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Studies in support of the implementation of the Mission – Wetlands and Blue Carbon

Final Report

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Contents

Abstract

Blue carbon ecosystems (BCEs), including mangroves, salt marshes, and seagrass beds, are vital for climate change mitigation, sequestering carbon at rates much higher than terrestrial ecosystems. Despite their significance, BCEs are increasingly threatened by both natural and human-induced pressures. This study aims to advance understanding of blue carbon in the EU, focusing on greenhouse gas (GHG) reporting, wetland mapping, and sequestration knowledge. Findings highlight inconsistencies in wetland classification and GHG reporting, between EU countries, especially for coastal wetlands. The research reveals gaps in conservation, with many BCEs lacking adequate protection and management. Through improved mapping and monitoring, the study proposes enhanced policy recommendations for better conservation and integration of BCEs into EU climate strategies. Furthermore, the study investigates blue carbon restoration projects, emphasizing barriers such as the absence of reliable sequestration metrics and uncertain financial models. The results stress the importance of standardizing reporting, improving restoration efforts, and leveraging diverse funding mechanisms to maximize the climate mitigation potential of BCEs.

Keywords: *Blue Carbon, coastal ecosystems, carbon sequestration, climate change mitigation, greenhouse gas reporting, wetland mapping, restoration, EU policy, conservation, carbon stocks.*

Executive summary

Blue carbon refers to the carbon captured and stored in coastal and marine ecosystems such as mangroves, salt marshes, and seagrass beds. These ecosystems sequester carbon at rates up to ten times higher per unit area than terrestrial ecosystems, presenting opportunities for climate change mitigation. Because they serve as long-term carbon sinks, the restoration, protection, and sustainable management of blue carbon ecosystems are increasingly explored as climate mitigation strategies. However, despite their critical role, blue carbon ecosystems (BCEs) are among the most threatened marine environments globally, facing degradation from both natural and human-induced pressures. This study aimed to enhance knowledge of blue carbon within the EU, focusing on: (i) assessing current greenhouse gas (GHG) emissions and removal reporting across EU Member States (MS) (*Task 1*), (ii) improving wetland mapping across the EU (*Task 2*), and (iii) advancing knowledge of blue carbon sequestration (*Task 3*). Expert engagement and dissemination of findings were achieved through a stakeholder workshop (*Task 4*) and the preparation of a manuscript for publication (*Task 5*).

Assessment of Blue Carbon Reporting and Accounting (*Task 1*)

Task 1 evaluated GHG inventories and reporting mechanisms to identify gaps in emissions and removal accounting for wetlands. A detailed review of National Inventory Reports (NIRs) assessed how MS estimate and report emissions from freshwater and coastal wetlands. Findings were compiled into a newly developed relational database (*Deliverable 1*) to evaluate completeness, accuracy, and reliability of reporting and an overview was presented (*Deliverable 2*). Key insights included:

- Inconsistent wetland classification: Coastal wetlands are frequently overlooked, with only one MS (Malta) explicitly reporting net CO_2 emissions from coastal wetlands, despite 22 MS having a sea border.
- Gaps in completeness and accuracy: Inconsistent classifications and methodologies contribute to reporting uncertainties, with some significant wetland areas overlooked, such as mangroves in French overseas territories classified under forest land and seagrasses absent from all NIRs.
- Feasibility of EU-wide reporting: Challenges related to land-use data gaps, emission factor uncertainties, and inconsistent national monitoring capacities result in a ‘low to medium’ to ‘medium’ feasibility rating for implementing EU-wide coastal wetland reporting. While remote sensing could enhance completeness, substantial improvements in data collection, methodological standardization, and national implementation are necessary to enhance the

feasibility and reliability of comprehensive reporting. Administrative costs for comprehensive coastal wetland reporting are estimated between €14 million (Tier 1) to €252 million (Tier 3) over 2026–2041.

Wetland Mapping and Protection Status (*Task 2*)

Task 2 examined the distribution, protection status, and temporal changes of BCEs across the EU (*Deliverable 3*) to inform conservation strategies. Analysis of existing spatial data revealed that BCEs span over 2 million hectares across the EU and its outermost regions, with seagrasses comprising the largest share (over 1.4 million ha), followed by tidal marshes (~400,000 ha) and mangroves (primarily in French Guiana). Key findings included:

- Spatial distribution: Distribution of BCEs varies significantly across MS, with Denmark and Italy holding the largest mapped seagrass areas, while Romania and France contain the most extensive tidal marshes.
- Protection gaps: Although many BCEs fall within designated protected areas, conservation management remains inadequate. Strengthening protection under IUCN-defined categories and implementing targeted management measures could improve outcomes.
- Temporal trends: Mixed trends are observed across BCEs. Mangroves in French Guiana are expanding, while tidal marshes exhibit both gains and losses depending on data sources. Seagrass trends remain uncertain due to mapping inconsistencies, but long-term records indicate a net loss of approximately 32,864 hectares between 1869 and 2016.

To support policy development, a Blue Carbon Roadmap (*Deliverable 4*) was created, recommending:

- Enhancing mapping accuracy through systematic protocols and advanced methods (remote sensing, drones, and field validation);
- Standardising monitoring systems across MS to facilitate collaboration, data sharing and alignment with EU-wide objectives;
- Integrating BCE monitoring with EU climate and biodiversity strategies, including the European Green Deal, Biodiversity Strategy 2030, and Marine Strategy Framework Directive;
- Establishing short-, medium-, and long-term objectives for improved monitoring and conservation.

Blue Carbon Sequestration and Restoration (*Task 3*)

Task 3 investigated drivers influencing BCE status and distribution, assessed carbon stocks, and evaluated blue carbon initiatives in the EU (*Deliverable 5*). Key pressures on BCEs include climate change, human activity, land-use changes, and pollution. However, research priorities are often influenced by political interest and funding rather than ecological urgency.

Newly available carbon core data enabled estimates of carbon stocks at depths of 30 cm and 100 cm, confirming that seagrass meadows generally store more carbon than tidal marshes, with deeper soil layers significantly increasing storage potential. The study provided the first EU-wide blue carbon stock estimate, reinforcing BCEs' role in climate mitigation.

An assessment of blue carbon restoration projects across the EU, UK, and Australia identified key barriers to scaling up restoration for climate mitigation:

- Lack of sequestration metrics: Restoration success is typically measured through ecological indicators (e.g., transplant survival), with no before/after sequestration measurements identified for seagrass projects in Europe.
- Uncertain financial models: Carbon revenues are considered a supplementary rather than primary funding mechanism. No European blue carbon restoration projects had generated carbon credits by 2024, suggesting that long-term viability requires combining carbon credits with alternative revenue streams, such as seaweed products, ecosystem service valuation, blended public and philanthropic funding, or direct payments from sectors benefiting from BCE restoration, such as tourism, insurance, and aquaculture.

Conclusion

This study highlights the critical role of BCEs in climate mitigation and biodiversity conservation. While significant progress has been made in understanding BCE distribution and emissions, key challenges remain in reporting consistency, classification accuracy, and financial feasibility. Strengthening EU-wide reporting, improving mapping technologies, integrating BCEs into climate policies, and enhancing restoration efforts will be essential to maximising their climate mitigation potential.

1. Introduction

The European Union (EU) commitment to climate neutrality is outlined in the European Green Deal[1], which aims to transform the EU into a resource-efficient and competitive economy with net-zero emissions by 2050. Numerous initiatives have followed, exploring different sectors' potential to enable climate mitigation, with nature-based solutions increasingly recognized as crucial contributors to these ambitious goals (e.g., 2030 Biodiversity Strategy[2], Fit for 55 Package[3], EU Climate Law[4], Blue Economy Action Plan[5]). As part of this broader environmental and climate policy framework, blue carbon has emerged as a potential component in enhancing carbon sequestration, mitigating greenhouse gas (GHG) emissions, and supporting biodiversity conservation.

Blue carbon ecosystems (BCEs) - such as wetlands, mangroves, seagrasses, and salt marshes - accumulate and store organic carbon within their sediments, making them an important element of climate change mitigation. Strategies to harness their mitigation potential include protection, sustainable management, and restoration of BCEs. Beyond carbon sequestration, BCEs provide crucial ecosystem services, including coastal protection, biodiversity enhancement, and fisheries productivity. Despite their importance, these habitats are among the most threatened marine environments globally, facing rapid degradation due to both natural and anthropogenic pressures[6]. The degradation of these ecosystems not only reduces their carbon sequestration capacity but also leads to the release of stored carbon, potentially turning these vital sinks into sources of GHG emissions. Conversely, effective protection and restoration of BCEs can enhance their carbon sink capacities, contributing significantly to climate change mitigation.

[1] European Commission, 2019. The European Green Deal. Brussels: European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640

[2] European Commission, 2020. EU Biodiversity Strategy for 2030: Bringing nature back into our lives. Brussels: European Commission. Available at: https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en

[3] European Commission, 2021. 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. Brussels: European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

[4] Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R1119

[5] European Commission, 2021. A new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:240:FIN

[6] Moraes, O., 2019. Blue carbon in area-based coastal and marine management schemes – a review. Journal of the Indian Ocean Region, 15(1), pp. 1–15.

Efforts to increase knowledge about BCEs and their carbon storage capacity is advancing, with numerous projects and initiatives being implemented - particularly under the *Horizon Europe Mission 'Restore Our Ocean and Waters by 2030'*. Within its restoration pillar, the Mission supports collaborative projects that develop innovative solutions for blue carbon conservation, enhance monitoring systems, and implement large-scale restoration activities across EU Member States (MS).

The Mission supported this study[7] which aims to contribute to the knowledge of blue carbon storage in the EU. It focuses on:

- Assessing current reporting processes across MS on GHG emissions and removals in wetlands.
- Improving wetland mapping across EU, with an emphasis on identifying land-use change patterns in blue carbon habitats and their underlying drivers.
- Addressing the lack of cohesive information on the effectiveness of past and ongoing initiatives aimed at enhancing blue carbon sequestration.
- Accelerating knowledge transfer on blue carbon sequestration interventions as a potential pathway for climate mitigation.

This report provides a detailed account of the project's achievements, highlights key challenges encountered, and outlines recommendations for future blue carbon conservation and management efforts within the EU.

2. Implementation report

2.1. Task 1

2.1.1. Description of the Task

The overall objective of this project is to extend the knowledge on "blue carbon" to enable preservation of blue carbon ecosystems in the EU and increase carbon sequestration within them to increase GHG mitigation. However, GHG emissions and removals from blue carbon ecosystems are relatively opaque compared to the United Nations Framework Convention on Climate Change (UNFCCC) monitoring of emissions, with different categories and areas represented within different recording categories. Task 1 aimed to identify how Member States within the EU report GHG

[7] CINEA/2023/OP/0005: Studies in Support of the Implementation of the Mission - Wetlands and Blue Carbon.

inventories for the different wetland classes and what this means in terms of climate change. Member States need to follow the reporting guidelines for GHG inventories adopted under the UNFCCC (and under Regulation (EU) 2018/1999, repealing Regulation (EU) No 525/2013 as of 30 December 2020). To assess the GHG inventory for each land use, the Member States follow the IPCC technical guidance. Member States are only required to use the 2006 IPCC Guidelines. According to the Article 20 of the Annex to Decision 18/CMA.1, however, they are encouraged to also use the "2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands". There is further elaboration about the methodologies to estimate emissions and removals in wetlands in the IPCC 2019 Refinement, but this has not yet been adopted under the UNFCCC.

The IPCC categories adopted under the Convention, which are currently used for reporting emissions and removals in wetlands are:

4.D.1. Wetlands remaining wetlands

1.1 Peat extraction remaining peat extraction

1.2 Flooded land remaining flooded land

1.3 Other wetlands remaining other wetlands

(Coastal wetlands, including vegetated (mangroves, saltmarsh and seagrass) and unvegetated)

4.D.2. Land converted to wetlands

2.1 Land converted to peat extraction

2.2 Land converted to flooded land

Land converted to other wetlands

(Coastal wetlands, including vegetated (mangroves, saltmarsh and seagrass) and unvegetated).

Coastal wetlands can potentially occur in any land-use category defined in Chapter 3, Volume 4 of the 2006 IPCC Guidelines (IPCC, 2013). Thus, the GHG emission reporting of wetlands may not match the mapped areas of wetlands reported within other tasks.

2.1.1.1. Sub-task 1.1: Setting the context: estimation, reporting and accounting requirements

2.1.1.1.1 Objective and scope

Overall, the aim of this subtask was to introduce the concept of blue carbon and begin to identify how it was reported within the European Union. This work described the legislation highlighted above and how future carbon estimation, accounting and reporting could be enhanced within the EU.

2.1.1.1.2 Methods

A literature review was performed, focusing on reports produced by the IPCC, EU and blue carbon accounting projects (e.g. Saltmarsh Blue Carbon in UK and NW Europe[8]). As well as a standard literature search using google scholar to enable further understanding of blue carbon and GHG monitoring within the EU.

An extensive stakeholder consultation was conducted by the team. The objectives of this stakeholder consultation were to 1) identify and engage with key GHG inventory practitioners (EU, UK, and USA) who have experience in compiling and reporting wetland inventories; 2) ask for their experience about creating and reporting these inventories, and to summarises the findings of “good practice” for the EU to consider.

Note: Some of the material in this section has been reproduced verbatim from email replies and from transcripts or notes of meetings. This has been done to ensure the reader can make their own judgement about the messages conveyed by the stakeholders. This means that some of the sentences will be colloquial.

Full details of this stakeholder consultation are provided in **Annex B**.

2.1.1.1.3 Results

Full results were presented in the interim report, and a summary is included here:

- Importance of blue carbon. Blue carbon refers to the carbon captured and stored in coastal and marine ecosystems like mangroves, salt marshes and seagrass beds. It has a large mitigation potential as these ecosystems sequester carbon at rates up to 10 times higher than terrestrial ecosystems, offering a nature-based solution for climate change mitigation (Ocean Conservation Trust, 2024). However, these ecosystems are at risk of degradation which can lead to significant carbon emissions. Key threats include pollution, land conversion, hydrological changes, climate change, and over-exploitation.
- Blue Carbon Reporting in the European Union. We report more fully in the introduction to this chapter (section 2.1.1) and in further detail within sections

[8] Mason, V.G., Wood, K.A., Jupe, L.L., Burden, A., Skov, M.W. 2022. Saltmarsh Blue Carbon in UK and NW Europe – evidence synthesis for a UK Saltmarsh Carbon Code. Report to the Natural Environment Investment Readiness Fund. UK Centre for Ecology & Hydrology, Bangor. 36pp

2.1.1.2 and 2.1.1.3 on the full reporting mechanisms related to blue carbon and wetland emissions within the EU.

- **Current Reporting**: EU member states report greenhouse gas (GHG) inventories under UNFCCC guidelines, but blue carbon ecosystems are often aggregated with other wetlands.
- **Legislation**: Regulation (EU) 2023/839 sets targets for carbon removals, including blue carbon ecosystems, aiming for climate neutrality by 2030.
- **IPCC Guidelines**: The IPCC 2013 Wetlands Supplement and 2019 Refinement provide methodologies for estimating emissions and removals from wetlands, but these are voluntary.

- **Future Carbon Estimation, Accounting, and Reporting for EU Member States.** Accurate mapping of blue carbon ecosystems is crucial for effective reporting and climate mitigation efforts, this is discussed further in Task 2. There is ongoing research to enhance blue carbon sequestration and integrate methodologies into GHG inventories. The EU is working on improving knowledge transfer and developing a cohesive approach to blue carbon sequestration, which will inform future policy decisions. It is thought that recording GHG emissions and removals more accurately within the EU may lead to better conservation of these ecosystems, as has happened with other Land Use and Land Use Change and Forestry (LULUCF) categories.

2.1.1.1.4 Key deliverables

Table 2-1 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 2	Presentation of reporting on blue carbon	Final: June 2024	PowerPoint presentation and interim report

2.1.1.2. Sub-task 1.2: EU Member States' wetlands reporting: review and database development

2.1.1.2.1 Objective and scope

The objective of this task was to provide a relational database Microsoft Access, populated with a wide range of GHG inventory data for the wetlands sector from a selection of countries: the EU Member States, the UK and the USA.

The database was created to help determine how the EU Member States estimate and report emissions and removals from wetlands, and whether they include or disregard freshwater and coastal wetlands in their aggregated totals.

This database contains GHG emissions and sequestration for the wetlands sector classified according to the wetlands categories set out in the 2006 GLs, and the 2013 IPCC wetlands supplement. The database also contains a wide range of associated metadata.

2.1.1.2.2 Methods

All data was taken from the GHG inventory submissions to the UNFCCC in 2023. Emissions data was extracted for the years 1990 and 2021, to provide a baseline and the most recent year at the time.

This review task considered the whole of the wetlands reporting category.

A three-step approach was taken:

Step 1: Conducting a high-level review to enable the development of a data capture template

Step 2: Developing a data capture template and relational database

Step 3: Conducting a detailed review, collecting the necessary data and entering the data.

The data collected and entered into the database included:

- Emission sub-categories used for reporting, showing the extent of disaggregation within the wetlands category
- GHG emissions and carbon removals according to IPCC wetlands category (taken from the CRFs)
- Carbon pools considered in estimates of carbon stock change (e.g. above-ground and below-ground biomass, dead organic matter, soil carbon)
- Key Categories, either level, trend, or both (taken from the CRFs)
- Land use (wetland) categories and activities used to classify wetland areas for use in emissions estimation (e.g. vegetation types such as tidal (salt) marsh, seagrass; activities such as extraction, drainage, rewetting) (data taken from the CRFs)
- Methodological Tier used to estimate emissions and removals (data taken from the CRFs)
- Methodological information (taken from the National Inventory Reports (NIRs))

- Classification of emission factors (default, or country specific) (data taken from the CRFs)
- Activity data collected (such as areas of wetlands) (data taken from the CRFs)
- Uncertainties reported (taken from the NIRs)
- Reporting limitations (taken from the NIRs)
- UNFCCC Expert Team Review comments taken from the latest Annual Review Reports. This was used to help identify issues of Transparency Accuracy Completeness Comparability and Consistency (TACCC), and any issues with the wetlands inventory (taken from the NIRs).

The material reviewed was taken from the National Inventory Reports (NIRs) for EU Member States and the Common Reporting Format (CRF) tables for each EU Member State (both available at https://unfccc.int/ghg-inventories-annex-i-parties/2023), the Annual European Union greenhouse gas inventory 1990–2021 and inventory report 2023 Submission to the UNFCCC Secretariat, and the UNFCCC Expert review Team comments for the 2023 submission. Although the CRF tables are available online and in a similar format, there is no Application Programming Interface (API) developed to connect these tables to analysis tools.

For Step 2 (development of the data capture template and relational database), we constructed a database using Microsoft Access.

Data capture templates were developed to enable data entry into the relational database. The data collection template made use of the functionality within MS Access. Records were made available for each EU Member State.

The development of the database was an iterative process, and refinements were made following user testing, including testing by the Commission. In consultation with the Commission, a series of queries and data export options were implemented in the database.

2.1.1.2.3 Results

The main results from the analysis of the data extracted for the database are covered in Sub-task 1.3. High level summary is provided in section below, while a short user guide can be found in Annex A.

Analysis of data – high level summary

The full analysis of the data held in the database is covered in the section on subtask 1.3. However, Figure 2-1 illustrates the variation across Member States for emissions in the two overarching categories 4.D.1 Wetlands remaining Wetlands and

4.D.2 Land converted to Wetlands. Further disaggregation is not possible within a graph, due to the extent of submissions with NO, NA, IE notations (and thus no data). There is variation in emission factors used by the Member States, although many use country specific emission factors (Table 2-2) some do use the IPCC default. There is also variation in tier used to make these assessments, with tiers ranging from tier 1 (IPCC default) to tier 3 (Table 2-2). How tier and emission factor impact reporting is discussed further in 2.1.1.7.

Reporting - high level conclusions

- Often coastal wetland stock change is not included or has been combined with data from other types of wetlands and reported under other wetlands (but this is often not clear). For example, only one EU country (Malta) specifically reports net CO2 emissions from coastal wetlands.
- There are “important” areas of wetlands, including mangroves, in overseas territories. Some Member States (for example France) do consider mangroves in their reporting, but report these in the forest-land category.
- Seagrass is not mentioned in the Member State NIRs, although we know that there are areas of seagrass within the EU (Table 2-2). Salt marshes are also not reported specifically.
- In the EU, 22 Member States have a sea border – so there is potentially a large area of coastal wetlands in the EU. However, countries do not differentiate coastal wetland areas from wetlands in their CRF tables.
- The level of disaggregation used to classify wetlands is very different for each country. For countries who list them, the sub-categories included in the CRF tables are diverse.
- Some countries report more detailed information, with additional sub-categories in the reporting table.
- This illustrates the lack of consistency in the level of disaggregation of the reporting for wetlands between reporting Parties. The source of activity data related to each category or sub-category can be specified in the NIR, but this information is often difficult to locate or is not specified.

Figure 2-1 Net annual CO_2e emissions (positive values) or removals (negative values) from wetlands (kt) for net CO_2 for Wetlands remaining Wetlands (4.D.1) and Land converted to Wetlands (4.D.2)

Data are from CRF tables, table 4.D.1 and 4.D.2, 2023 submission, for reporting year 2021. Where there is no data, the submission returned a value of either IE = included elsewhere; NA = not applicable; NO = not occurring.

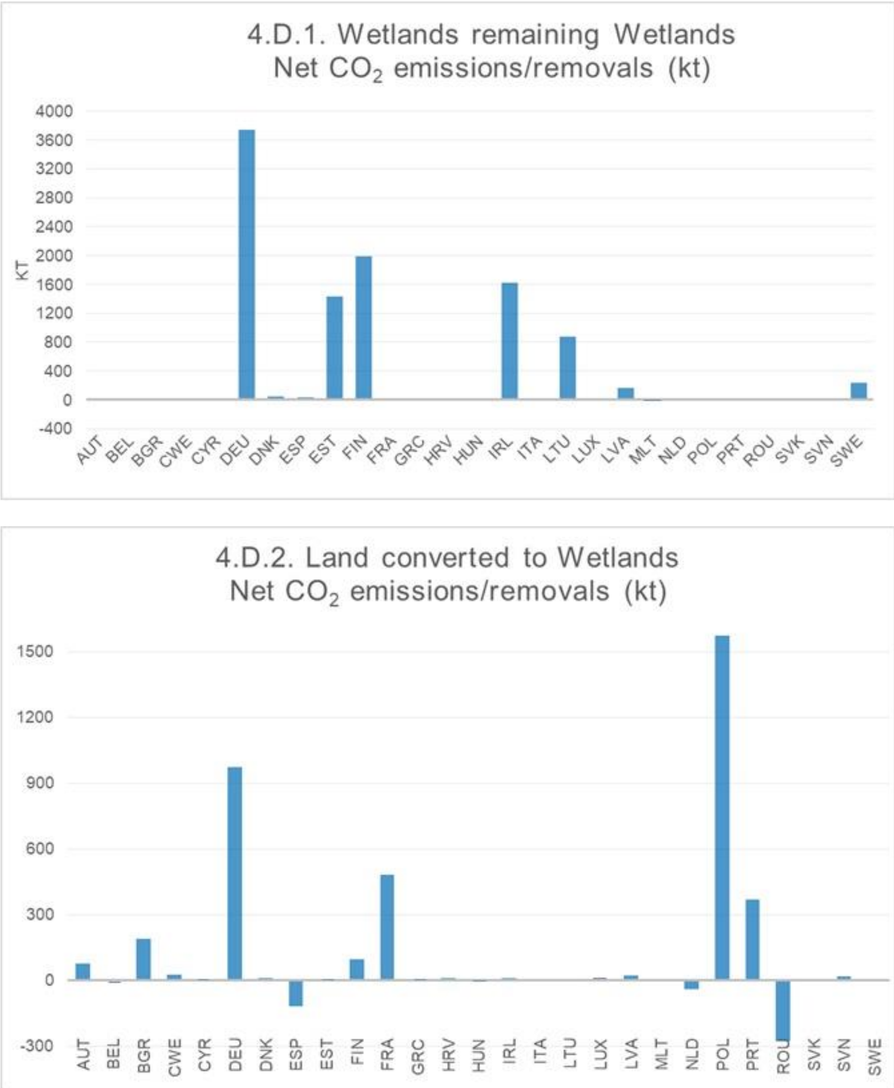


Table 2-2: Emission factor and Tier used by each Member State for reporting CO_2 within the 4.D Wetlands category

Data are from CRF tables, table 4.D, 2023 submission, for reporting year 2021. Acronyms CS = Country Specific; D = IPCC Default; IE = included elsewhere; NA = not applicable; NO = not occurring, if blank, no emission factor / tier stated for CO_2.

Country	Emission Factor	Tier
AUSTRIA	CS	T2, T3

Country	Emission Factor	Tier
BELGIUM	CS	CS, T1
BULGARIA	D	T1
CROATIA	D	T1
CYPRUS	CS, D	T1
CZECH REPUBLIC	CS, D	T1, T2, T3
DENMARK		
ESTONIA	CS, D, OTH	T2
FINLAND	CS, D	T1, T2, T3,
FRANCE	CS, D	T1, T2
GERMANY	CS, D	T2, T3
GREECE		
HUNGARY	D, NO	NO, T1
IRELAND	CS, D	D, T1, T2, T3
ITALY		
LATVIA	CS, D	T1, T2
LITHUANIA	D	T1
LUXEMBOURG	CS, D	T1
MALTA	D, OTH	T1
NETHERLANDS	CS, D	T1, T2
POLAND	D	T1
PORTUGAL	CS, D	D, T1, T2
ROMANIA	CS, D	T1, T2
SLOVAKIA		
SLOVENIA	CS, D	D, T1, T2
SPAIN	CS, D	T1, T2
SWEDEN	CS	T2, T3

2.1.1.2.4 Key deliverables

Table 2-3 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 1	Deliverable 1 relational database to be developed in Microsoft Access or equivalent. This database will show land-use, land use change and	Draft: June 2024	Access database

DLV number	Deliverable name	Date of submission	Format of submission
	associated greenhouse gas emissions and sequestration classified according to 2013 IPCC guidelines.	Final: March 2025	Access database

2.1.1.2.5 Challenges encountered during implementation

- Volume of data:
  - There were 29 NIRs to review (27 MS, UK, and USA). Each NIR is several hundred pages long, and although the section relevant to the wetlands sector is perhaps several pages long, other relevant material might be found in sections which are tens or hundreds of pages long. It was therefore necessary to search the NIRs carefully to ensure all the relevant material was identified.
  - There were 29 CRFs to review. It was not possible to simply copy and paste data from the relevant CRF tables into the database because each of the relevant tables had a unique structure. The project team therefore created code to extract and process the CRF data into a form suitable for the database. It was still necessary, however, to manually review and clean the extracted data before it could be used.
- Variability in level of detail:
  - The level of detail, the location and the transparency of information in the NIRs was variable.
  - The reporting requirements for using the CRF are tightly specified, but there is still some flexibility in the sub-sectoral detail that countries can report. As a consequence, it was necessary to develop software routines that had sufficient flexibility to handle the variability in reporting.
- Strategies used to overcome challenges
  - The team used a member of staff with VBA coding experience to develop software to extract data from the CRFs. It was also necessary to deploy additional resources beyond those initially budgeted to check that the data extracted from the CRFs were in a form suitable for the database.

