow bay: Lac Bay. The Lac Bay mangroves are in a protected Ramsar site[6]. There are three mangrove species present within the lac, with most of the area being dominated by red (*Rhizophora mangle*) and black mangroves (*Avicennia germinans*; Davaasuren & Meesters, 2012). However, the overgrazing by roaming livestock and land use changes within surrounding areas are increasing the rate with which sediment is filling up the bay, leading to the degradation of mangroves (Davaasuren & Meesters, 2012; Senger et al., 2021).

Through proper management, the Lac Bay mangroves can be restored. For instance, one management option is to reopen old channels and restore the water flow throughout the mangroves. A local organisation working on this is Mangrove Maniacs together with STINAPA.

Restoring mangroves strengthens multiple ecosystem services, including enhanced biodiversity, coastal protection, water quality and carbon sequestration. An example calculation will be provided for the potential amount of CO_2 that restoration projects can sequester.

4.1.2 Mangrove Bonaire - Example Calculation

To calculate the biomass carbon of the mangrove system, the carbon content and the dry weight of the biomass are needed. Taking the average biomass carbon content of mangroves from several studies (Hiraishi et al., 2014; Kridiborworn et al., 2012; Owers et al., 2018), a 46% biomass carbon content was found. Using the classification of Hiraishi et al. (2014) and with Bonaire having a dry climate with tropical temperatures, a growth rate of 3.3 tonnes of dry matter/ha/yr was assumed (Hiraishi et al., 2014). With this information the biomass carbon of the mangroves can be calculated with Formula 3:

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[6] A Ramsar site is a wetland site designated to be of international importance under the Ramsar Convention (https://www.ramsar.org/)

$$BC_{mangrove} = 46\,\%C * 3.3\ tDW/ha/yr * (44/12) = 5.57\ tCO2/ha/yr$$

To calculate the sediment carbon, the sediment carbon content, depth of the sample and dry bulk density needs to be known. A study on carbon dynamics of the mangroves forests in Bonaire found that the sediment organic carbon in the upper 30 cm is on average 31% in intact mangroves compared to 20% in degraded mangrove areas (Senger et al., 2021). The dry bulk density can be calculated from the carbon content with a pedotransfer function developed by Abdelbaki (2018):

$$DBD = 1.449e^{-0.03*C}$$

With this function a DBD of 0.57 g/cm³ was calculated for the intact mangrove sediment and 0.79 g/cm³ for the degraded system. With these values the sediment carbon for the degraded mangrove can be calculated (baseline system):

$$SC_{degraded\ mangrove} = 200\ gC/kg * 30\ cm * 0.79\ g/cm^3 * (44/12)\ /10 = 1749\ tCO2/ha$$

And the sediment carbon of the intact mangrove (target system):

$$SC_{intact\ mangrove} = 310\ gC/kg * 30\ cm * 0.57\ g/cm^3 * (44/12)\ /10 = 1949\ tCO2/ha$$

The mangrove forest extent in Lac Bay of red and black mangroves has been estimated to be 170 hectares (Davaasuren & Meesters, 2012). From these mangroves, 45 ha are dense healthy mangroves, 45 ha moderately dense mangroves and 80 ha sparse degraded mangroves (Davaasuren & Meesters, 2012). Assuming a growth of the sparse mangroves to be restored of 20 years, the carbon sequestration potential of the restoration is:

$$TEC_{restoration\ potential} = (1949tCO2/ha - 1749tCO2/ha) + (5.57tCO2/ha/yr * 20yr) * 80ha$$
$$= 24978\ tCO2$$

Taking the standard emission factor into account (20%), this results in a total net storage potential of **19982 tCO2**. These calculations show the large carbon sequestration potential of mangrove restoration projects. However, several other aspects and assumptions need to be added to improve these carbon calculations, such as a baseline biomass carbon measurement and the duration of storage. The depth of the mangrove sample is something that also will need to be reconsidered, as mangrove peat has been found up to the limestone layer at a depth of 60-100 cm, which is significantly larger from the here used 30 cm sample depth. Additionally, it will be important to consider other positive effects of the mangrove system, such as an increase in biodiversity and coastal protection.

4.2 Seagrass – Example Calculation

Seagrasses ecosystems provide important ecosystem services such as nutrient cycling, biodiversity, coastal protection and carbon sequestration. Seagrasses rank amongst the most efficient natural carbon sinks. However, seagrass ecosystems are being threatened by nutrient and sediment discharges causing eutrophication[7] and coastal developments, leading to a global decline of 7% per year since 1990 (Waycott et al., 2009). Therefore, the restoration, conservation and management actions of seagrass ecosystems are important to, among other benefits, sequester carbon.