2.1.1.2.6 Lessons learned and recommendations for future work

The database has been a useful tool to provide data that supports an understanding of how EU Member State wetland emissions are reported. It is recommended that the database is updated with the most recent data at intervals to be decided by the EU Commission.

2.1.1.3. Sub-task 1.3: Classification of greenhouse gas emissions and removals

2.1.1.3.1 Objective and scope

The objective of this task was to classify the land use, land use change and associated greenhouse gas emissions and removals of all wetlands according to the 2013 IPCC guidelines (The 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands[9]). The focus was on evidence for emissions from wetlands, and how these emissions are reported.

The scope of the work included the following:

- collect the estimates of CO2 removals and GHG emissions from wetlands from data that is already available in literature and government reports;
- make estimates of CO2 removals and GHG emissions from wetlands for Member States who do not already report these data, but only if sufficient information is available;
- provide the European Commission with a summary of the reporting by EU Member States, showing how the reporting varies among Member States, and how Member States have classified their estimates of emissions and removals.

There was much interaction between the work under this subtask and other subtasks, particularly sub-task 1.1 (contributed to the evidence review), sub-task 1.2 (used the produced database as an information source), sub-task 1.5A (completeness and accuracy of reporting), and stakeholder consultation activities (Annex B).

2.1.1.3.2 Methods

The evidence review looked for reported emissions from wetlands in the EU, outside of the formal reporting to the UNFCCC. The review was also used to search for data that could allow estimates to be made where these were not reported to the UNFCC.

[9] https://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html Accessed 24 February 2025.

The EU MS CRF tables and NIR documents were interrogated, and extracts were made and incorporated into a database under sub-task 1.2. The database was used in this task to provide summaries of reporting by EU MS.

New estimates of net GHG emissions from wetlands were not made because there was not sufficient information available to do this. The information lacking was activity data at a MS level, specifically areas of wetlands by type of wetland, and with information about management. Consultation with example MS confirmed the need for more activity data.

2.1.1.3.3 Results

Wetlands definitions

The categories used for wetlands reporting to the UNFCCC provide a starting point for definitions used in wetlands reporting. Compilers of GHG national inventories report net emissions in Common Reporting Tables (CRT), and formerly in Common Reporting Format (CRF) tables. The current CRT provided by the UNFCCC allows compilers to use two main categories: wetlands remaining wetlands, and land converted to wetlands. These categories are used to report emissions from managed wetlands. There is no requirement to report emissions from unmanaged wetlands because these emissions are not anthropogenic. For wetlands remaining wetlands there are sub-categories for peat extraction, flooded land, other wetlands and coastal wetlands. For land converted to wetlands, there are multiple sub-categories for conversions from multiple land uses converted to multiple wetland types (e.g. forest land converted to flooded land); there are no categories for conversion to coastal wetlands, so any such conversion would be reported as a conversion to other wetlands.

By reviewing the MS NIR documents, we make the following observations.

<u>Countries provide definitions of “wetlands” in their NIR</u>

We observed that the level of specificity and the range of entities included under wetlands are different from one country to another. Some examples follow.

- In Italy, wetlands include: “lands covered or saturated by water, for all or part of the year. Reservoirs or water bodies regulated by human activities have not been considered”.
- However, in Finland, wetlands include: “peat extraction areas and peatlands that do not fulfil the definition of Forest Land, Cropland, Grassland or Settlements. Inland waters, which comprise reservoirs and natural lakes and rivers, are included in Wetlands. Peat extraction areas, lands converted from

other land use to Wetlands as well as Wetlands that have undergone a change in land management are considered managed lands”.

- The NIR for Germany (published 2023) states that: “Pursuant to the 2006 IPCC Guidelines, the "Wetlands" land-use category must subsume all those land areas where soils are intermittently or constantly waterlogged, or covered with water, and that do not fall within the land-use categories 4.A [forest land], 4.B [cropland], 4.C [grassland] and 4.E [settlements]. In the German inventory, these areas are combined in the sub-categories Terrestrial Wetlands (IPCC: Other Wetlands) and Waters (IPCC: Flooded Land). In addition, all areas that are related to Peat extraction are combined within an additional sub-category under the land-use category Wetlands”
- For the Netherlands, the Wetland land use category mainly comprises open water. Land use on peat areas is mainly Grassland, Cropland, or Settlements. Emissions from drainage in peat areas are included in carbon stock changes in organic soils for these land use categories.

From these examples, we can see that reservoirs are included in the definition in Finland Germany and the Netherlands but excluded in Italy. There are some differences about the inclusion or not of types of peatlands, and sometimes a lack of clarity.

<u>Some countries define some areas of wetlands as unmanaged</u>

- Sweden reports 7,409 kha of wetland area, but only an area of approx. 10 kha that is used for peat extraction is assumed to be managed. This has an important impact on the emission reporting, as only emissions from managed wetlands are reported in the CRF tables.
- In Ireland, wetlands are also split between unmanaged wetlands (including peatlands not commercially exploited, inland marshes, salt marshes, moors and heathland and intertidal flats) and managed peatlands, which are those wetland areas drained for the purpose of commercial exploitation and harvesting of peat for energy and horticultural products.

<u>Coastal wetlands definition</u>

The IPCC 2013 Wetlands Supplement gives a definition of coastal wetlands: “Coastal wetlands generally consist of organic and mineral soils that are covered or saturated, for all or part of the year, by tidal freshwater, brackish or saline water and are vegetated by vascular plants”. Chapter 4 refers specifically to “tidal freshwater and salt marshes, seagrass meadows, and mangroves”.

Some countries like Ireland include coastal wetlands in their definition but list them as unmanaged. Therefore, they are not taken into account in the reporting.

France mentions mangroves in the NIR but includes it under the IPCC category "Forestland". It is possible that some other countries include one or several coastal entities under other IPCC categories.

Wetlands area and relationship to emissions

Analysis of the data provided in CRT/CRF tables and NIRs for each of the EU 27-MS revealed that 81% of the total area for wetlands in the EU can be found in seven MS; and 59% of the total wetland area is found within two countries – Sweden (32%) and Finland (27%) (Table 2-4).

The total area of wetlands reported by MS in the CRF tables include managed and unmanaged wetlands, and emissions are estimated for only managed wetlands. Therefore, it is not unexpected that the reported data indicate that net CO_2e emissions are not proportional to the total area of wetlands. For example, Sweden, the country with the largest area of wetlands, reports emissions equivalent to only 1.15% of net CO_2e emissions from wetlands across the EU. The small percentage is because Sweden assumes large areas of wetlands are unmanaged and therefore the emissions are not anthropogenic and not reported. Germany, accounting for only 3.5% of wetland total area reports the largest net CO_2e emissions equating to 48.2% of the total net CO_2e emissions from wetlands across the EU.

Table 2-4: Areas (kha) of wetlands by EU Member State, and percentages of total rea of wetlands in the EU

Country	Rank	Total area of wetlands (kha)	% of total area of wetlands in EU
SWEDEN	1	7409	31.6%
FINLAND	2	6423	27.4%
POLAND	3	1365	5.8%
IRELAND	4	1226	5.2%
ROMANIA	5	1022	4.4%
NETHERLANDS	6	824	3.5%
GERMANY	7	812	3.5%
FRANCE	8	743	3.2%
SPAIN	9	601	2.6%
ITALY	10	515	2.2%
LATVIA	11	397	1.7%
LITHUANIA	12	361	1.5%
GREECE	13	301	1.3%
HUNGARY	14	269	1.2%
BULGARIA	15	232	1.0%

Country	Rank	Total area of wetlands (kha)	% of total area of wetlands in EU
PORTUGAL	16	186	0.8%
CZECH REPUBLIC	17	169	0.7%
AUSTRIA	18	154	0.7%
DENMARK	19	131	0.6%
SLOVAKIA	20	94	0.4%
CROATIA	21	75	0.3%
BELGIUM	22	56	0.2%
ESTONIA	23	36	0.2%
SLOVENIA	24	15	0.1%
CYPRUS	25	4	0.0%
LUXEMBOURG	26	1	0.0%
MALTA	27	0	0.0%

Source: CRF table published 2023 (2021 data).

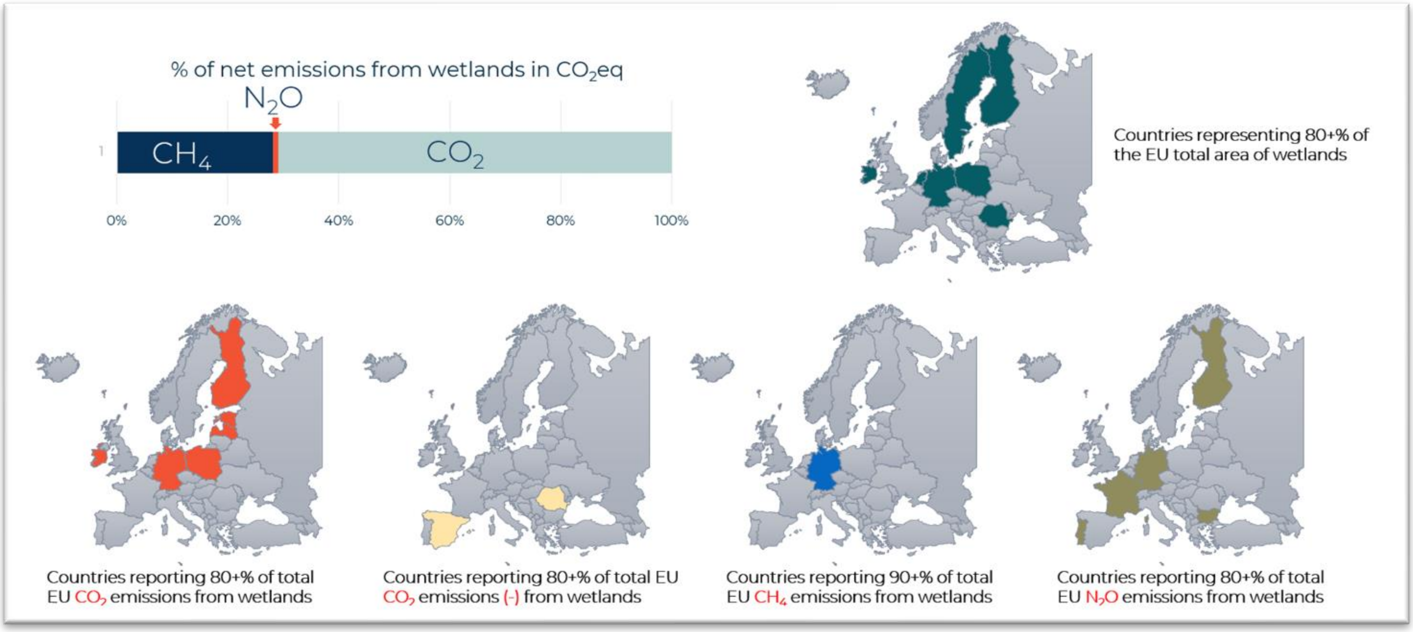
Net emissions from wetlands reported by EU Member States

Error! Reference source not found. provides a visual representation of the reporting of emissions from wetlands in the EU in 2021, based on inventory submissions in 2023. Emissions were dominated by CO_2 and CH_4, with a small contribution from N_2O.

- Of the total net CO_2 emissions in the EU from wetlands, 81% were from five countries: Germany, Finland, Ireland, Poland, Estonia.
- Of the total N_2O emissions in the EU from wetlands, 86% were from five countries: Finland, Germany, Portugal, Bulgaria, France.
- Of the total CH_4 emissions in the EU from wetlands, 92% were from Germany (alone).

The chart also shows the two countries (Romania, Spain) that had 88% of the total net removals (identified as “CO_2 emissions (-)” on the chart) from wetlands in the EU; this is the total net removals from wetlands in countries that reported overall net removals, but we note that for all countries the total net emissions or removals can be a mix of emissions and removals.

Figure 2-2: Overview of the current reporting of wetland emissions in the EU



The large differences between MS in emissions estimates for each gas are shown in the following three tables (Table 2-5, N_2O; Table 2-6, CH_4; Table 2-7, CO_2e). For N_2O (Table 2-5), 20 MS reported emissions, and 91% of the EU N_2O emissions from wetlands were reported by six MS. For CH_4 (Table 2-6), 92% of the EU CH_4 emissions from wetlands were reported by Germany, and only eight out of 27 MS reported any CH_4 emissions from wetlands. For total GHG emissions (CO_2e, Table 2-7), Germany reported the greatest emissions and 92% of net EU emissions from wetlands were reported by the seven countries shown in Table 2-7.

Table 2-5: Emissions of N_2O from the six Member States with greatest N_2O emission estimates.

Country	N_2O emissions (kt)	N_2O emissions (kt CO_2e)	% of EU N_2O emissions from wetlands
FINLAND	0.31	80.9	39
GERMANY	0.15	39.0	19
PORTUGAL	0.09	24.1	12
BULGARIA	0.07	19.4	9
FRANCE	0.06	16.5	8
IRELAND	0.04	11.5	5

Table 2-6: Emissions of CH_4 from the eight Member States with greatest CH_4 emission estimates.

Country	CH_4 emissions (kt)	CH_4 emissions (kt CO_2e)	EU CH_4 emissions from wetlands (%)
GERMANY	196.4	5498.0	92.2
IRELAND	9.4	262.4	4.4
LATVIA	3.1	87.5	1.5
FINLAND	2.7	74.7	1.3
DENMARK	1.3	35.2	0.6
SWEDEN	0.1	4.0	0.1
ESTONIA	0.0	0.1	0.0
SPAIN	0.0	0.0	0.0

Table 2-7: Net emissions of CO_2e from the seven Member States with greatest net CO_2e emission estimates.

Country	Net CO_2e emissions from wetlands (kt)	% of total net CO2e emission in EU
GERMANY	10251	47.3
FINLAND	2243	10.4
IRELAND	2083	9.6
POLAND	1586	7.3
LATVIA	1526	7.0
ESTONIA	1446	6.7
LITHUANIA	876	4.0

For reference, in Table 2-8 the areas of wetlands are presented for each EU MS, together with net emissions or removals for CO_2, CH_4, N_2O and CO_2e. Only five of the 27 MS report net removals of CO_2 (net negative emissions) from wetlands, Table 2-8; of the total net negative emissions reported by EU MS, 68.8% are from Romania, 19.4% Spain and 10.2% from Netherlands. This is the total of national net removals from wetlands in countries that reported overall net removals, but we note that for all countries the total net emissions or removals can be a mix of emissions and removals. There is a range of complex factors that control the magnitudes of emissions and removals and some but not all of this information is presented in the NIRs.

Table 2-8: Net CO_2e emissions (positive values) or removals (negative values) from wetlands (kt) by gas and as total CO_2e as submitted to the UNFCCC by each EU MS.

Country	Net CO_2 emissions from wetlands (kt CO_2)	CH_4 emissions from wetlands (kt CO_2e)	N_2O emissions from wetlands (kt CO_2e)	Total net emission from wetlands (kt CO_2e)
SWEDEN	239	4	1	244
FINLAND	2087	75	81	2243
POLAND	1586	NA	0	1586
IRELAND	1800	262	11	2083
ROMANIA	-279	NO	1	-278
NETHERLANDS	-41	NO, NE	2	-39
GERMANY	4714	5498	39	10251
FRANCE	495	NO, IE, NA	16	518
SPAIN	-79	0	0	-78
ITALY	NO,NE	NO	0	NO
LATVIA	1433	87	6	1526
LITHUANIA	872	NE, NO	4	876
GREECE	2	NO	0	2
HUNGARY	61	NO	0	61
BULGARIA	191	NO	19	211
PORTUGAL	371	NO	24	395
CZECH REPUBLIC	27	NO, NA	0	27
AUSTRIA	76	NO	0	76
DENMARK	54	35	0	90
SLOVAKIA	NO	NO	0	NO
CROATIA	12	NO	1	13
BELGIUM	-4	NA	0	-4
ESTONIA	1444	0	2	1446
SLOVENIA	20	NO	0	20
CYPRUS	0	NO	0	0
LUXEMBOURG	2	NO	0	2
MALTA	-0.01	NO	0	-0.01

Source: Data are from CRF tables, table 4 and 4.D, 2023 submission, for reporting year 2021. IE = included elsewhere; NA = not applicable; NO = not occurring.

Uncertainties

In GHG inventories reported under the UNFCCC, a quantitative uncertainty analysis is performed by estimating the 95 percent confidence interval of the emissions and removals estimates for individual categories and for the total inventory. The IPCC

2006 GLs provides methodologies to estimate uncertainties using two methods: Approach 1 (error propagation – mathematically straightforward) and Approach 2 (Monte Carlo simulation – mathematically more complex). The Approach 1 uncertainties methodology assumes all parameters are normally distributed and does not account for variations in uncertainty in the time series unlike the Monte Carlo approach which takes into account these factors. The 95 percent confidence interval is enclosed by the 2.5th and 97.5th percentiles of the probability density function.[10]

Error! Reference source not found. provides an overview of the uncertainty parameters used by MS in their methodologies to estimate emissions from wetlands, for the five MS representing 82% of CO_2e emissions from wetlands in EU. Four parameters are listed in the table: 1) the combined uncertainty of the activity data and emission factors i.e. on the emissions; 2) the uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty; 3) the uncertainty in trend in national emissions introduced by activity data uncertainty; 4) the uncertainty introduced into the trend in total national emissions.

Table 2-9. Uncertainties (Approach 1) for CO_2 for inventory data year 2021, submission year 2023.

Country	IPCC category	Combined uncertainty (%) (uncertainty on the emissions in the category)	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty (%)	Uncertainty in trend in national emissions introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in total national emissions (%)
Finland	4D1. Wetlands remaining Wetlands	156			9.644
Finland	4D2. Land converted to Wetlands	150			0.452
Germany	4.D Wetlands	29.26	0	0.17	0.03
Ireland	4.D Wetlands	103.7	0.89	0.25	0.85
Latvia	4.D.1 Wetlands remaining Wetlands – Carbon stock change, living biomass	1.098	0.005	0	0

[10] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Volume 1, Chapter 3, p. 3.7.

Country	IPCC category	Combined uncertainty (%) (uncertainty on the emissions in the category)	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty (%)	Uncertainty in trend in national emissions introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in total national emissions (%)
Latvia	4.D.1 Wetlands remaining Wetlands – Carbon stock change, dead organic matter	0.071	0	0	0
Latvia	4.D.1 Wetlands remaining Wetlands – Carbon stock change, organic soils	0.557	0.003	0.001	0
Latvia	4.D.2 Land Converted to Wetland - Carbon stock change, organic soils	2.467	0.004	0	0
Latvia	4.D. Wetlands 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Peat extraction from lands, drained organic soils	0.05	0	0.006	0
Latvia	4.D. Wetlands 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Peat extraction from lands, rewetted organic soils	2.464	0.004	0	0
Poland	4.D Wetlands				

Uncertainties associated with estimating emissions and removals in wetlands are expected to be relatively large as complex biological processes control emissions. Uncertainties reported by Finland and Ireland are large and > 100%. Latvia reports uncertainties of only a few percent, and these are small in absolute terms. Some MS, for example Poland, do not report uncertainties at all. Based on the data in the table, the uncertainty introduced into the trend in total national emissions is relatively small (relative to the combined uncertainty), and where reported are less than 10%. This is an important observation as the uncertainty on the trend in emissions (or removals) can help provide confidence in the outcomes of actions that mitigate emissions or enhance removals.

Allocation of emissions to reporting categories

Evaluation of submissions from EU Member States (MS) National Inventory Reports (NIR) and CRF tables submitted by EU MS to the United Nations Framework Convention on Climate Change (UNFCCC), provided an overview of the current reporting and how emissions are allocated to categories.

The five classifications used by the 2013 IPCC Wetlands Supplement[11] are:

- Drained Inland Organic Soils,
- Rewetted Organic Soils,
- Coastal Wetlands,
- Inland Wetland Mineral Soils,
- Constructed Wetlands for Wastewater Treatment.

These classifications show the coverage of the Wetlands Supplement but are not used for reporting. The Wetlands supplement states that “The lands covered in the Wetlands Supplement may occur in any of the IPCC land-use categories.” The allocation of wetlands emissions to land-use categories is not done in a consistent way between MS. For coastal wetlands, often stock change is not included, or has been combined with data from other types of wetlands and reported under “other wetlands”. For example, only one EU country (Malta) specifically reports net CO_2 emissions from coastal wetlands (-0.0135 kt CO_2). Although Croatia includes “coastal lagoons” in their wetlands definition, they have not separated coastal wetlands emissions from other wetland emissions in the CRF table. The term “coastal wetlands” is not included in any other CRF table or NIR, even though 22 Member States have a sea border. There are important areas of wetlands, including mangroves, in outermost regions of the EU, which are an integral part of the EU. Some MS with outermost regions (for example France) consider mangroves in their reporting, but report these in the forest-land category. Seagrass is not mentioned in the MS NIRs, although we know that there are areas of seagrass within the EU (see Task 2) Salt marshes are also not reported specifically.

[11] https://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html last accessed 27 February 2025.

For coastal wetlands, in summary we note that 22 EU MS have a sea border, but only Malta differentiates coastal wetlands emissions from other wetlands in their CRF tables.

The level of disaggregation used to classify wetlands is very different for each country. For countries who list them, the sub-categories included in the CRF tables are diverse. Member States don't provide the same level of disaggregation in their reporting in CRF table 4.D and are not consistent in the nomenclature used. However, all the MS use the reporting categories required by the UNFCCC, for reporting emissions and removals in wetlands (see Table 2-10).

Table 2-10: Net CO_2 emissions (kt CO_2) for five example EU Member States, and for the UNFCCC reporting categories.

Category	Finland	Germany	Ireland	Latvia	Poland
4.D.1. Wetlands remaining wetlands	1990.7	3740.2	1624.0	161.4	11.8
4.D.1.1 Peat extraction remaining peat extraction	1823.5	2343.8	1624.0	140.7	11.8
4.D.1.2 Flooded land remaining flooded land	3.9	NO	NO	IE,NA	NO,NA
4.D.1.3 Other wetlands remaining other wetlands	163.3	1396.5	NO	20.7	NO
4.D.2. Land converted to wetlands	96.7	973.6	10.3	22.7	1574.1
4.D.2.1 Land converted to peat extraction	20.8	24.3	4.6	NO	1574.1
4.D.2.2 Land converted to flooded land	0.8	NO	NO	NO,IE	NO,NA
4.D.2.3 Land converted to Other Wetlands	75.0	949.3	5.7	22.7	NO

IE = included elsewhere; NA = not applicable; NO = not occurring

Some countries report more detailed information, with additional sub-categories in the reporting table. For example, for the category "4.D.2.2 Land converted to flooded land": 13 countries out of 27 do not have specific sub-categories to detail the reporting of 4.D.2.2. 12 countries have sub-categories "4.D.2.2.1 Forest land converted to flooded land" and "4.D.2.2.2 Cropland converted to flooded land". 13 countries have the sub-category "4.D.2.2.3 Grassland converted to flooded land" and 17 countries report "4.D.2.2.5 Other land converted to flooded land". Some countries disaggregate their reporting even more. Germany for example have seven sub-categories under "4.D.2.2.2 Cropland converted to flooded land".

This illustrates the lack of consistency in the level of disaggregation of the reporting for wetlands between reporting MS. The source of activity data related to each category or sub-category can be specified in the NIR, but this information is often difficult to locate or is not specified.

2.1.1.3.4 Key deliverables

The key deliverables for Task 1 do not relate specifically to this sub-task.

2.1.1.3.5 Challenges encountered during implementation

The challenges encountered during the implementation of this subtask related to availability of data. The data presented by MS in CRF tables and NIR documents were not presented in a consistent way, for example, with differing levels of disaggregation, and this made interpretation of data difficult. This was overcome to some extent by use of the database developed under Sub-task 1.2.

2.1.1.3.6 Lessons learned and recommendations for future work

This sub-task illustrates the lack of consistency in the level of disaggregation of the reporting for wetlands between reporting MS. The source of activity data related to each category or sub-category was to some extent specified in the MS NIRs, but this information was often difficult to locate or was not specified.

Recommendations

- Harmonised definitions across the EU, for managed wetlands, including for managed coastal wetlands, would be a step forward towards a consistent approach to reporting. Wetlands areas that are not managed are not included in assessments of GHG emissions for national inventory reporting, and the extent of wetland exclusion from emissions assessment varies between MS.
- The EU Commission could encourage MS to clearly specify in their NIR whether or not coastal wetlands (tidal freshwater, salt marshes, mangrove, seagrass) are included under the IPCC category "wetlands", and if it's under managed or unmanaged wetlands. This will improve transparency and comparability.
- In the event that the EU seeks to improve the harmonisation of wetland emissions reporting, work will be needed to determine how the timeseries of emissions can be updated, particularly the early years (1990s), when data availability may be more limiting.

2.1.1.4. Sub-task 1.4: Review of coastal wetlands reporting in the USA

2.1.1.4.1 Objective and scope

The objective of this subtask was to examine how the USA produces its reports for coastal wetlands.

The scope of the work was:

- A summary of methodologies used, AD and EFs, QA/QC applied and uncertainties
- A consultation with the USA GHG inventory team to provide insight on the methodological choices the USA has made, how the US team has processed activity data and what, if any, difficulties they have had in doing so.
- A review and summary of any issues in the latest UNFCCC AAR relevant to the wetlands sector.

2.1.1.4.2 Methods

The work included a review of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022, U.S. Environmental Protection Agency (2024), supplemented with information from:

- 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement)
- additional academic articles on USA coastal wetland reporting.
- additional IPCC guidance

We have also held a number of discussions with experts involved in the preparation of the inventory. These discussions have informed this report. Discussions were held to both confirm insights from the review of the inventory and additional articles on USA coastal wetland reporting, as well as to provide additional insights, particularly in regard to the production of activity data.

Discussions were held with:

- Environmental Geoscience Group Member, US Geological Survey;
- Ag/LULUCF lead, Environmental Protection Agency (EPA);
- Two members of Silvestrum Climate Associates - This company compiles the estimates for the inventory.

2.1.1.4.3 Results

Annex C provides details of the findings of the review and consultation with the USA experts. Here we present a summary of the main findings of the review and consultation with the USA experts, with a number of key points of relevance for the EU.

Methodology

In assessing emissions and removals from coastal wetlands, the USA account for the biomass, dead organic material (DOM; including litter and dead wood stocks) and soils of coastal wetlands. They account for emissions and removals from five emission pools:

- Biomass carbon stock changes
- Soil carbon stock changes
- DOM (dead wood & litter) carbon stock changes
- Methane Emissions
- Nitrous Oxide Emissions from Aquaculture in Coastal Wetlands

As the IPCC guidelines direct, the USA inventory does not estimate what the carbon stock is each year but does estimate the change from previous years.

Annex C provides further information on definitions, data sources (activity data and emission factors), key categories, uncertainties; Quality Assurance, Quality Control and Verification; and planned improvements, as well as key methodological deviations from IPCC guidance, gaps and limitations, and outstanding questions.

Activity Data

A summary of the methods the USA uses to produce activity data is included in Annex C. USA experts noted that robust activity data and maps are essential in the production of an inventory.

Seagrass: The USA inventory includes both mangroves and tidal marshes but not seagrasses because activity data is more difficult to gather through remote sensing. Some states in the US are developing programmes to gather activity data and work is underway to examine the feasibility of incorporating seagrass soil and biomass carbon stocks into the 'Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands' inventory estimates. US Inventory compliers are waiting to see how far these states get and then look to replicate methods. Seagrasses are likely to be of relevance for the EU, as this is a more common vegetated state of coastal wetlands in Europe where mangrove wetlands are rare. Therefore, understanding and/or working with the US on seagrass reporting and elsewhere will be key in developing the EU inventory. Consideration will need to be given to what the seaward extent of seagrass activity data should be.

Managed Land: A large part of discussions in the early development of the US inventory focused on whether to use an activity or managed land proxy for wetlands. The USA decided on managed land because nearly every wetland in the USA can be considered managed or influenced by anthropogenic factors. Using managed land has made accounting for emissions a lot easier for the USA as you are looking at land cover change for all wetlands, and then prescribing emission factors associated with that change. Thus, it avoids needing to separate wetlands based on natural and/or managed drivers. USA experts recommended the EU take a similar approach in their own inventories.

Satellite Imagery: The USA utilise remote mapping from the National Oceanic and Atmosphere Administration (NOAA) who source satellite imagery from NASA. There may be an opportunity for the EU to utilise satellite imagery from the European Space Agency (e.g. Copernicus – see Table 2-11) if available. This would ensure consistent activity data across the EU and reduce costs in collection. Otherwise, an option may be to give the Space Agency a role in verification of data.

Mapping: There are various limitations noted by experts related to the mapping data used for the inventory i.e. no distinction between tidal and non-tidal areas. The US Geological Survey noted that it is critical that there are improvements in mapping to be able to visualise where land management of wetlands is needed.

Salinity estimates: A discussion was raised about the potential for assessment of salinity using remote sensing data and spectral information. However, USA experts were not confident that this was possible.

Impounded Waters: Additional commentary on IPCC methods regarding impounded waters was noted.

Certain emission factors are not complete and make estimations uncertain:

- There were discussions in 2017 and an opportunity to include in IPCC methodology emission factors for opening tidal restrictions to impounded waters to increase salinity and reduce methane emissions. This was not included and so remains uncertainty of emission estimates. A 2019 refinement was also not undertaken.
- USA use freshwater emission factors instead for impounded waters to estimate emissions.
- The US EPA is analysing impoundments but are primarily considering larger dams and drinking water reservoirs. However, the issue for coastal wetland reporting is the smaller infrastructure impoundments across larger areas of coastal wetlands i.e. causeways.

Uncertainty

Methane: The biggest uncertainty for the USA is the inventory is methane emissions. This is due to difficulties in assessing salinity conditions between palustrine and estuarine wetlands when developing activity data. It is likely that the EU will face similar uncertainty challenges in relation to reporting methane emissions. In particular, salinity and methane considerations may be more pronounced for an EU inventory as the Mediterranean and Baltic seas have variable salinity. It is yet to be seen if these will be difficult to accurately map along the coast at the level needed for an acceptable level of uncertainty, but this will need to be a consideration.

Depth of Soil Losses: A significant uncertainty for the USA is the depth of soil carbon lost via management activities, sea level rise, or natural impacts such as hurricanes when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands. An assumption of 1 m depth of disturbed soil lost is made, however the actual soil lost and consequently the amount of soil carbon stock, will differ for each loss event. This makes accurately determining emissions difficult. Similar challenges are likely for an EU inventory and will need to be considered.

Impounded wetlands: Impounded wetlands further raise the level of uncertainty associated with methane emissions as hydrological functions may be restricted by transport or other built infrastructure, therefore increasing the palustrine condition of wetlands and methane emissions. Accurate mapping of impounded wetlands and consequently the measurement of methane emissions, would help to reduce uncertainty in the USA inventory. The EU should be aware of the impact of impounded coastal wetlands and the issues of accurately reporting methane emissions. Removing impoundments on coastal wetland natural functions may offer a big opportunity to reduce emissions.

Lateral Carbon Flux: The USA has an ambition to include lateral carbon flux (the tidal exchange of dissolved carbon exported to estuary and coastal waters, that may be stored in the ocean long-term) in the inventory in the future. Lateral transfer of organic carbon to coastal wetlands and to marine sediments within U.S. waters is the subject of ongoing scientific investigation. There is currently no IPCC methodological guidance for lateral fluxes of carbon. For an EU inventory they noted it should look at carbon stock and stock changes in soil, methane changes but may also want to look at lateral flux.

Stratification

The USA stratify wetlands emissions/removals estimates by differing climate zones. Determining how activity data is stratified will be important in determining the accuracy of estimates for EU reporting, particularly due to the wide range of temperatures and climates across the continent.

Workstream Development Approach

Developing methodologies and preparation of the inventory: In discussions with the US EPA, a key recommendation for others developing their own inventory was that a first inventory should aim to use Tier 1 methods. This will allow time for the inventory and Tier 2 methodology to develop over time as there are bound to be difficulties and inconsistencies in activity data initially. US experts noted in initial discussions in their inventory development that there were several differing views and claims around certain models that could undertake Tier 2 and Tier 3 methodology. However, they decided to undertake their first inventory at Tier 1 with the aim to then improve over time to ensure methods were correct and consistent, even though in some cases they had relatively advanced data. There is a risk that if inventory methods are rushed and mistakes are made, that this could lead to a loss of confidence in reporting. This is likely to be particularly important in the political structure of the EU with different members states and different current reporting levels and methodologies.

Consistency and agreement on key issues: Ensuring consistency in the development of activity data and the methods undertaken in inventory compilation in essential. US experts noted that as long as methods were similar or comparable then compilers are able to compare data across different areas of the country/geography. As part of this it is also key to agree on key issues to avoid disagreement or confusion i.e. definitions, or the managed land issue. The recognition of the conversion of coastal wetlands to open water, saw areas of disagreement with some experts pushing for it to be recognised as a natural process, and others viewing it as anthropogenic. In the end the USA recognised it as being affected by rerouted sediment supply. If there is no consistent data unit and classification, particularly across multiple member states in the EU context, processing data can become extremely difficult.

General Approach: USA experts expressed confidence in the robustness of their approach to produce their inventory. They noted that getting key people together early is essential to make sure all involved are clear on scope and methods. A key benefit was getting remote sensing data provided by the NOAA for no cost. US experts also noted that there is always going to be some limitations but as long as they are recognised and managed, then that is appropriate. EU can learn from this overall approach.

Other considerations: The US EPA discussed ways of working within another workstream within the EPA to develop criteria to assess air pollutants. To ensure consistency and manage resourcing, the EPA develop state level estimates which are then given to the individual state offices to sense check data. A similar central management approach could be undertaken within the EU with Member States sense checking data prepared and managed by a central team?

Utilizing the Scientific Community: Once the USA had determined methods, definitions, units, classifications, etc for compiling the inventory they were able to utilize the science community to fill gaps in data. They found many experts across the country had useful data and knowledge to fill data gaps for reporting purposes. Having parameters set, ensured clarity in roles and made it easy to mobilise a lot of expertise quickly. The EU may be able to undertake a similar approach with their own science community once EU reporting begins.

Preparation of estimates: Discussion with USA experts in the development of the inventory have provided insights into how the inventory is developed and prepared. They estimated:

- It is around a two-to-three-year process to get the coastal wetlands section of the inventory compiled and ready for the inventory and a two-to-three-month process to prepare the dataset, primarily because activity data are already compiled by NOAA.
- Remote sensing data development does not require much effort and resourcing for the inventory team because it is already compiled by NOAA. Verifying, including ground truthing, is more difficult and requires more effort.

Cost

Experts gave rough estimates of the relevant cost of preparing the coastal wetland section of the inventory. They estimated a cost of around $50,000 USD annually, based on their expert judgement. This is within the context that they are now undertaking Tier 2 methods for the majority of reporting, and base activity data is largely supplied to them free of charge from NOAA. Very approximately, the cost of developing this data set for the US was 2 million USD and in addition another 2 million USD was spent in verification of the mapping data.

Impacts of Climate Change

Consideration needs to be given to the impacts of climate change and sea level rise on coastal wetlands emissions and removals, and consequently how that is reported. The US Geological Survey noted this is beginning to be explored, with experiments developing models to consider impacts being run at Herring River in Cape Cod, Massachusetts. The NOAA are also starting to explore what the impact of warmer oceans in the face of climate change will be on overall salinity and consequently methane emissions.

Mapping should also be confirmed with ground verification; this will substantially increase costs.

Reporting tools

In terms of collecting reporting data for the inventory, US experts suggested to utilise coding programmes as opposed to spreadsheets. Using spreadsheets as the primary tool makes quality assurance (QA) extremely difficult to undertake. Coding would allow an improved QA process and updates to be made all at once.

2.1.1.4.4 Key deliverables

The key deliverables for Task 1 do not relate specifically to this sub-task.

2.1.1.4.5 Challenges encountered during implementation

The challenges encountered during this review were related to the large amount of information available, both from publications and also from the insight provided by experts. We have provided a summary to capture the key points.

2.1.1.4.6 Lessons learned and recommendations for future work

The USA estimates of costs appear to be surprisingly small (see 0). The main challenges for the USA team related to the availability of activity data and the availability of expertise to make the estimates. A large proportion of the monitoring occurs within different budgets.

The USA started at a low spatial resolution and then increased granularity to state level, this took a lot of time. They recommended that it is best to start at the highest spatial resolution level then aggregate up.

2.1.1.5. Sub-task 1.5A: Completeness and accuracy of reporting by EU Member States

2.1.1.5.1 Objective and scope

The objective was to assess the completeness and accuracy of the reporting of all wetlands – freshwater and coastal.

Completeness means that an inventory covers all sources and sinks for the full geographic coverage, as well as all gases included in the IPCC Guidelines in addition to other existing relevant source/sink categories which are specific to individual Parties (and therefore may not be included in the IPCC Guidelines).

Accuracy is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, so far as can be judged and that uncertainties are reduced so far as is practicable.

Completeness must be assessed before accuracy and is easier to assess than the accuracy of reporting. Completeness can be judged if estimates of emissions and removals are reported from all appropriate sources and sinks in the wetlands sector. Accuracy can be assessed where there is reasonable completeness, and depends on several factors, including the correct application of suitable IPCC methodologies and the quality of the underlying activity data.

2.1.1.5.2 Methods

Completeness checks of EU MS inventories for wetland emissions reporting were achieved by generating and interrogating a relational database using Microsoft Access, populated with a wide range of GHG inventory data for the wetlands sector from a selection of countries, including all EU Member States. Details are in section 2.1.1.2.3

Accuracy, as far as was possible with the lack of transparency regarding completeness, was assessed by examining the recommendations from reviewers of national inventory reports.

2.1.1.5.3 Results

Completeness

This sub-task overlaps significantly with Sub-tasks 1.2 and 1.3 (see earlier sections). Data are presented elsewhere showing which countries have reported wetland emissions removals. In Figure 2-1 Net annual CO2e emissions (positive values) or removals (negative values) from wetlands (kt) for net CO2 for Wetlands remaining Wetlands (4.D.1) and Land converted to Wetlands (4.D.2)

Data are from CRF tables, table 4.D.1 and 4.D.2, 2023 submission, for reporting year 2021. Where there is no data, the submission returned a value of either IE = included elsewhere; NA = not applicable; NO = not occurring., some data are presented showing net CO_2 for Wetlands remaining Wetlands (4.D.1) and Land converted to Wetlands (4.D.2). Further data are shown in Table 2-8, showing total net emission from wetlands (kt CO_2e); that table also shows that all WE MSs except for Italy and Slovakia reported a value for total net emission from wetlands, with Italy and Slovakia using the notation key NO (not occurring). EU MSs varied in the level of disaggregation of reporting net emissions/removals from wetlands, making it difficult to determine the level of completeness for each wetland type.

In the Poland NIR (chap. 6.5.4, pp.264–267), it was reported that default EF values with equation 7.6 and other default parameters of the 2006 IPCC Guidelines (vol. 4, chap. 7, pp.7.9– 7.16) were used for estimating N_2O emissions from drained soils. However, N_2O emissions from drainage and rewetting were reported as “NA” in CRF table 4(II), as noted by the Expert Review Team (ERT). The ERT further recommended that Poland report N_2O emissions from drainage and rewetting of organic soils in CRF table 4(II) in accordance with the UNFCCC Annex I inventory reporting guidelines. The details of the GHG inventory review process under the UNFCCC are provided in the URL of the footnote to this sentence.[12]

Accuracy

Six accuracy issues and recommendations from previous review reports were found from review of 2023 submissions. Four remain unresolved (Belgium, Cyprus, France and Netherlands). Two are currently being addressed (Poland and Portugal).

For Belgium, it was recommended that they apply the organic soils estimation method instead of the mineral soils estimation method for land-use change from wetland to forest land, taking into consideration the occurrence of drainage practices for converted peatlands. The ERT considered that the recommendation had not been resolved because the Party neither applied the organic soils estimation method nor alternatively provided in the NIR the information provided during the review, namely that no wetlands conversions to forest land occur on organic soils.

For Cyprus, the ERT recommended reporting only emissions for newly constructed dams and flooded mines and construction sites and this is not resolved as the Party continued to report in CRF table 4.D removals from mineral soils for land converted to wetland.

France was requested to either report information to demonstrate that the methodology used to estimate carbon stock changes in land converted from and to wetlands produces more accurate and/or precise estimates than the IPCC methodology (2006 IPCC Guidelines, vol. 4, equation 2.26), or apply the IPCC methodology for estimating GHG emissions and removals from drained and rewetted organic soils. Neither has since been implemented due to current land-use monitoring approaches not allowing for accurate tracking of changes in organic soils for wetlands.

[12] https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/review-process

The Netherlands were asked to report the correct estimation results for mineral soils under wetlands remaining wetlands in the NIR and CRF table 4.D. However, the ERT considered that this was not addressed because the Netherlands has not corrected the allocation of carbon stock changes in mineral soils in the wetlands remaining wetlands category.

Poland has not used the correct notation key "NE" for reporting net carbon stock change in soils for subcategory 4.D.1.2.

It was recommended that Portugal revise the assumption of constant areas for wetlands, settlements and other land between 1970 and 1994, which is currently being addressed.

Three additional findings and recommendations were made during the individual review of the Party's 2022 annual submission for Ireland (1) and Malta (2).

For Ireland, reporting may not be in accordance with the UNFCCC Annex I inventory guidelines as CH_4 the implied emission factor per unit area for drained organic soils in wetlands used in CRF table 4(II) for 2020 (99.16 kg CH_4/ha) is the highest of all reporting Parties. It was recommended that the correct CH4 emissions data be presented in subsequent submissions.

Malta submitted estimates for carbon stock change from category 4.D.2 land converted to wetlands for the first time in the 2022 submission. Carbon stock change was noted as constant; however, this was not the case and it was recommended that the correct carbon stock changes in biomass and soil for category 4.D.1 wetlands remaining wetlands are calculated from the area time series and reported. Secondly, soil carbon stock changes arising from conversion to wetlands were reported as zero which contradicts the NIR. The ERT recommended that Malta update the calculation for soil carbon stock change in category 4.D.2 using the EF for recolonization of tidal marsh in its CRF tables and NIR in its next submission.

Uncertainties associated with estimating emissions and removals in wetlands are expected to be relatively large as complex biological processes control emissions. However again there was large variations across EU MS, for example Finland and Ireland report uncertainties greater than 100%; Germany reports uncertainties of approximately 30%, but Latvia reports uncertainties that are very small at less than 5% and Poland does not report uncertainties.

2.1.1.5.4 Key deliverables

The key deliverables for Task 1 were not allocated to this sub-task.

2.1.1.5.5 Challenges encountered during implementation

Please see sections 2.1.1.2.5 and 2.1.1.3.5.

2.1.1.5.6 Lessons learned and recommendations for future work

Please see sections 2.1.1.2.6 and 2.1.1.3.6.

To overcome some of the challenges, the following recommendations could be considered.

Immediate actions

- The EU could encourage MS to clearly specify in their NIR whether or not coastal wetlands (tidal freshwater, salt marshes, mangrove, seagrass) are included under the IPCC category "wetlands" for both wetland areas and reporting of emissions, and whether they are listed under managed or unmanaged wetlands. This will improve transparency and comparability.
- The EU could increase the transparency of reporting by encouraging Member States to include coastal wetlands as a subcategory in the CRF table 4.D, most likely under 4.D.1.3 Other wetlands remaining other wetlands or 4.D.2.3 Land converted to other wetlands.

Looking to the future

- Implement new methodologies: The EU could encourage all the MS to implement the methodologies in the IPCC WS methodologies for estimating GHG fluxes from wetland ecosystems. This implementation may need support from the Commission to help the work to be done efficiently, and to ensure methodological compatibility between MS.
- Expand activity data collection: Countries would need to gather data on wetland areas that were not previously included, such as coastal wetlands (mangroves, tidal marshes, seagrass meadows), inland organic soils, and constructed wetlands for wastewater treatment.
- Use updated emission factors: The WS provides updated emission factors for various wetland types, which need to be applied in calculations.
- Conduct more sophisticated inventories: For countries where wetlands are a major source of emissions, reporting will need to go beyond the minimum Tier 1 and conduct more detailed Tier 2 and 3 inventories.
- Assess wetland extent: Countries need to estimate the area of their various wetland types to use with the provided emission factors.

- Include new wetland categories: The inventory needs to be expanded to include categories like coastal wetlands that were not previously covered.
- Monitor land-use changes: Countries need to track changes in wetland areas and management practices over time to accurately report emissions and removals.
- Develop country-specific data: To move beyond Tier 1 reporting, countries might need to develop their own emission factors and activity data specific to their national circumstances.
- Train personnel: Staff responsible for inventory compilation are likely to need training in the new methodologies and emission factors.
- Updates to reporting systems: National inventory systems and reporting formats may need to be updated to accommodate the new wetland categories and data.

These additional activities would allow countries to produce more complete and accurate estimates of GHG fluxes from wetland ecosystems in their national inventories and improve the transparency of reporting.

2.1.1.6. Sub-task 1.5B: International efforts to improve reporting

2.1.1.6.1 Objective and scope

These results of this task summarise our assessment of the ongoing efforts at an international level to improve the reporting of all GHG inventories in wetlands, both coastal and freshwater. The task was one part of this large project, so necessarily it is a fairly “light touch” review.

In the last decade, the IPCC Task Force on National GHG inventories has made considerable progress to update the guidance available to GHG inventory compilers regarding wetlands. Key developments include the 2013 Wetlands Supplement and the 2019 Refinement. However, since the publication of the Wetlands Supplement, there have been considerable scientific advances in the understanding of the magnitude and causal factors controlling GHG emissions and carbon fluxes in wetlands, and this short literature review has identified relevant material.

2.1.1.6.2 Methods

The method used for performing the evidence review was based on the Natural England (2013) evidence review methodology to ensure a systematic approach. The scope of the review focused on the reporting of wetlands globally, and the classification and methodologies used to estimate inventories for different countries worldwide that have wetlands.

Our review had five main steps:

1. Define search strategy including keyword list compilation and define inclusion/exclusion criteria.
2. Searching for evidence and record findings.
3. Title and abstract screen.
4. Evidence extraction.
5. Evidence synthesis and evidence gap identification.

2.1.1.6.3 Results

Methods for identifying activities and areas

Although the reporting requirements of the GHG inventory submissions under the UNFCCC do not specifically focus on wetlands (or coastal blue carbon ecosystems), all countries are encouraged to use the 2013 Wetlands Supplement alongside the 2006 IPCC guidelines. It is thought that if wetland emissions and removals are reported more accurately there will be a greater drive to conserve these areas and consider them to be more valuable assets. For example, the Ramsar Convention on Wetlands (first signed in 1971), was one of the first international conservation agreements, promoting the importance of wetlands globally (Kingsford, et al., 2021). One of its key initiatives was the development of the Ramsar Sites Information Service (RSIS), which collects and disseminates data on wetlands of international importance. The RSIS includes detailed information on wetland types, ecological characteristics, and threats, helping to improve the identification and reporting of wetland areas. Although studies have shown that these voluntary schemes may not be as effective as national reporting (Davidson et al., 2019). The Convention on Biological Diversity's Global Biodiversity Framework includes specific targets for the restoration and protection of wetlands and links to the other aforementioned organisations (Ramsar and UNFCCC). The framework encourages countries to adopt national targets and action plans for wetland conservation, integrating wetland data into broader biodiversity monitoring efforts.

Improving the identification of activity data and areas for wetlands involves several methodologies, including remote sensing, field surveys, and data integration (Table 2-11). Remote sensing technologies (satellite imagery, drones and aerial photography) are increasingly used to map and monitor wetlands. These tools provide high-resolution data that can be used to identify wetland boundaries, assess changes over time, and detect disturbances (US EPA, 2002). Existing remote sensing approaches can be used to map vegetation and inundation dynamics which could improve both emissions accounting and carbon burial rates. There have been recent improvements in mapping coastal wetland vegetation biomass, vegetation species classification and seasonal dynamics (Holmquist et al., 2018). Field surveys are essential for ground-truthing remote sensing data and collecting detailed information on wetland characteristics. These surveys involve measuring physical, chemical, and biological parameters to assess wetland health and function. For example, Brophy et al., (2019) used ground truthing alongside LiDAR elevation mapping to measure estuary loss. However, the key to providing accurate activity data is through thorough data integration from multiple sources to enable comprehensive wetland reporting, thus combining the remote sensing data with ground truthing and existing databases to create a unified dataset. Table 2-11 provides examples of the different monitoring tools available.

Land representation is a critical component of national greenhouse gas (GHG) inventories, as it ensures that land-use categories and changes are accurately captured and reported. For the majority of land uses, spatially explicit land-use data is presented which includes detailed maps and GIS data. It is good practice that a country clearly defines the concept of 'coastal land' for example seagrasses may not fall under typical national land representation rules. Defining the concept of 'coastal land' and its seaward limits can assist overcoming such challenges (Green et al., 2021). Definitions used from the IPCC refer to coastal lands being based on their proximity to the coastline and their ecological characteristics, whilst Ramsar information may assist in these definitions. However, inclusion of mangroves may also be dependent on the national definition of Forest Lands (LULUCF) (Green et al., 2021).

Table 2-11: Monitoring tools to support reporting of GHG emissions and removals from wetlands (coastal and freshwater).