Here an example calculation will follow for the carbon stored in seagrass ecosystems from the mean of a global dataset (Fourqurean et al., 2012). The biomass carbon can be calculated from the sum of the carbon stored in the above-ground and below-ground biomass:

$$BC_{seagrass} = AGB + BGB = (0.75\ tC/ha + 1.76\ tC/ha) * (44/12) = 9.2\ tCO2/ha$$

The soil carbon can be calculated with Formula 4, with the sediment carbon content being 2.5%, the dry bulk density 1.03 g/cm³ and the depth of the sample being 100 cm (Fourqurean et al., 2012):

$$SC_{seagrass} = 25\ gC/kg * 100\ cm * 1.03\ g/cm^3 * (44/12)/10 = 944\ tCO2/ha$$

The Total Ecosystem Carbon of the seagrass ecosystem is:

$$TEC = 9.2\ tCO2/ha\ + 944\ tCO2/ha\ = 953\ tCO2/ha$$

Including the standard emission factor (20%), this would result in a Net Storage Potential of **763 tCO_2/ha**. However, from this value the baseline carbon (TEC_b) present at the beginning of a project start would still have to be subtracted and the permanence of storage would have to be considered. Furthermore, data from field measurements or from similar climates, hydrodynamic conditions and species will be critical to improve the accuracy of the carbon calculation for seagrass projects.

4.3 Seaweed Sinking Research – Arbon Earth

Seaweeds (macroalgae) have attracted attention due to their fast growth and potentially high carbon sequestration. A suggested pathway of moving the carbon stored in the seaweed biomass from the short-term to the long-term carbon cycle, is sinking the seaweed to the deep ocean.

ONCRA has been in close collaboration with a seaweed innovator: Arbon Earth. Arbon Earth has developed a novel method, by creating floating Oceanpods from bamboo and natural rope on which seaweed can settle. The seaweed species that is used is *Saccharina latissimi* (sugar kelp). As the weight of the fast-growing kelp increases and the air pockets in the bamboo decrease, the Oceanpod sinks to the deep ocean, where the carbon is stored for hundreds of years. Until this happens, the Oceanpods create a temporary ocean ecosystem.

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[7] Eutrophication: the process in which a water body becomes overly enriched with nutrients, leading to the plentiful growth of simple plant life.

For the carbon calculation of Oceanpods, a slightly different approach has been taken due to several reasons. First, as the seaweed is not rooted in sediment, all carbon is stored in the biomass and no carbon is directly stored in the sediment (TEC=BC). Secondly, as the Oceanpods are free-floating devices in the open ocean, the baseline carbon is assumed to be 0 (TEC_b=0). Thirdly, because the biomass that is sunk to the deep sea is stored below 1000 meter depths, the duration of storage is assumed to be well over 100 years, thus L=100/100=1.

The amount of carbon in the Oceanpods is comprised of three types of biomass carbon (BC): macroalgae biomass, bamboo biomass and natural rope biomass (e.g., hemp). The carbon contents, dry weights and biomass carbons are shown in Table 1, with the biomass carbon being calculated form Formula 3. The unit used is an Oceanpod, which is assumed to have 20 meters of rope on a 2-meter bamboo rod. For the macroalgae a conservative estimate for biomass was used (0.33 kgDW/m rope), including a loss rate of 20% to factor in predation, remineralization and destruction of Oceanpods before macroalgae can settle.

Table 1. The carbon content, dry weight and therefrom calculated biomass carbon of an Oceanpod, which includes macroalgae, bamboo and rope.

Type of biomass	Carbon content	Dry weight	Biomass carbon
Macroalgae	0.29% C	13.20 kgDW/Oceanpod	14.21 $kgCO_2$/Oceanpod
Bamboo	0.49% C	1.37 kgDW/Oceanpod	2.48 $kgCO_2$/Oceanpod
Rope	0.44% C	1.31 kgDW/Oceanpod	2.11 $kgCO_2$/Oceanpod
Total			**18.8 $kgCO_2$/Oceanpod**

Lastly, because of a high level of uncertainty in the project emissions, a Life Cycle Assessment (LCA) was used of the full project cycle (cradle-to-grave) to determine the emissions (NewEconomy, 2023). It was found that compared to 1 tCO_2 sequestration, 0.033 tCO_2 is emitted (3.3%), resulting in a net storage potential of **18.2 $kgCO_2$** per Oceanpod.

4.4.1. Scaling the Seaweed Industry – Alexander Ebbing

Alexander Ebbing is a marine biologist with more than a decade of experience in seaweed farming, specialised in the domestication of kelp. Macroalgae have been found to have a large carbon sequestration potential, globally about 600 tCO_2 per year (Krause-Jensen & Duarte, 2016). Kelp (brown seaweeds) are one of the fastest growing plants on Earth. Alexander's goal is to make kelp farming available for everyone and to opensource the technology to successfully cultivate kelp. Here we will introduce this plan and give an example calculation based on data that Alexander has gathered (Ebbing, 2022).

A major bottleneck for regenerative aquaculture is scalability. There have been many good ideas and prototypes for seaweed cultivation, but the real difficulty arises when you want to scale the idea to make a real impact. Considering this, Alexander believes that the necessary scale will only be reached if projects are rolled out decentrally by empowering small-scale farmers. After all, many hands make light work.