Method	Description	Reference
Stakeholder consultation (as part of project)	Interviews with • IPCC Lead author; • UK CEH (UK GHG Inventory Team); • US GHG Inventory team; • Stakeholder Workshop These interviews revealed the status of the implementation of the Wetland Supplement methodologies, and the costs and timescales of this work.	See in this report Annex B and Section 2.1.1.4Review of US Coastal Wetlands
National or regional level wetland monitoring and assessment programmes	CONUS is the coastal wetland inventory for the United States. This was calculated by combining maps of wetland type and change with soil, biomass, and methane flux data from literature reviews. The US Inventory approach for coastal wetlands applies a general methodology of: (1) defining the coastal land base, recognized as all lands that include wetlands seawards of the highest tides and landward of the extent of the US land representation	Holmquist et al., 2018

Method	Description	Reference
	Canadian Wetland Inventory (CWI) is a national initiative aimed at mapping and monitoring wetlands across the country. The CWI uses a combination of remote sensing, field surveys, and GIS technologies to create detailed maps of wetland areas, although only recently has this been achieved, through google earth Landsat, and sentinel mapping.	Fournier et al., (2007); Amani et al., 2019; 2021
	The Australian Wetlands Monitoring and Assessment Program (WetMAP), established in 2014, focuses on measuring the effects of environmental water on wetland ecosystems, including vegetation and fauna. Mainly in the state of Victoria, it provides information on the ecological status of the wetlands and biodiversity within them.	Papas et al., 2021
	Wetlands international is the only network organisation in Europe bringing together non-governmental organisations with a shared objective to safeguard and restore wetlands. Wetlands International used to have a Wetland Inventory and Monitoring Specialist Group (WIMSG), for mapping however this now part of the Global Wetland Outlook.	Tooth and Waal, 2019
National GHG inventories (GHGI) and NDC reporting	The US GHG Inventory approach for coastal wetlands applies a general methodology of defining the coastal land base, recognized as all lands that include wetlands seawards of the highest tides and landward of the extent of the US land representation (see task 1.4 for more details on the USA Coastal Wetlands reporting)	Crooks et al., 2018
	Fiji has combined tiered approaches to include mangroves and seagrasses within it's national GHG reporting. Mangrove ecosystems have begun to be evaluated, mapped and carbon stocks assessed, supporting development of tier 2 inventory reports. Seagrass and tidal marshes have not been measured or monitored to the same extent and currently tier 1 data is used.	Green et al., 2021
	Indonesia has included substantial areas of mangroves within their NIR/NIDs these are under the forest land use category (https://unfccc.int/sites/default/files/resource/Indonesia%20NID1.pdf). However, research is ongoing in refining emission factors for GHG reporting for mangroves and peatland, as well as the measurement of GHG fluxes within tropical coastal wetlands.	Murdiyarso, et al., 2024; Comer-Warner et al., 2022.
Carbon accounting modelling approaches and concepts	BlueCAM uses Australian data to estimate abatement from carbon and greenhouse gas sources and sinks arising from coastal wetland restoration (via tidal restoration) and aligns with the Intergovernmental Panel for Climate Change guidelines for national GHG inventories. BlueCAM uses different parameter values for each climatic region, thereby estimating regionally specific abatement when implementing coastal wetland restoration.	Lovelock et al 2023

Method	Description	Reference
	Regional carbon cycle assessment and processes (RECCAP2) (now includes coastal ecosystems (blue carbon). RECCAP2 is a bottom-up effort by the global research community and driven by the Global Carbon Project with partner groups which builds from existing lobal and regional projects and voluntary contributions. RECCAP2 will design and perform a set of global syntheses and regional GHG budgets of all lands and oceans and explore mechanisms by which to deliver regular updates of these regional assessments based on scientific evidence, considering uncertainties, understanding of drivers, and retrospective analysis of recent trends.	Global Carbon project (https://www.globalcarbon project. org/reccap/)
Voluntary methodologies	UK Saltmarsh Carbon Code, phase 1 undertook a feasibility analysis of the Verified Carbon Standard VM0003 vs. a UK code. Provided recommendations on the best way forward to develop a fully operational UK domestic Saltmarsh Code.	CEH, 2025
	Verra – Verified Carbon Standards (VCS) methodologies, VM0033 methodology for tidal wetlands and seagrass restoration. Methodology outlines procedures to quantify net GHG emission reductions and removals from restoration that can be used for carbon accounting.	Verra, 2025
Remote sensing and satellite imagery	Group on Earth Observations Wetlands Initiative provides a framework for cooperation, development and communication in the field of earth observations of wetlands. GEO-Wetlands offers a Community of Practice as a platform for cooperation and knowledge-exchange; thereby, serving as a framework for collaborative development of the Global Wetlands Observation System.	Rebelo, et al (2018)
	Sentinel-2 is an Earth observation mission from the Copernicus Programme. It aims to monitor changes in land surface conditions. The satellites have a wide swath width (290 km) and a high revisit time. This capability will support monitoring of changes on the Earth's surface. Remote sensing techniques for GHG inventories: Sentinel-2 is the recommended option as for more details assessments of spatial extent, density, and species compositions for mangroves at smaller scales (e.g., 100–1000 ha)	Sentinel-2 | Copernicus Data Space Ecosystem Malerba et al., 2023
	Copernicus is an Earth Observation programme and is one of the key drivers of publicly available global environmental data and monitoring systems. Under the Dynamic Land Cover product, Copernicus offers annual global land cover maps and cover fraction layers, providing a detailed view of land cover at three classification levels. It uses modern data analysis techniques to ensure temporal consistency and accuracy. It includes continuous field layers, or "fraction maps", that provide proportional estimates for vegetation and ground cover for the land cover types. Coastal data held includes inland marshes, exploited peat bogs, unexploited peat bogs and salt marshes. Land cover and land use mapping produces land cover classifications at various level of detail, both within a pan-European and global context. At the pan-European level, these are complemented by detailed layers on land cover characteristics, such as imperviousness, forests, grassland, water and wetness and small woody features. At global level, the land cover mapping follows the FAO's modular-hierarchical Land Cover Classification System.	www.copernicus.eu

Method	Description	Reference
	LandSat. In the US, the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) is a Landsat-based land cover mapping product with 23 land cover classes, including six types of intertidal wetlands defined by two types of salinity (palustrine and estuarine) and three types of vegetation (emergent, scrub/shrub, and forested). Remote sensing techniques for GHG inventories: Landsat imagery is the recommended option for mapping mangrove forest dynamics at large scales (>1000 ha) over half a century. The Landsat archive offers nearly biweekly global imagery since 1972 and is one of the most widely used remote sensing datasets for mapping exercises	Holmquist et al., 2018; Malerba et al., 2023
Global datasets and mapping projects	The global Marsh soil organic carbon (MarSOC) dataset can be used to support large-scale models of soil carbon in tidal marshes and improve global estimates of carbon stored in these coastal ecosystems. The MarSOC dataset includes 17,454 data points, The tidal Marsh Soil Organic Carbon (MarSOC) database contains 17,454 data points, each with geographic coordinates, collection year, soil depth, and site information (country, site name) from 2,329 unique locations, and 29 countries. The MarSOC dataset can be used for new global or large-scale estimates of tidal marsh soil organic carbon and also provide a foundation for additional data collection and collaboration to improve soil organic carbon in tidal marsh estimates, especially from underrepresented areas.	Maxwell et al., 2023
	OpenLandMap is an open compendium of global (gridded) environmental datasets (bio-geophysical variables). The OpenLandMap presents systematic listings of published data sets with emphasis on publicly available data sets available under open data license	OpenLandMap.org
	The Global Lakes and Wetlands Database (GLWD) v2 distinguishes a total of 33 non-overlapping wetland classes and provides a static map of the world's inland surface waters. The total combined extent of all classes including all inland and coastal waterbodies and wetlands of all inundation frequencies, covers 18.2 million km^2, equivalent to 13.4 % of total global land area.	Lehner, et al., 2025

Classification of activities – how countries define their wetlands

The UNFCCC has established guidelines for the classification and reporting of GHG inventories. These guidelines ensure that countries provide consistent, transparent, and comparable data on GHG emissions and removals (see Sub-task 1.5A and 1.5C for further information). The classification system is designed to categorise emissions and removals by sources and sinks, facilitating accurate tracking and reporting, and ensures consistency across countries worldwide. However, how a country categorises their wetlands can vary between nations, as the interpretation of the wetland reporting category may lead to some areas being considered as forest e.g. mangroves can be defined as 'forest' dependent on canopy height, which has important implications for wetland reporting with the NIRs (Brown et al., 2021). Activities data are typically interpreted as the area coverage of land cover type and/or land cover change events (Holmquist et al., 2018) combined with management. Table 2-12 highlights some brief case study examples of the process and classification differences between countries.

Table 2-12: In brief case study examples of the process and classification of wetland reporting.

Country	Process	Classification	Reference
Australia	Since 2017, Australia has reported coastal wetlands within its GHG inventory and reported mangroves within its forest category. It provides annual activity and emissions data for coastal aquaculture production and seagrass removal due to capital dredging projects. The seagrass excavation model has a Tier 2 model structure using country-specific parameter values estimated from pooled data collected from the scientific literature and stratified by coastal region. For mangroves the inventory uses the Full Carbon Accounting Model (FullCAM) to estimate emissions and removals from the LULUCF sector at Tier 3.	Mangrove forests, tidal marshes and seagrasses are present in Australia's tidal and near coastal zones. Combined they cover up to 12 million hectares of coastal wetlands around Australia's 60,000-kilometre coastline (mainland plus islands) and store an estimated 3 billion tonnes of carbon, mostly in the soil. As mangrove forests are generally bordered by seawater on the lower side and by salt marsh on the higher side, it is assumed that any emerging coastal mangrove forest does so on land which was previously tidal marsh or bare tidal flat and is therefore allocated to wetland converted to forest land	Australia, NIR 2022
Costa Rica	Currently the inventory using Tier 1 emission factors for wetlands. However, through the EPA and the US Department of State's Transparency Accelerator for Greenhouse Gas Inventories, Costa Rica is acquiring necessary new technical capacities to implement the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement as part of their national GHG inventory systems	Costa Rica has a National Wetland Inventory to map and protect its coastal wetlands including 22,000 hectares of mangroves (99% of which are on the pacific coast). Costa Rica has all known types of tropical wetlands, including peatlands, palm swamps, salt marshes, coral reefs, seagrass beds, mangroves, and others. The National Wetlands Policy, established by Decree No. 40244-MINAE-PLA, outlines vigorous actions for the recovery of those wetlands that have suffered deterioration and are under threat, in addition to recognising their ecosystem services.	Blue Carbon Partnership 2023

Country	Process	Classification	Reference
Brazil	The parameters and emission/removal factors for each carbon pool of the different land uses and covers were estimated based on studies carried out in the country (Tier 2) and, in the absence of national data, default IPCC data (Tier 1) was used.	Brazil includes areas of marshes (formation in coastal zones), swamps, peat bogs or natural or artificial, permanent or temporary, stagnant or flowing, fresh, brackish or salty waters (excluding oceans). However, in their reporting classification this category is subdivided into Water (rivers and lakes) and Reservoirs, rather than mangroves and seagrasses etc, even though Brazil has the second largest area of mangroves worldwide.	da S. Bezerra, et al., 2022 ; Brazil NIR 2022

Governments need to know the location and extent of wetlands in their country and how their distribution has changed over time for the purposes of inventory reporting. This is generally accomplished by using remote sensing imagery and a geographic information system (Table 2-11) to compare, the historical changes in land use/ land cover for any number of target ecosystems, including wetlands. As part of inventory reporting, the level of detail can increase overtime, with the inclusion of default tier 1 emission data as a starting point for an inventory, which can develop to include more country specific data (subtask 1.5c). Indicators of ecosystem function and services could be more accurate if they were informed by datasets of ecological condition (Brown et al., 2021).

Data Gaps

A review of Nationally Determined Contributions (NDCs) showed that of the 163 submitted NDCs only 28 countries included a reference to coastal wetlands and that these coastal wetland systems were not uniformly integrated into their reporting (Herr, et al., 2017). Data gaps may be due to difficulties mapping the land coverage, classifying the wetland (activity data) – potentially being missed between surveys e.g. forests compared to rivers, or estuaries compared to marsh and grassland or in historical inaccuracy.

The Ocean Health Index (OHI), a comprehensive framework to assess and track the health of marine ecosystems globally and has completed assessments of coastal wetlands, however these are affected by data gaps which are perpetuated across conservation mechanisms (Brown et al., 2021). For example, the OHI scores are linked to IUCN Red List of Threatened Species assessments, so the same data gaps (such as coastal wetlands) will impact IUCN Red List assessments (Brown et al., 2021). Where wetlands have been classified as unmanaged, they do not need to be included within the inventory assessments, there are large differences in the methodology a country has used to define their classification (Table 2-12).

Greater standardisation across countries would improve our understanding of the importance of wetlands related to GHG emissions and removals and enhance conservation efforts.

Mapping

It is important to note that coastal wetlands are spread across both the land and the sea, but many indicators are developed for either the land or the sea, and are not intended to cross the coastal transition, so there is a gap at the coastal interface, (Brown et al., 2021). Often it is difficult to adequately map tidal flooding depth and inundation time at relevant scales and could be improved by integrating additional remote sensing and modelling data (Holmquist et al., 2018) as highlighted in Table 2-11. There are also issues related to water depth and turbidity. There is little guidance on remote sensing techniques for monitoring, reporting, and verifying blue carbon assets, while IPCC encourages Tier 3 methods where feasible, many countries currently use lower-tier methods due to constraints linked to limited data, technical resources, and financing (Malerba et al., 2023).

Classification – activity data and emission factors

Often countries want the emission factors used within their assessments to be country specific. For example, to account for coastal habitat in a UK-specific context (Tier 2), emission factors would need to be developed using direct measurements of soil C stock and GHG emissions (Burden and Clilverd, 2022). Data gaps may also relate to carbon sequestration for that ecosystem. Often depth, salinity and inundation gradients relevant to key GHG fluxes are also missing from datasets (Holmquist et al., 2018). Where one country may have a great depth of expertise, this is often country-specific data and may not be readily extrapolated globally thus knowledge gaps remain and limit the application of methodologies, an example of this is the estimation of methane emissions from fresh and brackish tidal wetlands, lack of validation of the approach for the estimation of recalcitrant allochthonous carbon, and understanding of carbon oxidation rates following drainage of mineral tidal wetland soils outside of the USA (Needelman, et al., 2018) where the research was developed, prevents its transfer to other countries. Some aspects of our understanding of wetlands are globally under researched within inventory reports, for example there is little data on the abundance and distribution of agricultural ponds in most of the world, and this knowledge gap complicates their inclusion in national GHG inventories (Malerba et al., 2022). Also, monitoring of tidal marshes and seagrass meadows is considerably less accurate due to limitations in separating these classes from other land cover types (Malerba et al., 2023). Globally precise information on the extent of tidal marshes, distribution change, or other ecosystem functions is lacking, highlighting a critical research gap given their potential value for climate change mitigation (Maxwell et al., 2023). Although recent estimates suggest that tidal marshes span over 52,880 km^2 across 120 countries (Worthington et al., 2023).

Historical data

If time series data back to 1990 are unavailable, it is suggested that surrogate data should be used, derived from statistical reports/databases containing information on temporal changes in proxy factors (Green et al., 2021).

A study on the Global Carbon budget by Friedlingstein et al., (2023) found that comparison of estimates from multiple approaches showed there were persistent large uncertainties in the estimate of land-use change emissions, a low agreement between the different methods on the magnitude of the land CO_2 flux and a discrepancy between the different methods on the strength of the ocean sink over the last decade. The data and models underpinning national GHG inventories are continually improving, although some data gaps remain, especially regarding flux of GHGs in blue carbon ecosystems, spatial patterns in emissions and removals within and among ecosystems, and the contribution of seagrasses (Vanderklift et al., 2022). Often mangroves are categorised under forest land use for the national inventory reporting, related to the canopy height of the mangrove. However, as 48-98% of carbon is stored within the soil of these ecosystems (Donato et al., 2011), it may be more appropriate for them to be accounted for under wetlands as they represent a large component of blue carbon ecosystems.

Overall, to date, very few countries have included coastal wetlands in their national GHG inventory, although there is growing interest in doing so. Ensuring that coastal wetlands are represented in ecosystem assessments will improve conservation outcomes.

2.1.1.6.4 Key deliverables

The key deliverables for Task 1 were not allocated to this sub-task.

2.1.1.6.5 Challenges encountered during implementation

Please see sections 2.1.1.2.5 and 2.1.1.3.5.

2.1.1.6.6 Lessons learned and recommendations for future work

Please see sections 2.1.1.2.6, 2.1.1.3.6 and 2.1.1.5.6

2.1.1.6.7 References

Amani, M., Mahdavi, S., Afshar, M., Brisco, B., Huang, W., Mohammad Javad Mirzadeh, S., White, L., Banks, S., Montgomery, J., & Hopkinson, C. (2019). Canadian Wetland Inventory using Google Earth Engine: The First Map and Preliminary Results. Remote Sensing, 11(7), 842. https://doi.org/10.3390/rs11070842

Amani, M., Brisco, B., Mahdavi, S., Ghorbanian, A., Moghimi, A., DeLancey, E.R., Merchant, M., Jahncke, R., Fedorchuk, L., Mui, A., Fisette, T., Kakooei, M., Ahmadi, S.A., Leblon, B., LaRocque, A., (2021). Evaluation of the Landsat-Based Canadian Wetland Inventory Map Using Multiple Sources: Challenges of Large-Scale Wetland Classification Using Remote Sensing. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 14, 32-52.

da S. Bezerra, D., de Lima Santos, A., Bezerra, J.S., Amaral, S., Kampel, M., Anderson, L.O., Mochel, F.R., Silva Nunes, J.L., de Araujo, N.A., Barreto, L.N., do S. S. Pinheiro, M., Celeri, M.J., Silva, F.B., Viegas, A.M., Manes, S., Rodrigues, T.C.S., Viegas, J.C., Souza, U.D.V., Santos, A.L.S., Silva-Junior, C.H.L., (2022). Brazil's mangroves: Natural carbon storage. Science 375, 1239-1239.

Blue Carbon Partnership - Blue Carbon and NDCs: Guidelines on Enhanced Action – 2nd Edition (2023) Available at: https://bluecarbonpartnership.org/document/blue-carbon-and-nationally-determined-contributions-guidelines-on-enhanced-action/

Brophy, L.S., Greene, C.M., Hare, V.C., Holycross, B., Lanier, A., Heady, W.N., O'Connor, K., Imaki, H., Haddad, T., Dana, R., (2019). Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PLoS One 14, e0218558.

Brown, C.J., Adame, M.F., Buelow, C.A., Frassl, M.A., Lee, S.Y., Mackey, B., McClure, E.C., Pearson, R.M., Rajkaran, A., Rayner, T.S., Sievers, M., Saint Ange, C.A., Sousa, A.I., Tulloch, V.J.D., Turschwell, M.P., Connolly, R.M., (2021). Opportunities for improving recognition of coastal wetlands in global ecosystem assessment frameworks. Ecological Indicators 126, 107694.

Burden, A., Clilverd, H., (2022). Moving towards inclusion of coastal wetlands in the UK LULUCF inventory. BEIS NAEI Report, UK CEH. Available at: Moving towards inclusion of coastal wetlands in the UK LULUCF inventory

Byun, C., Lee, SH. & Kang, H. (2019). Estimation of carbon storage in coastal wetlands and comparison of different management schemes in South Korea. Journal of Ecology and the Environment 43, 8 (2019). https://doi.org/10.1186/s41610-019-0106-7

Centre for Ecology and Hydrology (CEH). Saltmarsh code. Available at: https://www.ceh.ac.uk/our-science/projects/uk-saltmarsh-code

Chatting, M., Al-Maslamani, I., Walton, M., Skov, M.W., Kennedy, H., Husrevoglu, Y.S., Le Vay, L., 2022. Future Mangrove Carbon Storage Under Climate Change and Deforestation. Frontiers in Marine Science 9.

Chmura, G. L., Anisfeld, S.C., Cahoon, D. R., Lynch J.C., (2003). Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles, 17(4), 1111.

Comer-Warner, S.A., Nguyen, A.T.Q., Nguyen, M.N., Wang, M., Turner, A., Le, H., Sgouridis, F., Krause, S., Kettridge, N., Nguyen, N., Hamilton, R.L., Ullah, S., (2022). Restoration impacts on rates of denitrification and greenhouse gas fluxes from tropical coastal wetlands. Science of the Total Environment 803, 149577.

Copernicus (2020). Homepage | Copernicus. [online] copernicus.eu. Available at: https://www.copernicus.eu/en.

Crooks, S., Sutton-Grier, A. E., Troxler, T. G., Herold, N., Bernal, B., Schile-Beers, L., & Wirth, T. (2018). Coastal wetland management as a contribution to the US National Greenhouse Gas Inventory. Nature climate change, 8(12), 1109-1112.

Davidson N.C., Dinesen L., Fennessy S., Finlayson C.M., Grillas P., Grobicki A., McInnes R.J., Stroud D.A. (2019). A review of the adequacy of reporting to the Ramsar Convention on change in the ecological character of wetlands. Marine and Freshwater Research 70:11. doi: 10.1071/MF18328

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M., Kanninen, M., (2011). Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience 4, 293-297.

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

Fournier, R.A., Grenier, M., Lavoie, A., Hélie, R. (2007). Towards a strategy to implement the Canadian Wetland Inventory using satellite remote sensing. Canadian Journal of Remote Sensing, 33(sup1), S1–S16. https://doi.org/10.5589/m07-051

Friedlingstein, P., O'Sullivan, M., Jones, M.W., Andrew, R.M., Bakker, D.C.E., Hauck, J., Landschützer, P., Le Quéré, C., Luijkx, I.T., Peters, G.P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J.G., Ciais, P., Jackson, R.B., Alin, S.R., Anthoni, P., Barbero, L., Bates, N.R., Becker, M., Bellouin, N., Decharme, B., Bopp, L., Brasika, I.B.M., Cadule, P., Chamberlain, M.A., Chandra, N., Chau, T.T.T., Chevallier, F., Chini, L.P., Cronin, M., Dou, X., Enyo, K., Evans, W., Falk, S., Feely, R.A., Feng, L., Ford, D.J., Gasser, T., Ghattas, J., Gkritzalis, T., Grassi, G., Gregor, L., Gruber, N., Gürses, Ö., Harris, I., Hefner, M., Heinke, J., Houghton, R.A., Hurtt, G.C., Iida, Y., Ilyina, T., Jacobson, A.R., Jain, A., Jarníková, T., Jersild, A., Jiang, F., Jin, Z., Joos, F., Kato, E., Keeling, R.F., Kennedy, D., Klein Goldewijk, K., Knauer, J., Korsbakken, J.I., Körtzinger, A., Lan, X., Lefèvre, N., Li, H., Liu, J., Liu, Z., Ma, L., Marland, G., Mayot, N., McGuire, P.C., McKinley, G.A., Meyer, G., Morgan, E.J., Munro, D.R., Nakaoka, S.I., Niwa, Y., O'Brien, K.M., Olsen, A., Omar, A.M., Ono, T., Paulsen, M., Pierrot, D., Pocock, K., Poulter, B., Powis, C.M., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Rosan, T.M., Schwinger, J., Séférian, R., Smallman, T.L., Smith, S.M., Sospedra-Alfonso, R., Sun, Q., Sutton, A.J., Sweeney, C., Takao, S., Tans, P.P., Tian, H., Tilbrook, B., Tsujino, H., Tubiello, F., van der Werf, G.R., van Ooijen, E., Wanninkhof, R., Watanabe, M., Wimart-Rousseau, C., Yang, D., Yang, X., Yuan, W., Yue, X., Zaehle, S., Zeng, J., Zheng, B., (2023). Global Carbon Budget 2023. Earth System Science Data 15, 5301-5369.

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., Duke, N., (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20, 154-159.

Global Carbon Project (2019) Global Carbon Project (GCP). [online] Globalcarbonproject.org. Available at: https://www.globalcarbonproject.org/.

Green, C., Lovelock, C.E., Sasmito, S., Hagger, V. and Crooks, S., (2021). Coastal Wetlands in National Greenhouse Gas Inventories. Advice on reporting emissions and removal from management of Blue Carbon ecosystems. International Partnership for Blue Carbon; Commonwealth of Australia.

Guo, X., Liu, Y., Xie, T., Li, Y., Liu, H., Wang, Q. (2025). Impact of Ecological Restoration on Carbon Sink Function in Coastal Wetlands: A Review. Water, 17(4), 488. https://doi.org/10.3390/w17040488

Hamilton, J.. Kasprzyk, K., Cifuentes-Jara, M., Granziera, B., Gil, L., Wolf, S., Starling, G., Zimmer, A., Hickey, T. (2023). Blue Carbon and Nationally Determined Contributions. https://www.thebluecarboninitiative.org/policy-guidance.

Herr, D., von Unger, M., Laffoley, D. and McGivern, A., (2017). Pathways for implementation of blue carbon initiatives. Aquatic Conservation: Marine and Freshwater Ecosystems, 27, 116-129.

Holmquist, J. R., Windham-Myers, L., Bernal, B., Byrd, K. B., Crooks, S., Gonneea, M. E., ... & Weller, D. E. (2018). Uncertainty in United States coastal wetland greenhouse gas inventorying. Environmental Research Letters, 13(11), 115005.

International Panel on Climate Change (IPCC), (2006). Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Volume 4, Chapter 7, p.7.5.

International Panel on Climate Change (IPCC), (2013). Wetlands Supplement

International Partnership for Blue Carbon. (2021). Coastal Blue Carbon Ecosystems in International Frameworks and Conventions. Overview Report. First Edition. October 2021.

Kingsford, R.T., Bino, G., Finlayson, C.M., Falster, D., Fitzsimons, J.A., Gawlik, D.E., Murray, N.J., Grillas, P., Gardner, R.C., Regan, T.J., Roux, D.J., Thomas, R.F., 2021. Ramsar Wetlands of International Importance–Improving Conservation Outcomes. Frontiers in Environmental Science 9.

Lehner, B., Anand, M., Fluet-Chouinard, E., Tan, F., Aires, F., Allen, G. H., Bousquet, P., Canadell, J. G., Davidson, N., Finlayson, C. M., Gumbricht, T., Hilarides, L., Hugelius, G., Jackson, R. B., Korver, M. C., McIntyre, P. B., Nagy, S., Olefeldt, D., Pavelsky, T. M., Pekel, J.-F., Poulter, B., Prigent, C., Wang, J., Worthington, T. A., Yamazaki, D., and Thieme, M. (2025). Mapping the world's inland surface waters: an update to the Global Lakes and Wetlands Database (GLWD v2), Earth System Science Data Discuss. [preprint], https://doi.org/10.5194/essd-2024-204, accepted 2025.

Lovelock, C.E., Adame, M.F., Bradley, J., Dittmann, S., Hagger, V., Hickey, S.M., Hutley, L.B., Jones, A., Kelleway, J.J., Lavery, P.S. and Macreadie, P.I., (2023) An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. Restoration Ecology 31, no. 7

Macreadie, P.I., Anton, A., Raven, J.A., Beaumont, N., Connolly, R.M., Friess, D.A., Kelleway, J.J., Kennedy, H., Kuwae, T., Lavery, P.S., Lovelock, C.E., Smale, D.A., Apostolaki, E.T., Atwood, T.B., Baldock, J., Bianchi, T.S., Chmura, G.L., Eyre, B.D., Fourqurean, J.W., Hall-Spencer, J.M., Huxham, M., Hendriks, I.E., Krause-Jensen, D., Laffoley, D., Luisetti, T., Marbà, N., Masque, P., McGlathery, K.J., Megonigal, J.P., Murdiyarso, D., Russell, B.D., Santos, R., Serrano, O., Silliman, B.R., Watanabe, K., Duarte, C.M., 2019. The future of Blue Carbon science. Nature Communications 10, 3998.

Malerba, M.E., de Kluyver, T., Wright, N., Schuster, L., Macreadie, P.I., (2022). Methane emissions from agricultural ponds are underestimated in national greenhouse gas inventories. Commun Earth Environ 3, 306 (2022). https://doi.org/10.1038/s43247-022-00638-9

Malerba, M.E., de Paula Costa, M.D., Friess, D.A., Schuster, L., Young, M.A., Lagomasino, D., Serrano, O., Hickey, S.M., York, P.H., Rasheed, M. and Lefcheck, J.S. (2023) Remote sensing for cost-effective blue carbon accounting. Earth-Science Reviews, 238, p.104337

Maxwell, T.L., Rovai, A.S., Adame, M.F., Adams, J.B., Álvarez-Rogel, J., Austin, W.E., Beasy, K., Boscutti, F., Böttcher, M.E., Bouma, T.J. and Bulmer, R.H (2023) Global dataset of soil organic carbon in tidal marshes. Scientific data, 10(1), p.797.

Murdiyarso, D., Swails, E., Hergoualc'h, K., Bhomia,R., Sasmito, SD., (2024). Refining greenhouse gas emission factors for Indonesian peatlands and mangroves to meet ambitious climate targets, Proc. Natl. Acad. Sci. U.S.A. 121 (17) e2307219121, https://doi.org/10.1073/pnas.2307219121.

Natural England, (2013). Natural England Evidence Reviews: guidance on the development process and methods (NEER001). Natural England.

Needelman, B.A., Emmer, I.M., Emmett-Mattox, S., Crooks, S., Megonigal, J.P., Myers, D., Oreska, M.P. McGlathery, K., (2018). The science and policy of the verified carbon standard methodology for tidal wetland and seagrass restoration. Estuaries and Coasts, 41, 2159-2171.

Openlandmap.org. (n.d.). OpenLandMap. [online] Available at: https://openlandmap.org/?center=25

Papas, P., Hale, R., Amtstaetter, F., Clunie, P., Rogers, D., Brown, G, Brooks, J., Cornell, G., Stamation, K., Downe, J., Vivian, L., Sparrow, A., Frood, D., Sim, L., West, M., Purdey, D., Bayes, E., Caffrey, L., Clarke-Wood, B. and Plenderleith, L. (2021). Wetland Monitoring and Assessment Program for environmental water: Stage 3 Final Report. Arthur Rylah Institute for Environmental Research Technical Report Series No. 322. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Rebelo, L-M., Finlayson, C.M., Strauch, A., Rosenqvist, A., Perennou, C., Tøttrup, C., Hilarides, L., Paganini, M., Wielaard, N., Siegert, F., Ballhorn, U., Navratil, P., Franke, J. & Davidson, N. (2018). The use of Earth Observation for wetland inventory, assessment and monitoring: An information source for the Ramsar Convention on Wetlands. Ramsar Technical Report No.10. Gland, Switzerland: Ramsar Convention Secretariat.

Schuerch, M., Kiesel, J., Boutron, O., Guelmami, A., Wolff, C., Cramer, W., Caiola, N., Ibáñez, C., Vafeidis, A.T., (2025). Large-scale loss of Mediterranean coastal marshes under rising sea levels by 2100. Communications Earth & Environment 6, 128.

Sentinel-2 Copernicus Dara Space Ecosystem, C.D.S. (n.d.). Sentinel-2 | Copernicus Data Space Ecosystem. [online] dataspace.copernicus.eu. Available at: https://dataspace.copernicus.eu/explore-data/data-collections/sentinel-data/sentinel-2.

Simpson, L.T., Osborne, T.Z., Duckett, L.J., Feller, I.C. (2017). Carbon Storages along a Climate Induced Coastal Wetland Gradient . Wetlands, 1-13. http://dx.doi.org/10.1007/s13157-017-0937-x

Tooth, S., Waal, B. van der. (2019). The 'Global Wetland Outlook' report. Geography, 104(3), 154–159. https://doi.org/10.1080/00167487.2019.12094079

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Study Design for Monitoring Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-015 accessed at Methods for Evaluating Wetland Condition: Study Design for Monitoring Wetlands

Vanderklift, M.A., Herr, D., Lovelock, C.E., Murdiyarso, D., Raw, J.L. and Steven, A.D., (2022). A guide to international climate mitigation policy and finance frameworks relevant to the protection and restoration of blue carbon ecosystems. Frontiers in Marine Science, 9, 872064.

Verra, (2025). VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v2.1 Available at: https://verra.org/methodologies/vm0033-methodology-for-tidal-wetland-and-seagrass-restoration-v2-1/

Worthington, T.A., Spalding, M., Landis, E., Maxwell, T.L., Navaroo, A., Smart, L.S., Murray, N.J., (2023). The distribution of global tidal marshes from earth observation data. bioRxiv 2023.05.26.542433; doi: https://doi.org/10.1101/2023.05.26.542433

Xiong, Y., Mo, S., Wu, H., Qu, X., Liu, Y., Zhou, L., (2023). Influence of human activities and climate change on wetland landscape pattern—A review. Science of the Total Environment 879, 163112.

Zhao, P., Ge, S., He, D., Zhong, C., Wang, B., Wang, X., Wang, F. and Kao, S., (2022). Incorporating coastal blue carbon into subnational greenhouse gas inventories. Frontiers in Marine Science, 9, p.932984.

2.1.1.7. Sub-task 1.5C: The feasibility and cost of reliable EU wide reporting of coastal wetlands

2.1.1.7.1 Objective and scope

This section explores the feasibility and cost of implementing an EU-wide reporting system for coastal wetlands, in alignment with methodologies set out in the IPCC 2013 Wetlands Supplement.

2.1.1.7.2 Methods

The methodology broadly follows the approaches set out in the Better Regulation Guidelines and Toolbox. It has been necessary to make some adaptations to handle the limited economic data available.

Qualitative methodology to assess feasibility of blue carbon reporting

This sub-task seeks to assess the **feasibility and cost of reliable EU-wide reporting of coastal wetlands**. The assessment has been conducted for the following three IPCC methodological tiers and the period 2026-2041:

- Tier 1 refers to the most basic methodological approach, relying on default emission factors and broad assumptions from the IPCC, typically used when local data is unavailable. No measurement equipment is required; instead, reporting is based on activities for ecosystem identification and emission calculations using standardised emission factors.
- Tier 2 improves accuracy of estimation by incorporating country-specific emission factors and activity data instead of global averages. In addition, further data collection efforts are assumed to be required, when compared to Tier 1 activities. A limited use of measurement equipment is considered, following the model implemented in the UK.
- Tier 3 represents the most advanced methodological approach, using high-resolution modelling, direct measurements, and ecosystem-specific techniques to quantify carbon stocks and emissions with greater precision. The need for equipment to enable direct measurements has been considered.

There is a large increase in effort and cost moving from Tier 1 to Tier 3.

Table 2-13 shows the feasibility criteria definition and rating framework for the qualitative assessment. Completeness, accuracy and transparency are criteria used by the IPCC to guide GHG inventory quality. Feasibility and reliability are not part of the IPCC TACCC criteria but are criteria that are required as part of the scope of this analysis. We have created a definition of reliability, which is explained in Table 2-13. The definition combines elements of accuracy, completeness, transparency, and comparability.

Table 2-13. Feasibility criteria definition and rating framework for qualitative assessment

Criteria	Definition and assessment approach
Completeness	Completeness in coastal wetland GHG inventories refers to the inclusion of all relevant coastal ecosystems—such as seagrasses, salt marshes, and mangroves—in national greenhouse gas (GHG) inventories. It encompasses accounting for all pertinent carbon pools (above-ground biomass, below-ground biomass, soil carbon) and emission sources (e.g., land-use changes, degradation, restoration). • **Low feasibility** would mean that major coastal wetland ecosystems, such as seagrasses, salt marshes, and mangroves, cannot be included in national GHG inventories, leading to significant gaps in reporting. Key carbon pools, including above-ground biomass, below-ground biomass, and soil carbon, can, at most, be poorly documented or not accounted for at all. Emissions and removals resulting from land-use changes, degradation, and restoration will remain mostly unreported, making it difficult to assess the true climate impact of these ecosystems. • **Medium feasibility** would mean that some coastal wetland ecosystems can be included in national inventories, but coverage remains incomplete or inconsistent across Member States. While certain carbon pools can be accounted for, critical components—particularly soil carbon—will still be missing or estimated with high uncertainty. Reporting on emissions and removals from land-use changes, degradation, and restoration will remain partial. • **High feasibility** would mean that all key coastal wetland ecosystems can be fully integrated into national inventories, ensuring comprehensive coverage. All relevant carbon pools, including above-ground biomass, below-ground biomass, and soil carbon, will be systematically measured and reported, reducing uncertainty in carbon sequestration estimates. Emissions and removals from land-use changes, degradation, and restoration will be fully accounted.
Accuracy	Accuracy in coastal wetland GHG inventories refers to the correctness of data concerning carbon stocks and greenhouse gas (GHG) fluxes within coastal ecosystems like mangroves, saltmarshes, and seagrasses. Accurate reporting ensures that the measurements and estimates closely reflect the true carbon dynamics of these ecosystems, minimizing uncertainties and errors. • **Low feasibility** would mean that data on carbon stocks and GHG fluxes in coastal wetland ecosystems will remain highly uncertain and unreliable. Measurement methods will remain inconsistent, often relying on generalised estimates rather than direct field data, potentially leading to errors. Key factors influencing carbon dynamics, such as regional and ecosystem-specific sequestration rates, will not be well understood or incorporated into reporting. A lack of standardised data collection protocols and limited use of advanced monitoring technologies, such as remote sensing and in situ sampling, will further reduce the precision and correctness of reported values. • **Medium feasibility** would mean that some efforts can be made to improve the accuracy of coastal wetland inventories, but significant uncertainties would still exist. While certain regions might have reliable field measurements, data coverage will remain uneven, with some estimates still relying on broad default values rather than site-specific assessments. Standardised methodologies will exist but will not yet be fully implemented across all EU Member States, which could result in inconsistencies in data collection and reporting. Advances in remote sensing and carbon modelling can enhance precision, but verification through field measurements will still be limited in many areas, preventing full confidence in reported values. • **High feasibility** would mean that costal wetland reporting will be based on precise, well-documented, and verifiable measurements that accurately reflect the true carbon dynamics of coastal ecosystems. Data collection will follow standardised and widely accepted methodologies, ensuring consistency and reducing uncertainties across different regions. Advanced monitoring tools, such as high-resolution satellite imagery, direct field sampling, and automated sensors, will be routinely used to enhance the accuracy of carbon stock and GHG flux estimates. Strong verification mechanisms, including cross-checking reported values with independent datasets, will result in reporting that is both scientifically rigorous and reliable.

Criteria	Definition and assessment approach
Transparency	Transparency in coastal wetland GHG inventories refers to the clarity, openness, and accessibility of information regarding carbon sequestration and emissions within coastal ecosystems. It ensures that methodologies, data sources, assumptions, and uncertainties are clearly documented and available for scrutiny by stakeholders, facilitating trust and informed decision-making. • **Low feasibility** would mean that coastal wetland GHG inventories will, at best, lack clarity, openness, and accessibility, making it difficult for stakeholders to verify or understand the reported data. Methodologies, data sources, and assumptions will be poorly documented or entirely unavailable, which can lead to uncertainty about how carbon sequestration and emissions estimates are generated. Differences in reporting practices across EU Member States could create inconsistencies, while limited public access to data could reduce public trust on the information. • **Medium feasibility** would mean that some aspects of coastal wetland inventories will be transparent, but gaps and inconsistencies will remain. Methodologies and data sources will be documented, but they might not be easily accessible or consistently applied across all EU Member States. Some efforts will be made to disclose assumptions and uncertainties, but the level of detail will vary, making it difficult to compare data across different regions. • **High feasibility** would mean that coastal wetland inventories will be fully open, accessible, and clearly documented, so that all stakeholders can understand and verify the data. Methodologies, data sources, assumptions, and uncertainties will be systematically recorded and made publicly available, fostering trust and accountability. A standardised and harmonised reporting framework can achieve transparent reporting across all EU Member States.
Reliability	Reliability in coastal wetland GHG inventories refers to the consistency, dependability, and robustness of data and methodologies used to estimate carbon sequestration and emissions in coastal ecosystems. Reliable reporting ensures that carbon credits or offsets derived from these ecosystems are accurately quantified and verifiable, maintaining environmental integrity and stakeholder trust. • **Low feasibility** would mean that coastal wetland inventories will be inconsistent, prone to errors, and lacks dependability, making it difficult to trust the reported data. Methodologies for estimating carbon sequestration and emissions will vary widely across EU Member States, leading to discrepancies and uncertainty. Frequent revisions or corrections due to methodological weaknesses could undermine confidence in the data. • **Medium feasibility** would mean that coastal wetland inventories will somewhat reliable, but inconsistencies and uncertainties will persist. While some methodologies will be standardised, some variations in data collection and reporting across different countries will remain. Improvements in monitoring and verification processes will help enhance reliability, but gaps in long-term data series or methodological adjustments over time could still affect consistency. • **High feasibility** would mean that coastal wetland inventories will be consistent, robust, and dependable, applying methodologies that produce stable and verifiable results. Standardised reporting frameworks will be fully implemented across EU Member States, minimising discrepancies and ensuring methodological consistency. Long-term monitoring and verification systems will be in place, reducing uncertainties and enhancing trust in reported figures.

Quantitative methodology to estimate costs

The qualitative analysis is complemented by a six-step methodology to estimate the costs of coastal wetland inventories: specification and data collection, cost classification, activity and equipment requirement specification, unit cost analysis, normalisation, and aggregation, following the Better Regulation Guidelines and

Toolbox, especially, 'Chapter 8 – Methodologies for analysing impacts in impact assessments, evaluations and fitness checks'.[13]

Step 1 – Specification and data collection

The administrative costs of coastal wetland inventories can be divided into two main categories: personnel and equipment costs. These costs vary in scale depending on the IPCC methodology used,[14] with each tier requiring different levels of data accuracy and resource intensity.

For **personnel costs**, we have primarily drawn on the UK Department for Environment, Food and Rural Affairs (DEFRA) report "Defining Saltmarsh and the Roadmap for Its Potential Inclusion in the Land Use, Land Use Change, and Forestry (LULUCF) Inventory."[15] This document outlines key activities required for measuring greenhouse gas (GHG) emissions and removals from saltmarsh ecosystems, including data collection, monitoring, analysis, and reporting. Additionally, it provides indicative timeframes and cost estimates associated with these activities, making it a valuable reference for estimating the human resources needed for blue carbon reporting.

By leveraging the structured approach presented in the DEFRA roadmap, we have identified and adapted the relevant activities to an EU-wide context, so that our analysis and resulting estimates reflect the scale and complexity of reporting blue carbon across European Union Member States.

For **equipment costs**, we have conducted a targeted literature review and incorporated insights from discussions held during a stakeholder workshop on the 4th of February 2025. During this workshop, experts emphasized the critical role of high-precision tools to measure the carbon that might be sequestered by and emitted from vegetated coastal and marine ecosystems.

There are various methods available. Within these, flux towers and eddy covariance systems were identified as particularly effective for generating accurate data on carbon fluxes in coastal ecosystems. These systems can support Tier 2 or Tier 3

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[13] European Commission (2023). Better Regulation Toolbox. Available at: https://commission.europa.eu/law/law-making-process/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

[14] IPCC (2019) Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. Available at: CHAPTER 1

[15] Available at: Defining saltmarsh for inclusion in the LULUCF Inventory - ME5325

assessments, as defined by the IPCC,[16] allowing for a more precise and country-specific evaluation of carbon stocks and GHG emissions.

Workshop participants also highlighted that these measurement tools and systems are costly and could pose financial and logistical challenges for the large-scale implementation across the EU. Given their potential to enhance reporting accuracy, we have included flux towers and eddy covariance systems in our cost assessment, while acknowledging the need for further exploration of cost-effective alternatives.

A literature review was also conducted to identify technical specifications of flux towers and covariance systems to conduct a proportionate and relevant estimation of their associated costs. This process included determining the spatial coverage[17] (footprint) of the measurement technologies required for Tier 2 and Tier 3 reporting, especially based on evidence from the UK as a case study.[18] This review also identified the expected lifespan of these tools and systems[19], and the potential annual maintenance costs.[20] This evidence was also incorporated into analysis of reporting costs.

In summary:

- Personnel Costs: These costs account for the personnel time required for data collection, analysis, stakeholder engagement, and reporting; and have been derived primarily from the UK DEFRA report on saltmarsh inclusion in the UK GHG inventory.
- Equipment Costs: These costs account for the acquisition and maintenance of the equipment required to measure and assess blue carbon (such as flux towers and eddy covariance systems); estimated based on insights from literature available and a stakeholder workshop.

Step 2 – Cost classification

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[16] IPCC (2019) Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. Available at: CHAPTER 1

[17] Chu at al. (2021), Representativeness of Eddy-Covariance flux footprints for areas surrounding AmeriFlux sites, available at: Link

[18] UK Government. (2023, February 27). New national research project to focus on Essex saltmarsh. Link

[19] U.S. Department of Energy. (2015). FLUXNET: Database of fluxes, site characteristics, and flux-community information. OSTI. Link

[20] Meat & Livestock Australia. (2021). P. SH. 1195 - Final Report. Meat & Livestock Australia. Link

We have mapped and classified personnel and equipment costs into one-off and recurrent, following the Better Regulation Tools #56 'Typology of costs and benefits' and #58 'EU Standard Cost Model'. More specifically:

- One-off costs: Capital investments in equipment, setup costs for new monitoring systems, and initial data collection efforts that do not require frequent repetition.
- Recurrent costs: Expenses incurred regularly, such as annual staff salaries, data collection activities, and maintenance of measurement infrastructure.

Step 3 – Activity and equipment requirements for each reporting tier

Tier 1, 2, and 3 reporting approaches have been specified in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[21] (See Section 1.1). Each of these reporting tiers has different requirements, which are key drivers of cost, and thus, these were considered in depth.

More specifically, all activities required under the UK programme were assumed for Tier 2 and Tier 3 reporting across the EU, but only a subset was assumed for Tier 1 reporting. In addition, personnel costs for Tier 3 were assumed to align with Tier 2, due to a lack of evidence, albeit it is acknowledged that this may result in an underestimation of the actual costs for Tier 3. Table 2-14, below, outlines the activities relevant to each methodological tier.

Table 2-14. Personnel activity per tier and type, based on the UK experience

Activity	Relevant for Tier 1	Relevant for Tier 2 & 3	Type
Interpretation of wetland supplement requirement for coastal wetlands, including definitions of extent, types, management, and successful restoration	Yes	Yes	One-off
Assessment of a unified basemap of coastal wetland extent, land use and condition	Yes	Yes	One-off
Compilation of land use change (rewetting) time series of coastal wetland habitats	Yes	Yes	Recurrent
Sourcing of information on included management activities	Yes	Yes	Recurrent
Synthesis of GHG and C flux data from published work applicable to each coastal habitat, and compilation of database	No	Yes	Recurrent

[21] IPCC. (2007). 2006 IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/2007/

Activity	Relevant for Tier 1	Relevant for Tier 2 & 3	Type
Assessment of Tier 1 and Tier 2 emission factors for saltmarsh	Yes	Yes	One-off
Development of approach for long-term acquisition, use and quality control of activity data (land use, and land-use change data)	Yes	Yes	Recurrent (periodically)[22]
Scoping of implementation in dependent territories[23]	Yes	Yes	Recurrent
Calculation of annual emissions and removals from coastal wetlands, and development of models for inventory reporting	Yes	Yes	Recurrent
Uncertainty assessment of activity data and emission factors	Yes	Yes	Recurrent
Development of scenarios to assess the mitigation potential of coastal wetland restoration for use in annual inventory projections **NOTE:** This activity is not a requirement of a national GHG inventory, but is essential to help plan mitigation activities	No	No	Recurrent (Only if scenarios are generated)
Map out emissions reporting in the UNFCCC Common Reporting Table (CRT) software tables. Identify LULUCF land categories (grassland, cropland, wetland) and level of disaggregation, and any connections with reporting in other sectors and categories e.g., agriculture, grassland	Yes	Yes	One-off (Changes to CRT reporting requirements will mean this activity needs to be repeated)
Report on emissions inventory for coastal wetlands	Yes	Yes	Recurrent
Submit to the relevant government department (UNFCCC focal point) for approval	Yes	Yes	Recurrent

Source: Own elaboration based on the information contained in Defra's report "Defining Saltmarsh and the Roadmap for Its Potential Inclusion in the Land Use, Land Use Change, and Forestry (LULUCF) Inventory".

For **equipment** requirements, an analysis was conducted of the quantity of equipment (such as flux towers and covariate systems) required per hectare.

- For Tier 1 reporting, it has been assumed that there are no additional equipment costs, as this reporting does not rely on high-precision measurement tools or systems.
- For Tier 2 reporting, assumptions were developed based on the UK experience, i.e., considering the number of towers in the UK and the number of salt marsh hectares.

[22] Given that the cost is recurrent but occurs infrequently, and the exact frequency is unknown, we have classified it as a one-off expense for the purposes of this analysis. This approach may underestimate the true recurrent costs.

[23] "offshore areas over which the country has jurisdiction"

- For Tier 3 reporting, assumptions were established based on the footprint (coverage) of individual flux towers and covariate systems.

Table 2-15 below sets out the equipment requirement assumptions for Tier 2 and 3 reporting.

Table 2-15. Estimation of hectares covered by one equipment unit

Coverage	Tier 2	Tier 3
Hectares per equipment unit	2.940	314

Step 4 – Cost estimation by area (unit cost)

To effectively use the evidence sourced from the UK experience, cost data was standardised by the number of hectares of saltmarsh in the UK to create a "Cost per hectare", e.g., of saltmarsh for both personnel and equipment costs, acknowledging there is likely a positive relationship between the size of the area that is being assessed (i.e., area of vegetated coastal and marine ecosystems) and the volume of equipment and reporting activities required. The table below provides a breakdown of personnel and equipment costs per hectare.

Table 2-16. Estimation of per-hectare personnel and equipment costs by reporting tier

Personnel activity	Tier 1	Tier 2	Tier 3
Personnel costs			
One-off	9 €	9 €	9 €
Recurring	6 €	8 €	8 €
Equipment costs			
One-off	-	23 €	307 €
Recurring	-	2 €	31 €

In addition, given the lack of evidence and uncertainty surrounding these assumptions, a ±20% margin of error was applied to the estimated personnel costs. This accounts for potential variations in project scope, labour costs, and operational adjustments. The ±20% margin of error is supported by common practice in cost estimation, where a range of ±10% to ±25% is often used to account for uncertainties and variability in initial estimates.[24] This approach ensures that the analysis remains robust and reflective of potential real-world deviations.

Regarding equipment costs, information from several reliable sources was utilized and triangulated. This comprehensive approach has minimized the uncertainty associated with equipment cost estimates, making additional margins of error unnecessary for this component of the analysis.

Step 5 – Cost normalisation

The cost data has normalised to constant 2024 Euros (€). Conversions were based on:

- Official exchange rates from the European Central Bank (ECB) for currency conversion.
- GDP deflator evidence from Eurostat so that all figures are presented in constant 2024 values (real terms).

This approach ensures that all cost components are expressed in a comparable monetary unit, mitigating distortions arising from currency fluctuations and inflationary effects.

Step 6 – Cost aggregation and Net Present Value calculations

The per-hectare cost estimates were subsequently extrapolated to the European scale using coastal wetlands extent data from Eurostat land use statistics[25]. The per-hectare costs derived from the UK saltmarsh experience were applied to all coastal wetland ecosystems in Europe, based on the assumption that the required activities and equipment are similar across these ecosystems (e.g., seagrass meadows[26]). Additionally, the total coastal wetland area data from 2018 obtained from Eurostat were projected based on historical trends captured by the compound annual growth rate (CAGR) from 2009-2018.

Finally, the Net Present Value (NPV) of total costs of reporting was estimated for each tier reporting approach. This approach reflects the time value of money by discounting future costs to their present-day equivalent. In particular, the real social discount rate used was 3% in line with European Commission guidance.

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[24] Project Management Institute (2021). The standard for project management and a guide to the project management body of knowledge (PMBOK guide). Available at: PMBOK7.pdf

[25] From: https://ec.europa.eu/eurostat/databrowser/view/lan_lcv_ovw/default/table?lang=en

[26] Duarte, C. M., Marbà, N., & Terrados, J. (2021). Seagrass ecosystems and carbon sequestration. Annual Review of Marine Science, 13, 1–20. https://doi.org/10.1146/annurev-marine-042121-012329

2.1.1.7.3 Results

This subsection assesses the feasibility of blue carbon reporting in terms of i) completeness, accuracy, transparency, and likely reliability of timely production of the Wetlands Supplement inventory, and ii) cost.

Completeness, accuracy and transparency

Completeness

The feasibility of achieving completeness using Tier 1 methodologies is considered ‘medium’, as it relies on default emission factors, Member State specific data sets of land use, or perhaps generalised global datasets that might not account for country-specific variations in land-use changes, wetland types, or carbon pools. The completeness of Tier 1 estimation is contingent on the availability and quality of national activity data, particularly regarding land-use change monitoring. While the IPCC Wetlands Supplement (2013) has expanded methodological guidance for coastal wetlands, the extent to which national greenhouse gas inventories comprehensively include all relevant wetland types and carbon pools remains uncertain. In cases where land-use change data are incomplete or where wetland categories are not fully represented, reported estimates may not reflect actual emissions and sequestration levels.

The feasibility of achieving completeness with Tier 2 methodologies is considered ‘low to medium’, as this approach incorporates country-specific emission factors (which could be expensive and time consuming to obtain) and national datasets, allowing for more refined estimates. However, completeness remains dependent on the extent to which national monitoring systems capture land-use changes affecting coastal ecosystems. If national datasets do not fully cover wetland degradation, restoration, or expansion, reporting gaps may persist. Moreover, variations in national capacities for wetland mapping and carbon stock assessments could limit the overall comprehensiveness of Tier 2 reporting.