A good example of this decentralised approach is the American non-profit Greenwave, who aim to develop large-scale seaweed farms. They believe that the most efficient root for the scaling lies in teaching the craftsmanship of seaweed farming to as many people as possible. Ultimately, they want to convert local fishers into seaweed farmers. After all, fishers are the craftsmen of the sea, and they are ideally suited to provide craftsmanship at sea.

With a view to the European development of the North Sea, this decentralised approach with local fishers can also be critical. Alexander's work has therefore been dedicated to making the craftsmanship of sea cultivation, with an emphasis on seaweed cultivation, possible in a decentralised manner within the EU and the Netherlands. The first step he has taken together with NIOZ, was to develop a new method for kelp cultivation and make it accessible to everyone. By producing and publishing the first open-source bioreactor system (SeaCoRe system), the transition from lab to application has been made (Ebbing et al., 2021). This system helps by allowing seaweed farmers to propagate[8] macroalgae at their kelp farms, without the need for expensive laboratory settings and decentralizing the cultivation process. Now it is just a matter of finding the right players in the EU to bring this to the North Sea in a decentralised manner.

The uncertainties in today's seaweed proposition often arise from the business model. Cultivation of seaweed is currently relatively expensive and the true magic of seaweed biomass only begins when it can be used as a low-quality raw material (bioplastic, biostimulant, livestock feed). This can only be solved through large-scale cultivation, but to get there, many small-scale seaweed farms must first be healthy enough to grow. We must therefore look for a new business model in which there is more to be gained for small-scale farmers than just the value of seaweed biomass.

Alexander's quest in the coming years is to quantify the positive effect of seaweed permaculture and marine cultivation on the surrounding biodiversity. The added value of increased biodiversity can have the much-needed positive effect on the business model of seaweed farms, and marine cultivation in general, which will be essential in the North Sea in the coming years. ONCRA also aims at facilitating distributed growth, which is why a carbon calculation has been conducted for this innovative project.

4.4.2. Seaweed – Example Calculation

An example calculation for the carbon stored in seaweeds has been conducted from data gathered by Ebbing (2022). The calculation is made for giant kelp (*Macrocystis pyrifera),* as this is the largest and fastest growing kelp species.

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[8] Propagate: to breed seaweed by natural processes from the parent stock. For example, when fragments from seaweed plants are used as seeding materials.

Only the carbon stored in the biomass is calculated, as giant kelp is a floating species with no carbon stored directly in the sediment. Biomass carbon is calculated with Formula 3. The carbon content in the dry weight of Macrocystis spp. is assumed to be 26.5% (Zimmerman & Kremer, 1986). The biomass dry weight can be calculated from converting wet weight (WW) measurements to dry weight (DW) values, by:

$$B_{seaweed} = WW * DW/WW\ ratio$$

Table 2. Microcystic spp. wet weight (WW) values and dry weight wet weight ratios (DW/WW) from different studies with the mean shown at the bottom.

Wet weight (WW)		Unit	Source	Dry weight wet weight ratio (DW/WW)		Unit	Source
	25,85	kg/m/yr	(Tussenbroek, 1993)		12,5	%	Roesadji, 2010
	20,1	kg/m/yr	(Druehl & Wheeler, 1986)		12	%	(Hart et al., 1976)
	22	kg/m/yr	(North, 1970)				
	22,6	kg/m/yr			12,2	%	

From the average values of Table 2, the dry weight can be calculated:

$$DW = 22.6kg/m/yr * 12.2\%DW/WW = 2.77kgDW/m/yr = 0.003\ tDW/m/yr$$

Assuming that the kelp is planted in a similar fashion as corn is planted on land with a regular spacing of 1.5 meter, 4444 plants are present per hectare (Ebbing, 2022). Including a survival rate of 70%, the DW can be converted to hectares:

$$DW = 0.003tDW/m/yr * (4444plants/ha * 70\%) = 8.63\ tDW/ha/yr$$

From these values the total CO_2 stored in the biomass of the macroalgae can be calculated:

$$BC_{seaweed} = 26.5\%C * 8.63tDW/ha/yr * (44/12) = 8.39\ tCO2/ha/yr$$

Including the standard emission factor of 20%, a Net Storage Potential of **6.71 tCO2/ha/yr** is found. However, the permanence of the storage still needs to be considered, which is dependent on the usage of the seaweed (e.g. sinking, biostimulant).

5. Next steps

This is a third draft version of the *ONCRA Certification Protocol for Ocean-stored Carbon*. Several steps have been taken and will have to take place before the protocol is finalized:

1. First feedback round: the Climate Cleanup team provided internal feedback.
2. Second feedback round: feedback from selected ocean experts in the Climate Cleanup network was given. This was done to ensure a higher quality of the protocol and to implement the expertise of ocean experts.
3. Third feedback round: through publication on the Climate Cleanup website, an open feedback round by a larger audience is initiated. In addition, ocean experts are contacted personally for feedback.
4. Publishing the OSC protocol: the finished version of the Certification Protocol will be published.
5. Trial certification: a trial certification will be performed with feedback from ocean experts.
6. Certification of ocean projects: different ocean projects will be certified according to the protocol.

6. References

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