The feasibility of achieving completeness with Tier 3 methodologies is considered ‘low to medium’, as this approach relies on site-specific measurements (which are very expensive, and time consuming), high-resolution remote sensing, and advanced modelling (expensive) to assess carbon stocks and emissions. This tier provides the most comprehensive assessment by incorporating direct data on wetland condition, degradation rates, and restoration efforts. However, while Tier 3 methods offer the highest potential for completeness, their feasibility remains constrained by technical capacity and resource availability.

These limitations are further reflected in the findings of Sub-task 1.3, which highlights significant variations in how countries define and include wetlands in their reporting frameworks. Some countries, such as Sweden and Ireland, classify large portions of their wetlands as unmanaged, thereby excluding them from greenhouse gas inventories. This classification has direct implications for completeness, as it limits the extent to which emissions and removals from coastal wetland ecosystems are accounted for.

Given these inconsistencies across national reporting systems and the constraints associated with each reporting tier, there is some uncertainty in the overall feasibility of achieving completeness in coastal wetland GHG inventories, particularly where wetland classification practices and data availability hinder full inclusion in inventories.

Accuracy

It is important to set the context of the use of the term accuracy in this analysis. The IPCC Tier 1 methodologies have been created, and adopted under the UNFCCC, to generate GHG inventories that provide acceptable estimates of removals of carbon and emissions of GHGs. When EU MS use these methodologies, it provides comparability between their inventories. In absolute terms, the accuracy of IPCC Tier 1 methods for coastal wetlands may only be adequate, in part because scientific advances mean that updated and more accurate default EFs than the ones available in the Wetlands Supplement could now be generated.

Coastal wetland inventories created from **Tier 1** methodologies will be sufficiently accurate, as judged by GHG expert reviewers. However, uncertainties in estimates of emissions are likely to be high, and the inventories are likely to fail to account for national variations in ecosystem carbon sequestration and emissions. Since this tier applies generalised assumptions rather than country-specific data, reported values may deviate significantly from actual carbon fluxes, resulting in some inaccuracy.

The feasibility of achieving accuracy in **Tier 2** coastal wetlands inventories is considered ‘medium’, as country-specific emission factors and more refined methodologies reduce uncertainties. By incorporating national datasets, this approach better reflects local ecosystem characteristics, improving the precision of carbon stock and emissions estimates. However, data quality and consistency remain challenges, as variations in monitoring capacity, sampling frequency, and methodological approaches across countries can still introduce uncertainty into reported values.

The feasibility of achieving accuracy as part of **Tier 3** coastal wetlands inventories is ‘medium to high’, as this approach relies on direct field measurements, remote sensing, and advanced modelling techniques to assess carbon stocks and fluxes. These methods provide highly precise and site-specific data, significantly minimizing uncertainties and enhancing the reliability of emissions estimates. However, despite the methodological advantages, accuracy at this level remains contingent on the availability of high-resolution data and technical expertise, which may not be uniformly accessible across all countries.

Findings from Sub-task 1.3 highlight that the total wetland area reported by MS in the Common Reporting Format (CRF) tables includes both managed and unmanaged wetlands. However, emissions estimates are provided only for managed wetlands, leading to potential differences between wetland land area estimates and GHG inventory reporting. For instance, Sweden—despite having the largest area of wetlands in the EU - reports emissions equivalent to just 1.15% of the net CO_2 emissions from wetlands across the EU. This discrepancy is primarily due to Sweden's classification of large wetland areas as unmanaged, resulting in the exclusion of associated emissions from national inventories.

Transparency

It is important to set the context of the use of the term transparency in this analysis. A GHG inventory using any methodological tier can be transparent. Transparency means that the assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of information.

The feasibility of achieving transparency using a **Tier 1** methodology is 'high'. The Tier 1 IPCC methodologies are well-documented and can be applied consistently across countries. These methods facilitate comparability in reported emissions and removals. However, transparency is also dependent on the completeness and clarity of national activity data, particularly regarding land-use change classifications and the distinction between managed and unmanaged wetlands. While Tier 1 methodologies themselves are transparent, the extent to which MS clearly report wetland classifications and land-use transitions remains uncertain, potentially limiting overall transparency in reporting.

The feasibility of achieving transparency using a **Tier 2** methodology is 'high to medium'. MS will need to explain how they have used country-specific emission factors and datasets. There is some risk that MS will, at least when they first report their coastal wetland inventories, not fully transparently describe their methodological approaches. As their GHG inventories are reviewed, the reviewer comments should help the MS increase the transparency of their reporting. While the refinements in the Tier 2 methodologies, with respect to Tier 1, should improve the accuracy of national estimates, they might reduce comparability between countries if methodological choices and underlying data sources are not fully disclosed and understood. In some cases, documentation gaps in national monitoring systems—such as insufficient detail on wetland management status or land-use changes—can further limit transparency and hinder external verification of reported emissions and removals.

The feasibility transparency using a **Tier 3** methodology remains at a 'high to medium'. Using this tier will require complex site-specific measurements, advanced remote sensing techniques, and sophisticated modelling approaches. While these methods improve the accuracy and completeness of estimates, they also introduce challenges in transparency, as highly technical methodologies may be difficult to document concisely and completely. Additionally, documentation gaps and methodological variability across countries can make it difficult to compare results, reducing overall clarity and accessibility.

Findings from Sub-task 1.3 indicate that Member States provide limited publicly available information on how emissions and removals from coastal wetlands are reported, whether explicitly or implicitly. Moreover, the methodologies used for wetland classification - particularly the criteria for designating wetlands as 'unmanaged' - are not always well-documented.

Reliability

Achieving reliability is affected by previous dimensions (completeness, accuracy and transparency). The challenges in completeness—stemming from gaps in wetland coverage and land-use change data - directly impact the quality of national greenhouse gas inventories. Similarly, at Tier 1 and to a lesser degree at Tier 2 estimates remain uncertain and subject to significant variation. While standardized methodologies provide a foundation for reliable reporting, the absence of comprehensive national datasets and clear documentation on wetland classifications further undermines comparability. As a result, inventories of coastal wetlands in their current form are not yet completely dependable, with national inventories facing significant challenges in ensuring accurate and verifiable emissions estimates.

In this context, the feasibility of achieving reliability in **Tier 1** inventories is considered 'high' due to the use of global default emission factors and generalised datasets, which. The standardised methodologies enhance consistency,

For **Tier 2** inventories, the feasibility of achieving reliable outputs is considered 'low to medium' level, as national datasets and country-specific emission factors provide a more tailored approach to estimating emissions and removals. However, the reliability of Tier 2 reporting is highly dependent on the quality, availability, and consistency of national monitoring systems. Variations in data collection methods, wetland classification criteria, and emission factor derivations across countries introduce uncertainties that may undermine the robustness of estimates. If national monitoring systems lack comprehensive coverage of wetland degradation, restoration, or land-use transitions, reported values may still fail to reflect true carbon fluxes, limiting the overall reliability of this tier.

For **Tier 3** inventories, the feasibility of delivering reliably is considered 'high'. This reporting approach relies on direct field measurements, high-resolution remote sensing, and advanced modelling to generate more precise and consistent estimates. The integration of site-specific data enhances the accuracy of reporting and allows for more transparent tracking of carbon sequestration and emissions over time. However, Tier 3 methods are resource-intensive and require significant technical expertise, which can result in inconsistencies across countries, particularly where monitoring capacity is limited. The high level of detail in Tier 3 reporting does not inherently guarantee greater reliability if methodological choices, data gaps, or funding constraints affect implementation.

Conclusions

Based on this analysis, it is concluded that the overall feasibility of effective coastal wetland reporting could be between 'low to medium' and 'medium', overall.

- The feasibility of achieving completeness is limited by gaps in land-use change data, this could be alleviated by the use of remote sensing (satellite) data for a more complete data integration.
- At Tier 1, uncertainties will be relatively large. Accuracy will improve with the availability of country-specific data in Tier 2, and Tier 3. These approaches offer the most accurate estimates - albeit at high technical and financial costs.
- Transparency currently is hindered by the lack of clear documentation on methodologies, wetland classification criteria, and the implicit or explicit inclusion of wetlands in national greenhouse gas inventories. We expect that any MS should be able to produce a transparent inventory of coastal wetlands, at any tier.
- While Tier 1 benefits from standardized methodologies, MS will need to need to invest time and effort to produce transparent inventories at higher tiers as methodological complexity increases necessitating more detailed methodological descriptions, and detailed national datasets introduce complexities.
- Consequently, the feasibility of achieving reliability is also low, as incomplete datasets and uncertain emission factors limit the robustness and comparability of reported estimates.

While higher-tier methodologies improve the accuracy of MS national inventories, their feasibility is constrained by inconsistent national monitoring capacities. Current reporting frameworks do not yet provide a fully reliable basis for robust and verifiable GHG inventories for coastal wetlands accounting, and significant improvements in data collection, methodological standardization, and national implementation will be needed to enhance the feasibility of comprehensive coastal wetland reporting. Table 2-17, below, summarises the qualitative rating and assessment conclusions.

Table 2-17. Feasibility of coastal wetland reporting: high level conclusions

Criteria	Tier 1	Tier 2	Tier 3
Completeness	Medium	Low/Medium	Low/Medium
Accuracy	Compliance with Tier 1 methodologies will mean wetlands inventories will be judged as sufficiently accurate for national reporting	Medium	Medium
Transparency	High	High/Medium	High/Medium
Reliability	High	Low/Medium	High
Overall feasibility to achieve complete, accurate, transparent and reliable reporting	**Medium**	**Low/Medium**	**Low/Medium**

Estimated costs of coastal wetland reporting

As indicated by the findings of Subtask 1.3, Member States (MS), with the exception of Malta, do not currently provide inventories for coastal wetlands. Consequently, while some MS may include emissions/removals from coastal wetlands, these are not reported as a distinct category, leading to a lack of transparency regarding the methodologies employed.

Due to the limited information available on the efforts of MS to report on coastal wetlands, costs were calculated for the estimation of estimation and reporting of coastal wetland emissions in Europe across for three reporting tiers. Table 2-18 below presents the NPV for the period 2026–2041 using a 3% social discount rate, with a 20% uncertainty range indicated in parentheses: “low to high”.

The one-off costs are the "inventory set-up" costs. The recurring costs are expected to occur once a year. The timeframe we considered for the analysis is 2026-2041, which means over 15 years.

These costs are our best estimates. They were calculated from the information the project team was able to identify within the resources available for this task. The 20% uncertainty range is provided to give a sense of the likely uncertainty, but the uncertainty range could be much greater.

Table 2-18. Total costs as NPV (3% discount rate) for generating and reporting coastal wetland GHG inventories for all the EU 27 Member States

Value	Tier 1	Tier 2	Tier 3
One-off costs (EUR million, NPV) (Low – High)	2 (1 – 3)	12 (9 – 14)	131 (105 – 157)
Recurring costs (EUR million, NPV) (Low – High)	18 (14 - 22)	34 (27 – 41)	127 (101 – 152)
Total Costs (EUR million, NPV) (Low – High)	**20** (16 – 24)	**46** (37 – 55)	**257** (205 – 308)

Source: Own elaboration

The NPV total costs results were further annualized to express the equivalent constant annual cost over the 2026-2041 period, presented in the Table 2-19 below.

Table 2-19. Annualised cost over the period for generating and reporting coastal wetland GHG inventories for all the EU 27 Member States

Value	Tier 1	Tier 2	Tier 3
Annualised Costs (EUR million, NPV) (Low – High)	**1.7** (1.4 – 2.0)	**3.8** (3.1 – 4.6)	**21.6** (17.2 – 25.9)

Source: Own elaboration

Annex D provides the cost estimates using 2% and 4% discount rates.

To validate our cost estimates for implementing a Tier 2 methodology for coastal wetlands reporting in the EU, we compared our results with information provided by US stakeholders, as the United States is already routinely generating a coastal wetlands inventory using a Tier 2 approach. US stakeholders have indicated that their gross annual costs for implementing a similar Tier 2 methodology are very approximately €3.7 million. Given that the US has a larger extent of coastal wetlands than the EU and potential differences in cost structures, our results suggest a reasonable alignment with “real-world” implementation costs. Economic data gathered from the “USA series” of consultations is available in Annex C.

Conclusions

We conclude that the overall feasibility of effective blue carbon reporting could be between ‘low to medium’ and ‘medium’ overall, where effective reporting refers to complete, accurate, transparent and reliable reporting across Member States. In addition, while higher-tier methodologies may not necessarily improve completeness or transparency, they should improve accuracy and reduce uncertainty. The feasibility of coastal wetland inventories is constrained by inconsistent national monitoring capacities.

Furthermore, although there is limited information on the methodologies employed by MS to report GHG emissions from wetlands (Tier 1, Tier 2, or Tier 3), the analysis conducted provides a preliminary estimate of the potential administrative costs of implementing these tier reporting. The estimated costs for Tier 1 reporting are approximately € 14m (11m – 17m), while Tier 2 reporting could incur costs around € 41m (32m – 49m). For the more detailed Tier 3 reporting, the administrative costs are estimated to be € 252m (202m – 303m). These cost estimates represent the net present value for the period 2026-2041.

There are a range of assumptions and limitations to this analysis. In summary:

- Assumptions: The analysis assumes that the activities identified in the UK report are extrapolatable to the EU context. It also assumes that the Tier 2 methodology can use a reduced number of flux towers to refine country-specific emission factors.
- Limitations: The analysis is based on very limited information and data, primarily from the UK. This limitation is due to the scarcity of publicly available information on this topic. Additionally, the activities and personnel costs for the Tier 3 methodology were assumed to be the same as those for Tier 2. This assumption may lead to an underestimation of the actual costs associated with Tier 3. Finally, satellite-based monitoring systems such as Copernicus Sentinel-2 are likely to have significant data processing costs. These costs are not included in the analysis.

2.1.1.7.4 Key deliverables

The key deliverables for Task 1 were not allocated to this sub-task.

2.1.1.7.5 Recommendations

Based on the analysis, the following main recommendations are proposed to enhance the quality and feasibility of coastal wetland GHG inventory creation and reporting for the EU:

- Invest in activity data collection and processing: To address gaps in activity data and improve completeness, it is important to invest in processing existing remote sensing data, and high-resolution monitoring technologies, and, for more accurate and comprehensive mapping of coastal wetland and blue carbon ecosystems across the EU. This would include an analysis of the locations and extends of seagrass meadows. Clear, consistent, and accessible data-sharing platforms could be established to facilitate access to activity data for all MS.

- Standardise methodologies: To enhance comparability and accuracy, the EU should consider prioritising the development and adoption of “standardized” methodologies for estimating GHG inventories of coastal wetlands. These methodologies should be compatible with the IPCC Wetlands Supplement methodologies, but, tailored to the EU’s circumstances. This will ensure comparable reporting across Member States.
- Build capacity: Provide training and technical support for inventory practitioners involved in the generation and reporting of wetland inventories. This support could cover activity data acquisition, processing and quality control, and inventory generation, reporting and quality control.
- Encourage collaboration and knowledge Sharing: Strengthen collaboration between governments, scientific institutions, and other stakeholders involved in wetlands inventory preparation. This should be done with the aim of fostering knowledge and data sharing and improving the overall understanding of coastal wetland and blue carbon ecosystems. Initiatives like the Joint Programming Initiative on Blue Carbon should be expanded and supported.

2.1.1.7.6 Challenges encountered during implementation

- Description of issues faced. There is very little publicly available cost data.
- Strategies used to overcome challenges. Meetings were set up with the technical leads in the US and UK inventory team to acquire these data.
- Impact on project timeline and deliverables. None

2.2. Task 2

2.2.1. Description of the Task

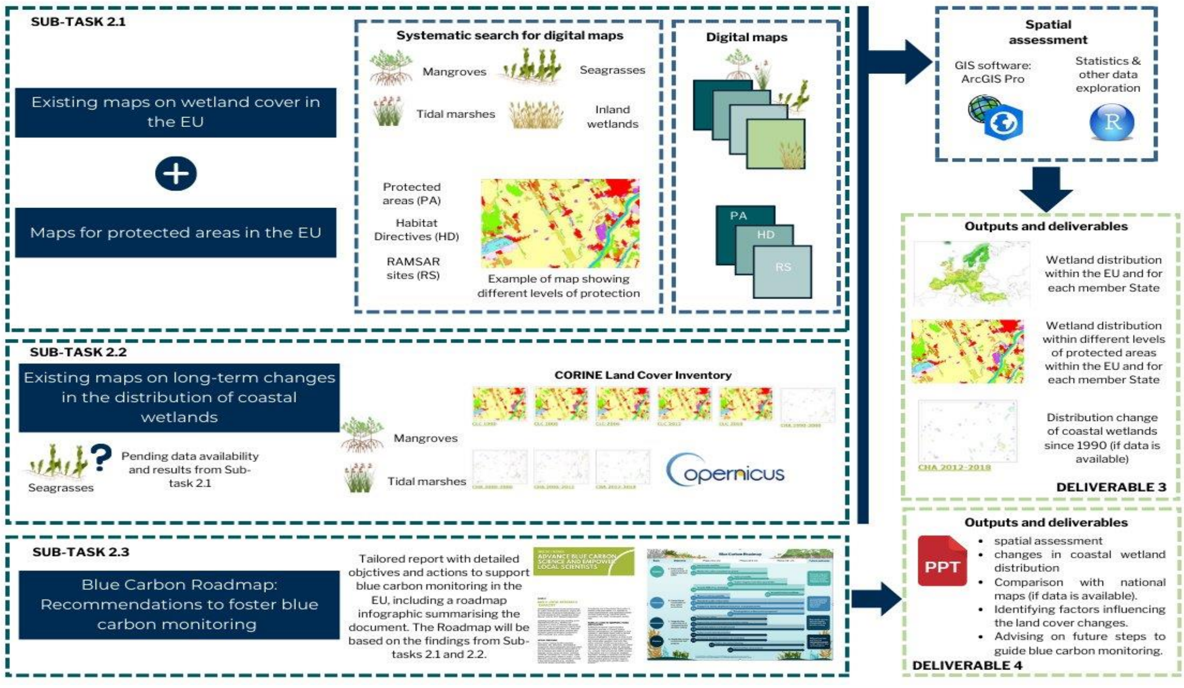
The goal of this task was to use existing spatial data (e.g., habitat mapping, protected areas, land cover, land cover change) to understand the distribution of coastal and freshwater wetlands within EU countries (Figure 2-3). More specifically:

- For coastal and freshwater wetlands:

- o Map the distribution of wetlands in the EU countries, including a comparative analysis among the datasets used in the analysis (sub-task 2.1).
- o Estimate how much area of these ecosystems are protected based on the presence of protected areas, including those under the EU Habitats Directive and Ramsar Convention (sub-task 2.1).

- For coastal wetlands:
  - o Map distribution changes of these ecosystems since 1990 based on existing digital maps (sub-task 2.2).
  - o Provide recommendations on how to improve map accuracy, including costs for different levels of accuracy and further steps needed to monitor changes in blue carbon ecosystems (sub-task 2.3).

Figure 2-3: Structural overview of Task 2 - Mapping the distribution of wetlands and changes in their extent



2.2.1.1. Sub-task 2.1: Mapping the distribution of coastal and freshwater wetlands and their protection level

2.2.1.1.1 Literature review

The objective of this task was to map the distribution of coastal and freshwater wetlands within the EU. For that, our first step was the conduction of a systematic search to identify relevant spatial datasets on the distribution of wetlands. For that, we conducted a systematic search to identify relevant spatial datasets on the distribution of wetlands, following the approach below:

- Search on online data repositories, such as INSPIRE, Google Earth Engine Data Catalogue, EMODNet, Copernicus, European Environment Agency, and UNEP Ocean Data Viewer. Keywords that will be used include 'vegetation', 'tidal marsh', 'seagrass', inland wetland', freshwater wetland', 'wetland', and 'peatland', 'land cover', 'land use'. We included mangroves in the systematic search and spatial assessment for Task 2 since they are a relevant blue carbon ecosystem and there are mangroves in EU outermost regions.
- Systematic search in the peer-reviewed literature using ISI Web of Science, Scopus, CORDIS, and Google Scholar to identify articles that included mapping of coastal and freshwater wetlands and therefore could include access to relevant spatial data.

We used a timeframe from 1990 until April 2024. The literature search incorporated a Boolean logic (i.e., AND, OR, *, $) to combine terms related to the ecosystem (i.e., mangrove, tidal marsh, inland wetland and seagrass), the dataset (i.e., habitat map), and the location (i.e., European Union, Germany, Portugal, Italy) (**Error! Reference source not found.**; terms #1, #2 and #3).

Table 2-20: Search terms included in the systematic search.

Term	Category	Search
#1	Ecosystem	TS= ("inland wetland*" OR "freshwater wetland*" OR "temperate wetlands*" OR "seagrass*" OR "salt marsh*" OR "saltmarsh*" OR "mangrove*" OR "eelgrass*" OR "posidonia" OR "zostera*" OR "tidal marsh*" OR "sea grass*")
#2	Dataset	TS= ("habitat mapping*" OR "habitat map*" OR "distribution map*" OR "map*" OR "modelled distribution*" OR "distribution*")
#3	Location	TS= ("Europe*" OR "European Union*" OR "[name of the 27 countries that are part of the EU]*"

TS = Topic. ISI Web of Science searches for the term within the Title, Abstract, Author and Keywords of the publication record.

The systematic search conducted on Web of Science using the above search terms found 363 papers. An initial search on Scopus using those same search terms found an additional 12 papers. These 375 papers were then uploaded to Covidence, a systematic review tool which automatically removes duplicates and allows for abstract and full text screening (Figure 2-4).

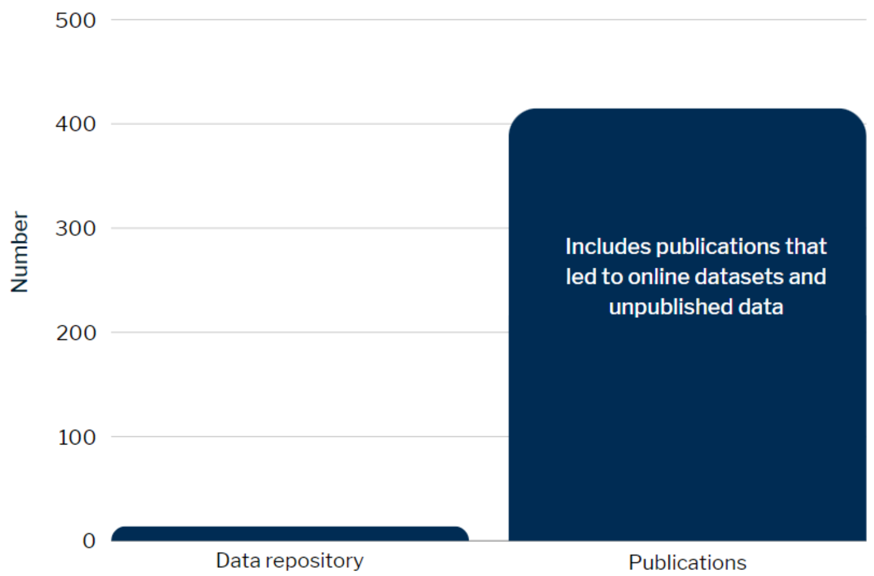
The abstracts of the 375 papers were then screened for relevance, i.e., they were required to contain a distribution map of a blue carbon or wetland ecosystem within the European Union (including EU overseas territories). Of the 375 papers, 298 were deemed relevant and moved to the 'full text review' section of Covidence. A further

69 papers were deemed irrelevant in the full text review, leaving 229 papers to be transferred to a master database created in Excel.

Papers that did not contain a distribution map of a blue carbon ecosystem, but detailed monitoring methods for those ecosystems, were copied to a separate tab of the Excel file. These papers were deemed relevant for the “Roadmap and Monitoring recommendations” (subtask 2.3).

A Google Scholar and google search was then conducted to pick up any relevant papers or reports within the grey literature that may have been missed in the WoS and Scopus search. The following search terms were used: ‘seagrass map European Union’, ‘salt marsh map European Union’, ‘mangrove map European Union’, ‘mangrove map Euro-pean territories’, ‘freshwater wetland map European Union’, ‘coastal wetland map Euro-pean Union’ and ‘peatland map European Union’ and the first two pages of the search results were looked at. This process found 46 additional relevant papers that were incorporated into the master database. While most of the publications found during the literature review were at country level, these were not available and/or at a relevant resolution.

Figure 2-4: Total number of online data repositories and relevant publications found during the literature search (sub-task 2.1). After a detailed screening process, the final dataset comprehended 229 relevant publications that potentially created/developed spatial datasets for the study region.



Once the search was completed, we conducted a manual review of the entire master database to identify the most relevant spatial datasets that were included in the spatial assessment. The criteria used for this selection was based on the resolution, accuracy details available, and reference year for the map. This shortlisted dataset was then added to a separated file to indicate the final maps used in this study (Table 2-21). During the manual review of the dataset, we have identified eight researchers that led scientific publications that generated relevant spatial datasets. In this case, we have contacted them by email to discuss the potential of them sharing the information with us. Of the eight researchers contacted, three of them responded. From their responses, we were able to access two additional datasets that were publicly available for seagrasses, which were also included in the shortlisted database.

While our data search included a comprehensive and systematic review of publicly available spatial datasets for the distribution of coastal and inland wetlands, there is a continuous emergence of new research on the topic. The Blue Carbon Roadmap (Sub-task 2.3) provides recommendations on how to overcome the data accessibility issues and other gaps, including the development of a centralised EU-level database for the storage and sharing of blue carbon data across Member States (Action 3.2).

Table 2-21: Summary table of the spatial datasets included in this study for the spatial assessment of coastal and freshwater wetlands.

Layer (Source)	Original Format	Reference year	Scale/Region	Resolution	Sub-task	Tier
Source datasets						
High-resolution Global Mangrove Forests (Jia et al., 2023)	Polygon	2020	Global	10 m	2.1	1
Global Mangrove Watch (Bunting et al., 2022)	Polygon	1996, 2007-2010, 2015-2020	Global	25 m	2.1; 2.2	1
Global distribution of tidal marshes (Worthington et al., 2024)	Raster	2020	Global	10 m	2.1	1
Global Wetland Map (Zhang et al., 2023)	Raster	2020	Global	30 m	2.1	1
Global distribution of seagrasses (version 7.1; UNEP-WCMC, Short, 2021)	Vector	-	Global	-	2.1	3

Layer (Source)	Original Format	Reference year	Scale/Region	Resolution	Sub-task	Tier
Current distribution of *Zostera* seagrass meadows along the SW coast of the Black Sea, Bulgaria (Berov et al., 2022)	Vector	-	Bulgaria	-	2.1	1
Seagrass mapping in Greek territorial waters using Landsat-8 satellite images (Topouzelis et al., 2018)	Vector	-	Greece	-	2.1	1
Seagrass meadows region (Helsinki Commission, 2013)	Vector	-	Baltic Sea	-	2.1	3
Danish coastal submerged aquatic vegetation 2018 (DHI, 2024)	Raster	2018	Denmark	10 m	2.1	4
CORINE Land Cover (2020)	Raster	1990, 2000, 2006, 2012, 2018	Europe	100 m	2.2	1-2
de Los Santos et al. (2019)	csv	1860 to 2016	Europe	-	2.2	-
Layers used for comparison purposes						
Global Mangrove Watch	Polygon	2020	Global	25 m	2.1	1
Extended wetland ecosystem layer (EEA, 2022)*	Raster	2018	Europe	100 m	2.1	2
Global Wetland Map (Zhang et al., 2023)	Raster	2020	Global	30 m	2.1	1

Layer (Source)	Original Format	Reference year	Scale/Region	Resolution	Sub-task	Tier
A modelled global distribution of the seagrass biome (Jayathilake & Costello, 2018)	Vector	-	Global	-	2.1	4
Global saltmarsh change, 2000-2019 (Campbell et al., 2022)	Raster	2000-2019	Global	30 m	2.2	1
High-resolution mapping of losses and gains of Earth's tidal wetlands (Murray et al., 2022)	Raster	1999-2019	Global	30 m	2.2	1

*This layer was derived from the Corine Land Cover (CLC) layer for the reference year of 2018, which has been reclassified into 20 wetland classes based on other ancillary layers. Therefore, this layer was selected to be used for comparison purposes instead of the CLC layer.

2.2.1.1.2 Wetland maps and spatial assessment

Over 10 spatial datasets were selected to extract data to map the extent of the inland and coastal wetlands within the EU Member States and their outermost regions (**Error! Reference source not found.**). In addition, 5 datasets were used to extract information for comparison purposes (**Error! Reference source not found.**). To provide a qualitative assessment on the accuracy and suitability of the input data layers to the final wetland maps, we followed the approach used in Lucieer et al (2019) and categorized the selected layers into 4 tiers. These tiers were defined as:

- Tier 1: spatial data that has been compiled by wetland mapping projects where different wetland types (e.g., mangroves, tidal marshes, seagrasses, inland wetlands) have been mapped using a robust classification method and independent accuracy assessments.
- Tier 2: spatial data that has been produced as a product derived from a Tier 1 dataset through a reclassification process based on ancillary spatial layers.
- Tier 3: spatial data that has been produced through the combination of spatial data from several sources that describe wetland distribution at global, regional and/or national levels.
- Tier 4: spatial data created based on species distribution models and/or identified a wetland class without a detailed classification (for example, submerged aquatic vegetation, including seagrasses and macroalgae).

To extract the data from the layers included in this study (***Error! Reference source not found.***), we created 4 mask files to represent 1) the limits of the 27 EU Member States (please note that Portugal and Spain include their outermost regions of Azores and Madeira, and Canary Islands, respectively), and 2) the limits of the remaining 6 outermost regions, 3) the economic exclusive zone (EEZ) of the 27 EU Member States, and 4) the EEZ of the 9 outermost regions (GADM, 2022; Flanders Marine Institute, 2023). In some circumstances, a manual check was conducted to ensure that only data intersecting the area of interest was included in the final maps.

Our final wetland maps were produced by merging data extracted by data derived from the different tiers. In areas where we had overlapping data sources, we followed the rules and criteria below:

1. The dataset that can best distinguish between wetlands from other land cover types was selected.
2. The dataset with the finest resolution was selected.
3. The dataset that has the most recent reference year was selected, unless an older dataset provided significantly greater classification detail, or was captured at a higher definition.

Source datasets were combined into a single habitat layer based on the criteria and rules described above. For that, we used a combination of GIS operations (such as select by location, merge, clip, intersect, erase, merge, union) in ArcGIS Pro version 3.3. Spatial data incorporated from each of the tiers have been reprojected from their original projection into the WGS_1984_Albers.

All spatial analyses were undertaken in ArcGIS Pro 3.3 through the Spatial Analyst, Geostatistical Analyst, and Image Analyst extensions. These tools were used to explore the digital maps found in Sub-tasks 2.1 and 2.2 and support the spatial assessment. Then, we used these geostatistical tools to calculate the distribution area (ha) of each wetland type and estimate the proportion (%) of wetland distribution per wetland type and level of protection. In this study, we used the World Database on Protected Areas (version April 2024), which is a comprehensive database storing information on global distribution of terrestrial and marine protected areas and other effective area-based conservation measures (IUCN, UNEP-WCMC, 2024). The IUCN classifies protected areas into management categories, which include:

1. Category Ia: Strict Nature Reserve
2. Category Ib: Wilderness Area
3. Category II: National Park
4. Category III: Natural Monument or Feature
5. Category IV: Habitat or Species Management Area

6. Category V: Protected Landscape or Seascape
7. Category VI: Protected Area with Sustainable Use of Natural Resources

For this study, we followed the IUCN management categories reported by the data provider to IUCN, and therefore, we have not excluded or combined any category, except for those protected areas where no protected area category has been provided. In this last case, we have combined the categories 'Not Reported', 'Not Assigned', and 'Not Applicable' into one category called 'Others'.

Here, we provide a spatial assessment for both inland and coastal wetlands to understand their different levels of protection across the EU Member States and Outermost Regions. We summarized our results based on the area protected by the different IUCN Categories, their designation levels (i.e., international, national or regional) and their implementation status (i.e., adopted, designated, established, inscribed, and proposed). For this analysis, we used the data as per the original information registered in the World Database on Protected Areas (version April 2024).

Mangroves

The High-Resolution Global Mangrove Forests (HGFM_2020; Jia et al., 2023) is the first mangrove forest dataset produced at 10 m spatial resolution, which is helpful in classifying smaller mangrove patches. In this case, we used this layer as the baseline data for our mangrove map for the outermost regions. In addition, the final map for this study was produced by including the distribution of mangroves across Saint Martin derived from Global Mangrove Watch version 3 (GMW; Bunting et al., 2022). Since both original files were downloaded in the shapefile format, we kept the original format. Further details about the spatial file are available in the Metadata file available in DLV3.

Tidal marshes

The distribution of global tidal marshes (Worthington et al., 2024) that has been released in early 2024 is the most comprehensive and up to date spatial data on the distribution of this ecosystem globally. In this case, we used this layer as the baseline data for our tidal marsh map for the European Union MS and outermost regions. For that, we used the mask files to extract the tidal marsh distribution within the EU region and outermost regions. Then, the final map for this study was produced following the same original format (raster at 10 m resolution). For comparison purposes with other datasets used/developed in this study, we also transformed this dataset into shapefile format. Further details about the spatial file are available in the Metadata file available in DLV3.

Seagrasses

The global distribution of seagrasses (version 7.1; UNEP-WCMC, Short, 2021) is the most comprehensive spatial dataset on the distribution of seagrasses. In this case, we used this layer as the baseline data for our seagrass map for the European Union MS and outermost regions. For that, we used the mask files to extract the seagrass distribution within the EU region and outermost regions. Then, we merged information from additional datasets available for the region (Helsinki Commission, 2013; Berov et al., 2022; Topouzelis et al., 2018; DHI, 2024) following the criteria described previously. Since most of the files used to create the seagrass map were in the shapefile format, we kept the original format. Further details about the spatial file are available in the Metadata file available in DLV3.

Inland wetlands

The global distribution of inland wetlands that has been released in 2023 as part of the global wetland map (GWL_FCS30; Zhang et al., 2023) is the most comprehensive spatial dataset showing the distribution of the following freshwater habitats:

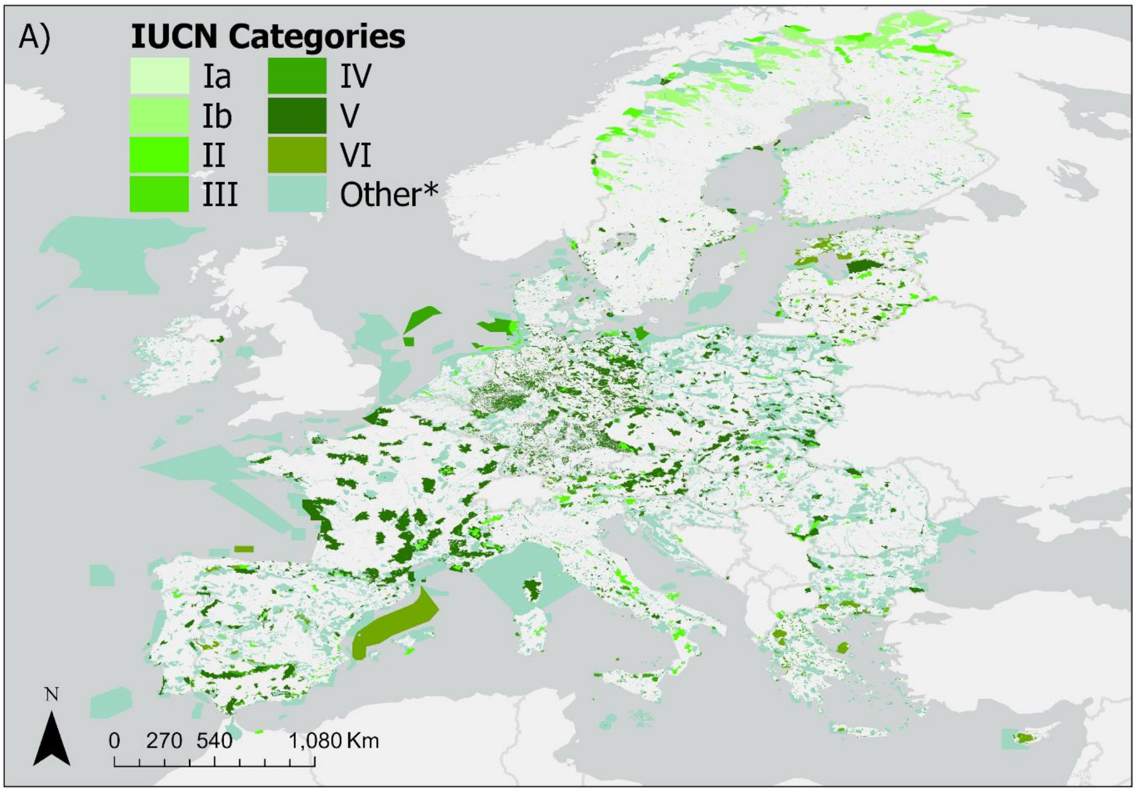
- Swamp: forest or shrubs that grow in the inland freshwater.
- Marsh: herbaceous vegetation, such as grasses, herbs, and low shrubs, that grow in freshwater.
- Flooded flat: Non-vegetated areas along the rivers and lakes.
- Saline: Saline soils and halophytic (salt tolerant) plant species along saline lakes.
- Permanent water: lakes, rivers and streams that are permanently flooded.

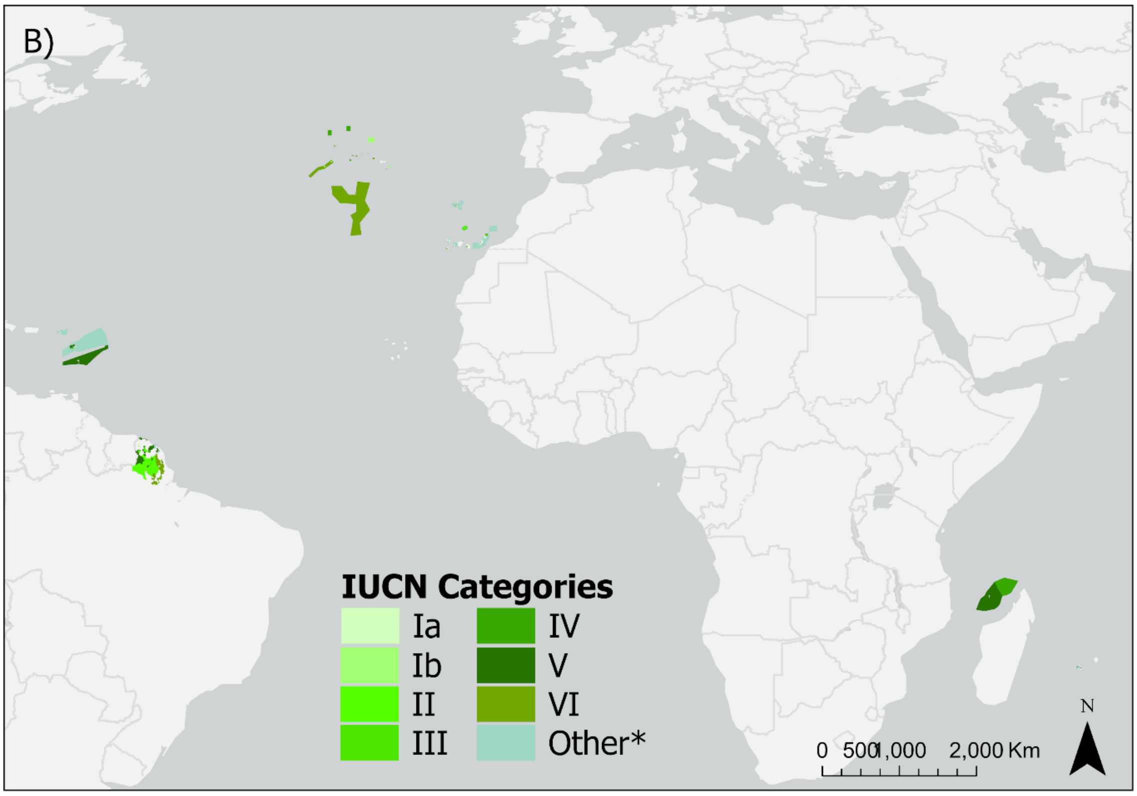
To this date, no publicly available spatial dataset for inland wetlands includes distinction between managed and unmanaged wetlands. In this case, we used the layer above as the baseline data for our inland wetland map for the European Union MS and outermost regions. As part of the data processing, we used a combination of tools to check for outliers in the different classifications for freshwater wetlands. Then, the final map for this study was produced following the same original format (raster at 30 m resolution), with an individual raster being created for each freshwater wetland type. The following codes were used: 1- Swamp; 2- Saline; 3 – Marsh; 4 – Permanent Water; 5 – Flooded Flats. For comparison purposes with other datasets used/developed in this study, we also transformed this dataset into shapefile format. Further details about the spatial file are available in the Metadata file available in DLV3.

A Supplementary Table file was provided as an additional document in DLV3 with supporting results for this Task. This Excel file includes Tables S1 to S17.

Figure 2-5: Coastal and inland wetlands within the European Union and their outermost regions are protected through different protection levels.

Here, we used the World Database on Protected Areas (version April 2024; IUCN, UNEP-WCMC, 2024). * Includes the following classifications: Not Reported, Not Applicable and Not Assigned.





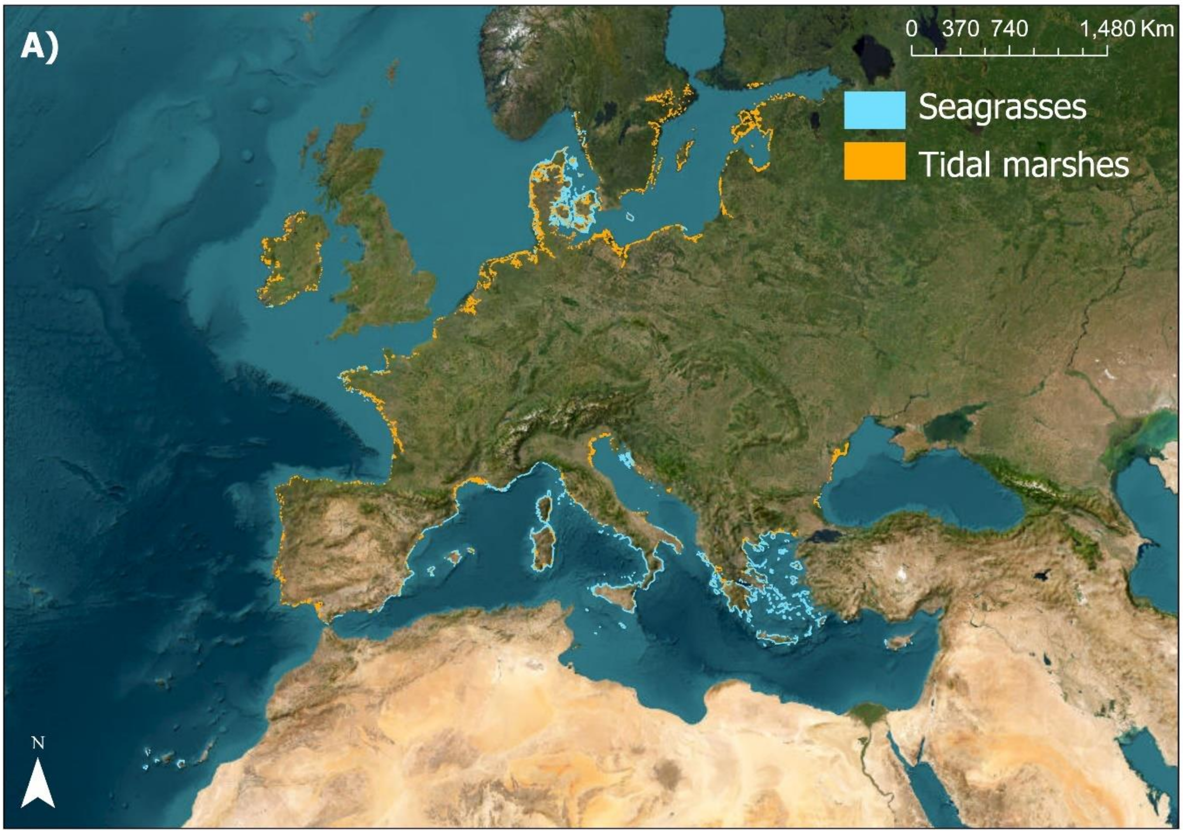
2.2.1.1.3 Outcomes

Coastal wetlands

We estimated that blue carbon ecosystems are distributed within more than 2 million hectares across the EU and their outermost regions (Figure 2-6, Table 2-22). From this total, mangroves are distributed within the outermost regions only (i.e., approximately 93,400 ha), with French Guiana holding ~94% of the extent. Tidal marshes are vastly distributed across the EU Member States, totalling over 400,000 ha (Table 2-22), with Romania and France holding the largest areas of the mapped tidal marshes (Table 2-22). We estimate that seagrass is the blue carbon ecosystem with the largest distribution in the study region, encompassing more than 1.4 million ha, with Denmark and Italy holding the largest mapped distribution (Table 2-22).

Figure 2-6: Mapped distribution of mangroves, tidal marshes and seagrasses within the EU region (A), including their outermost regions (B).

The spatial layers used to map the distribution of blue carbon ecosystems in this study are available on **Error! Reference source not found.**. The buffers around the polygons were increased for representation purposes. Here, we did not include maps of the outermost regions with smaller areas, or none mapped blue carbon systems.



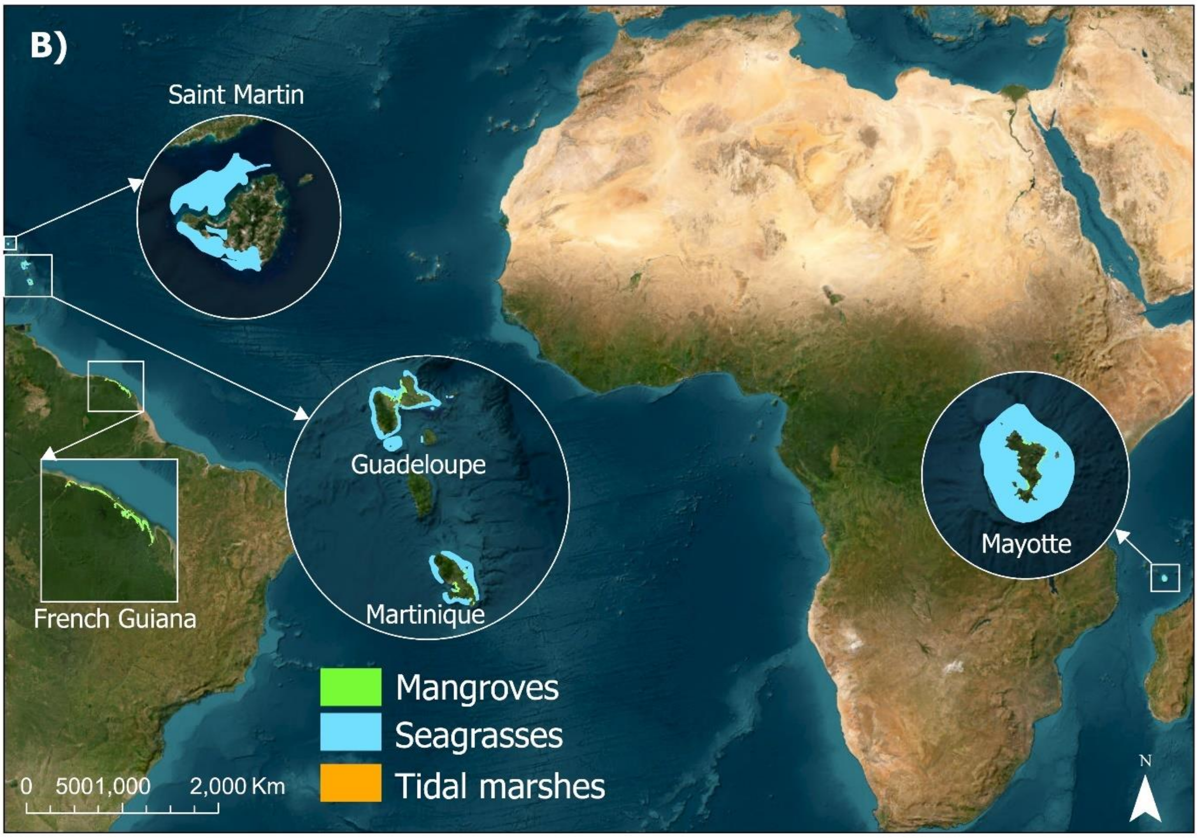


Table 2-22: Total distribution area (ha) of different blue carbon ecosystems within each EU Member State and outermost regions.

The spatial layers used to map the distribution of blue carbon ecosystems in this study are available on **Error! Reference source not found.**. Portugal and Spain include their outermost regions of Azores and Madeira, and Canary Islands, respectively. Values were rounded to the nearest integer.

EU Member State	Area (ha)		
	Mangroves	Tidal Marshes	Seagrasses
Austria			
Belgium		784	
Bulgaria		1,954	934
Croatia		5,162	29,794
Cyprus		220	6,986
Czechia			
Denmark		26,331	413,831
Estonia		26,954	9
Finland		731	
France		66,971	123,272
Germany		34,534	98,440
Greece		21,350	294,922

EU Member State	Area (ha)		
	Mangroves	Tidal Marshes	Seagrasses
Hungary			
Ireland		13,067	358
Italy		22,860	386,872
Latvia		16,344	1,140
Lithuania		3,944	726
Luxembourg			
Malta			
Netherlands		18,115	
Poland		16,116	3,134
Portugal		15,763	4
Romania		71,466	8
Slovakia			
Slovenia		142	
Spain		34,137	115,869
Sweden		11,695	4,285
Outermost regions			
Guadeloupe	3,152		76,033
French Guiana	87,968	478	*
Martinique	1,698		55,842
Mayotte	579		148,437
Réunion	*	19	*
Saint Martin	1		10,696

* Territories that are known to have blue carbon ecosystems according to the literature, but existing maps included in this study do not cover them.

Considering that we still face large uncertainties in the distribution of coastal wetlands across the EU and outermost regions, we used additional datasets to compare the distribution of coastal wetlands (Table 2-23). For mangroves, we estimated an area of approximately 93,398 ha (based on the high-resolution mangrove map developed by Jia et al., 2023). However, two additional datasets show that the distribution of this ecosystem across the outermost region can also vary between 69,383 ha to 91,774 ha, representing > 24,000 ha difference between the upper and lower bounds of their distribution (Table 2-23). For tidal marshes, the difference between the distribution extent estimated in this study (i.e., 508 ha in the outermost regions and 408,629 ha across the EU) and the secondary datasets were even higher (i.e., >12,000 ha difference for the outermost regions and 69,021 – 215,321 ha difference for the EU; Table 2-23). For seagrasses, we used the global modelled distribution of seagrasses (Jayathilake & Costello, 2018) to represent the upper bounds for their distribution. Amongst all coastal wetlands, seagrasses still face largest uncertainties in their distribution, mainly due to the challenges of mapping deeper seagrasses. While the modelled seagrass distribution (Table 2-23) represents an increase of seagrasses by >25% for the outermost regions and >100% for the EU, we need to highlight that the modelled distribution is based on the area suitable to support seagrass growth and not necessarily their occurrence.

Table 2-23: Secondary datasets used to estimate the distribution extent for comparison purposes for each ecosystem type included in this study.

	European Union	Outermost regions
Mangroves (Global Mangrove Watch; Bunting et al., 2022)	NA	69,383 ha
Mangroves (Global Wetland Map; Zhang et al., 2023)	NA	91,774 ha
Tidal Marshes (Global Wetland Map; Zhang et al., 2023)	623,950 ha	12,582 ha
Tidal marshes (Extended wetland ecosystem layer; EEA, 2022)	339,608 ha	Dataset does not cover the outermost regions
Seagrass (Modelled seagrass distribution; Jayathilake & Costello, 2018)	20,260,546 ha	374,053 ha
Inland wetlands (Extended wetland ecosystem layer; EEA, 2022)	1,026,622 ha	Dataset does not cover the outermost regions

Inland wetlands

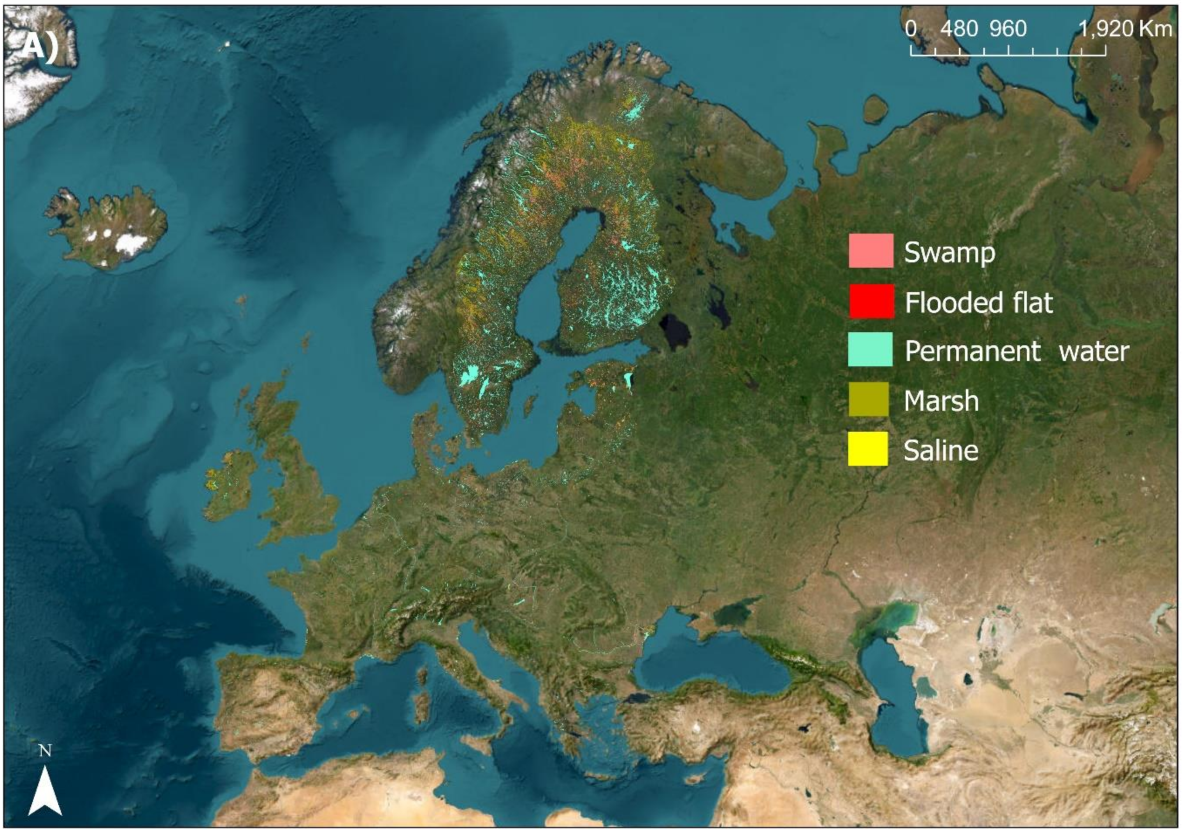
We estimated that inland wetlands are distributed within ~17 million hectares across the EU and their outermost regions (Figure 2-7, Table 2-24). From this total, approximately 250,000 hectares of inland wetlands are distributed across the outermost regions. In these areas, swamps would occur in approximately 153,776 ha, while marsh would be the wetland type with the smallest area (i.e., 20,430 ha). Flooded flats and permanent water would occur within 28,776 ha and 48,304 ha, respectively (Figure 2-7, Table 2-24). Saline do not occur within the outermost regions.

For the EU Member States, we estimate that they are likely to include approximately 16.7 million ha of inland wetlands within their territories (Figure 2-7, Table 2-24). From this total area, permanent waters would occur in approximately 8 million ha, while saline would be the wetland type with the smallest area (i.e., 4,720 ha; and limited to Austria, Hungary and Netherlands) (Figure 2-7, Table 2-24). Flooded flats, marshes and swamps would occur within 1.4 million ha, 4.8 million ha and 2.2 million ha, respectively (Figure 2-7, Table 2-24). However, a secondary dataset showed that inland marshes are distributed across 1 million ha, demonstrating that inland wetlands also face large uncertainties in their distribution across the EU.

For both coastal and inland wetlands, the large differences in the habitat mapping can be associated with the methodological approaches, spatial resolution, inclusion of habitat-specific ground-truthing data, and the temporal variability of these ecosystems. While this study provides an initial baseline information of coastal and inland wetlands for EU Member States and outermost regions based on existing data, we suggest that future studies should invest in the improvement of such maps by combining remote sensing technologies with field data (see Blue Carbon Roadmap in DLV 4 for further details and recommendations).

Figure 2-7: Mapped distribution of inland wetlands (e.g., swamps, flooded flats, permanent waters, marshes, and saline) within the EU region (A), including their outermost regions (B).

The spatial layers used to map the distribution of blue carbon ecosystems in this study are available on **Error! Reference source not found.**. The buffers around the polygons were increased for representation purposes. Here, we did not include maps of the outermost regions with small areas of inland wetlands.



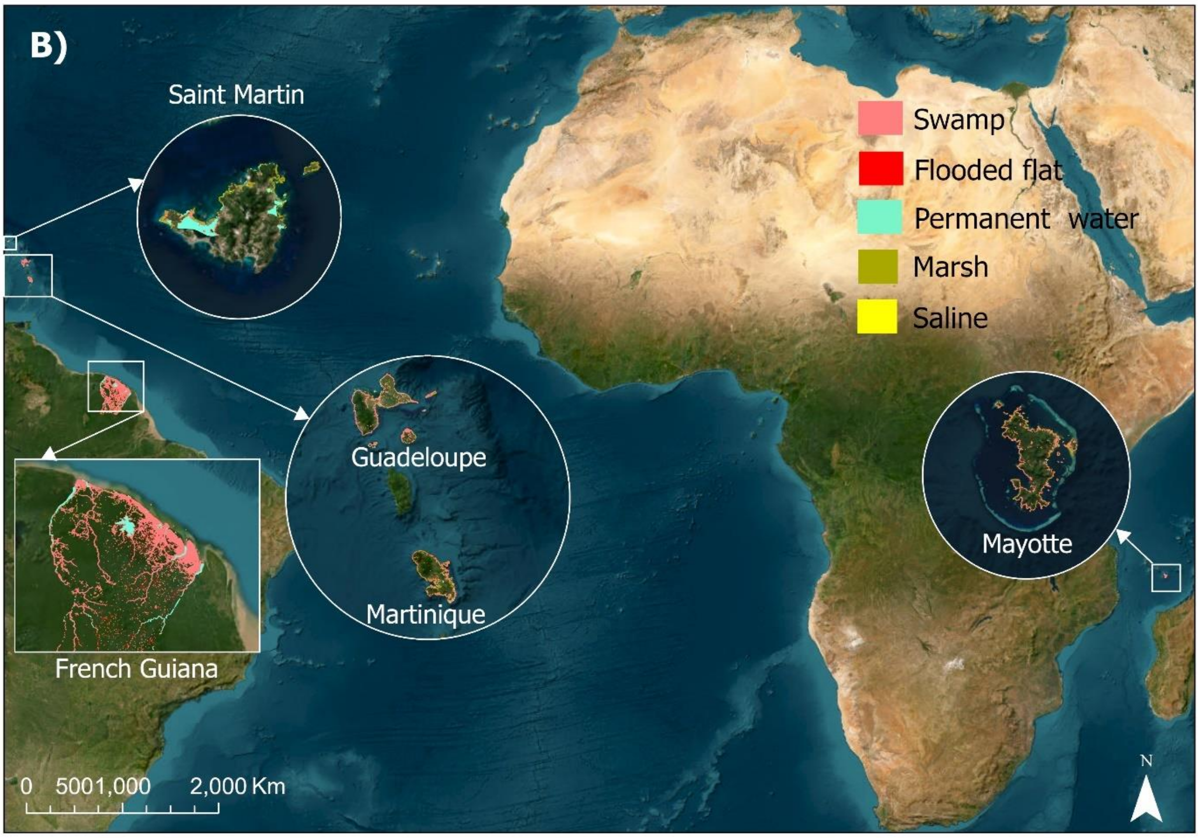


Table 2-24: Total distribution area (ha) of different inland wetlands within each EU Member State and outermost regions.

The spatial layers used to map the distribution of blue carbon ecosystems in this study are available on **Error! Reference source not found.**. Portugal and Spain include their outermost regions of Azores and Madeira, and Canary Islands, respectively. Values were rounded to the nearest integer.

EU Member State	Area (ha)				
	Flooded Flat	Marsh	Permanent Water	Saline	Swamp
Austria	6,759	14,054	83,301	2,056	2,982
Belgium	5,577	6,679	8,977		6,226
Bulgaria	13,846	16,829	101,854		6,450
Croatia	8,107	18,336	37,651		16,000
Cyprus	60	374	520		20
Czechia	15,008	2,677	39,818		3,427
Denmark	9,137	22,509	34,787		22,933
Estonia	24,495	128,123	210,382		97,146
Finland	413,047	1,623,737	2,633,085		502,509

EU Member State	Area (ha)				
	Flooded Flat	Marsh	Permanent Water	Saline	Swamp
France	71,866	72,245	207,830		32,402
Germany	83,820	85,312	257,044		60,104
Greece	13,398	27,386	90,052		9,331
Hungary	19,339	57,008	93,949	2,573	30,488
Ireland	24,308	321,052	91,693		38,273
Italy	16,597	25,449	203,660		4,769
Latvia	42,926	80,464	71,323		89,420
Lithuania	28,727	18,766	78,137		27,203
Luxembourg	304	34	345		21
Malta	0.01	9	2		0.2
Netherlands	21,290	40,129	63,814	91	17,860
Poland	63,542	67,741	275,522		49,459
Portugal	2,981	9,195	51,414		2,240
Romania	50,279	141,324	176,818		92,885
Slovakia	5,780	2,288	15,298		4,932
Slovenia	1,757	616	2,480		911
Spain	12,925	40,128	167,625		4,821
Sweden	460,509	1,998,706	3,090,209		1,094,651
Outermost regions					
Guadeloupe	146	752	58		964
French Guiana	27,503	19,011	47,568		152,433
Martinique	815	246	96		103
Mayotte	300	266	15		250
Réunion			37		
Saint Martin	12	155	531		26

Environmental Protections

Overall, we found that existing protected areas across the EU Member States and their outermost regions provide different levels of protection for coastal and inland wetlands (Table 2-25 and Table 2-26). Our estimates show that protected areas classified as IUCN categories VI and V are responsible for protecting 59% of the mangrove distribution overlapping existing protected areas. In addition, more than 50,000 ha of mangroves in the outermost regions are located within protected areas that did not report the IUCN management category (Table 2-25).

In addition, tidal marshes in the outermost regions are mainly protected by protected areas that have not reported their IUCN management categories (Table 2-25).

However, approximately 244 ha are also protected within IUCN categories IV and V (Table 2-25). In a similar pattern, around 79% of tidal marshes distributed across the EU Member States are protected by protected areas where the IUCN management category is unknown or considered to not be applicable (Table 2-25 and Table S1). However, it is important to highlight that the protected areas from all IUCN categories (I – VI) are playing an important role to conserve the remaining distribution of tidal marshes (Table 2-255 and Table S1).

Furthermore, seagrass meadows in the outermost regions are mainly being protected by Marine Nature Parks and other types of protected areas classified as IUCN category V (i.e., 222,100 ha; Table 2-25 and Table S2). In this case, protected areas with unknown IUCN management categories are also relevant, protecting an additional 162,884 ha of seagrass in the region (Table 2-25 and Table S2). In the EU Member States, approximately 70% of the distribution of seagrasses are also within protected areas with unknown IUCN management category (Table 2-25 and Table S2). Table S2 provides a detailed list of the protected areas acting to conserve seagrass across the EU Member States. Here, it is important to highlight that despite the management categories are unknown, these protected areas play a key role in conserving this ecosystem.

For inland wetlands, we estimate that 69% of flooded flats, 64% of marshes, 76% of permanent waters, 68% of swamps and 71% of salines distributed across the EU Member States are protected by protected areas where the IUCN management category is unknown or considered to not be applicable (Table 2-26, Tables S3 to S4). Similarly to tidal marshes, protected areas from all IUCN categories (I – VI) are also playing an important role to conserve the remaining distribution of inland wetlands (Table 2-26 and Tables S3 to S7).

In addition, for the outermost regions, 6,783 ha of flooded flats are distributed within protected areas of IUCN category V (Table 2-26 and Table S7). For marshes, approximately 9,800 ha are distributed across protected areas where the IUCN management category is unknown or considered to not be applicable (Table 2-26 and Table S7). In contrast, for permanent waters and swamps, most of their area (i.e., 2,745 ha and 65,889, respectively; Table 2-26 and Table S7) are distributed across IUCN category V protected areas.

If we analyse the number of protected areas distributed across the EU region, we found that protected areas at national level are the most numerous ones overlapping with the distribution of coastal and inland wetlands (Figure 2-8). This pattern is found for all wetland types included in this study, except for saline and seagrasses, in which regional level protected areas are the main protected areas overlapping these ecosystems (Figure 2-8). In contrast, we found that coastal and inland wetlands are mainly distributed (i.e., larger areas) across protected areas at regional level (Figure 2-8). For the outermost regions, protected areas at national level are also the most numerous protected areas overlapping coastal and inland wetlands (Figure 2-8).

However, different from the EU region, coastal and inland wetlands are largely distributed across these protected areas at national level, except for tidal marshes which most of their distribution is across protected areas at international level (Figure 2-8). From the protected areas identified in this study, only a small number of protected areas are under the status ‘adopted’, ‘inscribed’ and ‘proposed’, with the majority of them already being designated across both the EU and outermost regions (Figure 2-9). These results demonstrate the importance of having a network of protected areas at different designation levels.

Table 2-25: Total distribution extent (ha) of blue carbon ecosystems within different levels of protection in the EU region and their outermost regions.

Here, we used the World Database on Protected Areas (version April 2024; IUCN, UNEP-WCMC, 2024). Values were rounded to the nearest integer. The different levels of protection provide an important measure to conserve these ecosystems. However, it is important to highlight that such protected areas may overlap in certain locations, so the results below are presented as the total protected area overlapping blue carbon ecosystems within each IUCN category.

Outermost regions							
Blue carbon ecosystems	**Area (ha)**						
	IUCN Category I	**IUCN Category II**	**IUCN Category III**	**IUCN Category IV**	**IUCN Category V**	**IUCN Category VI**	**Other****
Mangroves		National Park (Core Area): 839 ha	Specially Protected Area: 2,101 ha	Biotope Protection Order: 327 ha	Marine Natural Park: 1,995 ha		Ramsar sites: 43,568 ha
				National Seaside and Lakeside Conservancy: 21,930 ha	National Park (Buffer Zone/Area of Adhesion): 1,819 ha		Specially Protected Areas: 6,894 ha
				National Natural Reserve: 25,164 ha	Regional Nature Park: 25,939 ha		
Tidal Marshes	Natural Park: 2 ha			National Seaside and Lakeside Conservancy: 116 ha	Regional Nature Park: 95 ha		Ramsar sites: 413 ha
				National Natural Reserve: 33 ha			Special Areas of Conservation (Habitats Directive): 11 ha

Outermost regions							
							Special Protection Area (Birds Directive): 11 ha
Seagrasses		Natural Park (Core Area): 2,060 ha	Specially Protected Area: 1,411 ha	Biotope Protection Order: 704 ha	Marine Nature Park: 198,654 ha		Ramsar sites: 10,310 ha
				Forest Managed Biological Reserve: 8 ha	National Park (Buffer Zone/Area of Adhesion): 20,439 ha		Specially Protected Area: 152,574ha
				National Seaside and Lakeside Conservancy: 2,528 ha	Regional Nature Park: 3,007 ha		
				National Nature Reserve: 211 ha			
				Regional Nature Reserve: 312 ha			
				Specially Protected Area: 0.25 ha			
EU Member States*							
Blue carbon ecosystems	**IUCN Category I**	**IUCN Category II**	**IUCN Category III**	**IUCN Category IV**	**IUCN Category V**	**IUCN Category VI**	**Other****
Tidal Marshes	Ia: 1,756 ha Ib: 3,054 ha	52,775 ha	328 ha	120,009 ha	75,608 ha	37,359 ha	1,134,711 ha
Seagrasses	Ia: 452 ha Ib: 1,098 ha	107,478 ha	495 ha	260,007 ha	82,342 ha	33,387 ha	2,506,878 ha

*Due to the large number of subcategories in each IUCN category, here, we provide a total area under each main IUCN category with a detailed list provided in Tables S1 and S2 from the Supplementary Tables file (Additional file submitted as part of the DLV 3).

** Includes the following classifications: Not Reported, Not Applicable and Not Assigned.

Table 2-26: Total distribution extent (ha) of inland wetlands within different levels of protection in the EU region and their outermost regions.

Here, we used the World Database on Protected Areas (version April 2024; IUCN, UNEP-WCMC, 2024). Values were rounded to the nearest integer. The different levels of protection provide an important measure to conserve these ecosystems. However, it is important to highlight that such protected areas may overlap in certain locations, so the results below are presented as the total protected area overlapping blue carbon ecosystems within each IUCN category.

Outermost regions							
Inland wetlands	**Area (ha)**						
	IUCN Category I	**IUCN Category II**	**IUCN Category III**	**IUCN Category IV**	**IUCN Category V**	**IUCN Category VI**	**Other****
Flooded Flats	Ia: 9 ha Ib: 84 ha	273 ha	74 ha	1,827 ha	6,783 ha	35 ha	2,282 ha
Marshes	Ib: 48 ha	64 ha	212 ha	7,062 ha	6,153 ha		9,873 ha
Permanent Waters	Ib: 5 ha	688 ha	132 ha	1,205 ha	2,745 ha	208 ha	1,480 ha
Saline							
Swamps	Ib: 120 ha	77 ha	99 ha	34,536 ha	65,889 ha	2 ha	47,845 ha
EU Member States*							
Inland wetlands	**IUCN Category I**	**IUCN Category II**	**IUCN Category III**	**IUCN Category IV**	**IUCN Category V**	**IUCN Category VI**	**Other****
Flooded Flats	Ia: 36,755 ha Ib: 134,570 ha	31,736 ha	2,862 ha	81,030 ha	90,570 ha	10,179 ha	883,416
Marshes	Ia: 210,823 ha Ib: 1.3 million ha	169,221 ha	1,197 ha	296,362 ha	130,987 ha	36,119 ha	3.9 million ha
Permanent Waters	Ia: 86,421 ha Ib: 300,784 ha	228,802 ha	7,970 ha	321,131 ha	624,729 ha	146,388 ha	5.5 million ha

Outermost regions								
Saline		National Park: 3,360 ha		Landscape and Nature Protection Area: 2,058 ha	Nature Park: 406 ha		Marine Protected Area: 0.1 ha
				Nature Conservation Act: 74 ha			Nature Reserves: 63 ha
							Ramsar site: 4,713 ha
							Special Areas of Conservation (Habitats Directive): 4,702 ha
							Special Protection Area (Birds Directive): 4,697 ha
Swamps	Ia: 87,734 ha Ib: 308,350 ha	81,598 ha	2,122 ha	172,597 ha	108,522 ha	19,095 ha	1.6 million ha

*Due to the large number of subcategories in each IUCN category, here, we provide a total area under each main IUCN category with a detailed list provided in Tables S7 from the Supplementary Tables file (Additional file submitted as part of the DLV 3).

** Includes the following classifications: Not Reported, Not Applicable and Not Assigned.

Figure 2-8: Number of protected areas and their area according to the designation status registered in the World Database on Protected Areas (version April 2024; IUCN, UNEP-WCMC, 2024) for the different inland and coastal wetlands. Values were rounded to the nearest integer.

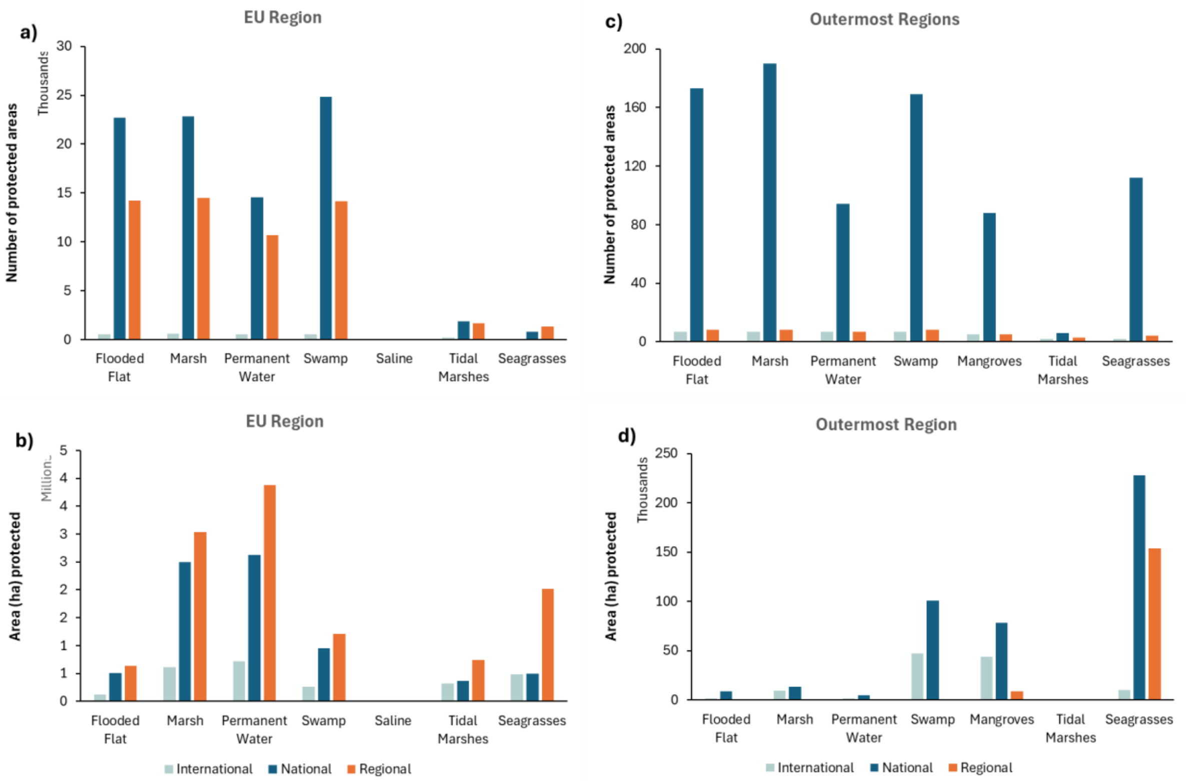
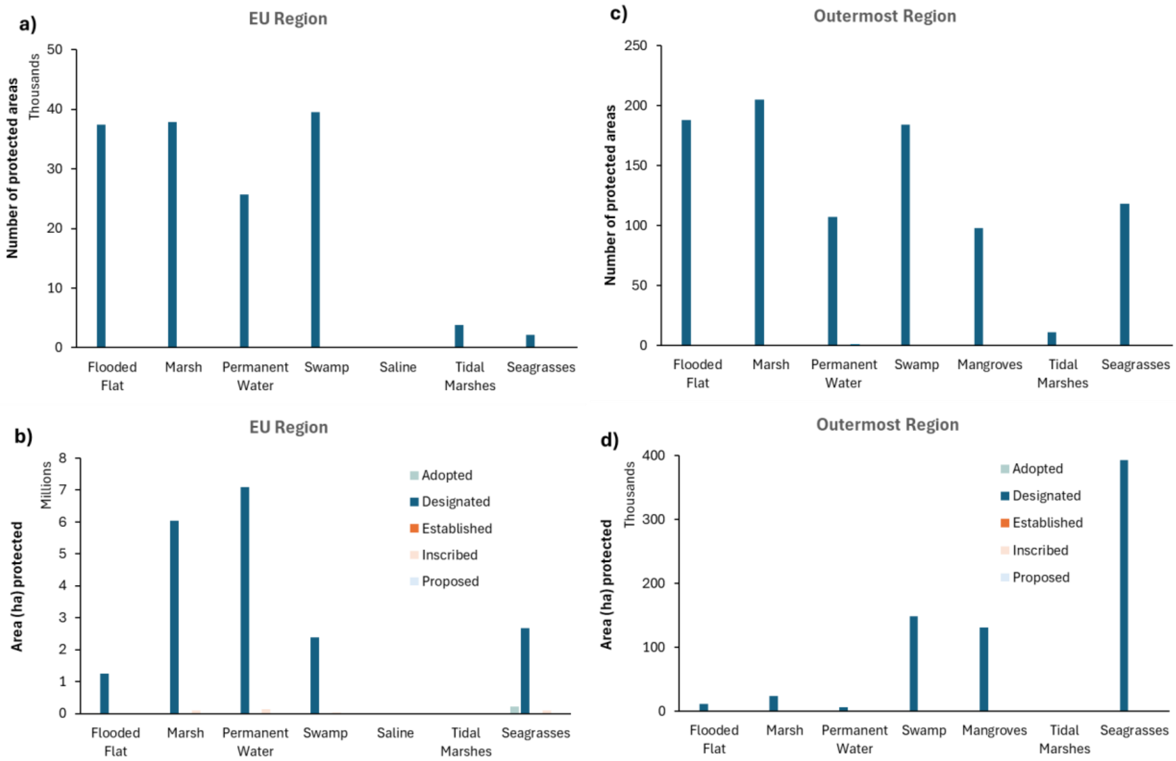


Figure 2-9: Number of protected areas and their area according to the implementation status registered in the World Database on Protected Areas (version April 2024; IUCN,

UNEP-WCMC, 2024) for the different inland and coastal wetlands. Values were rounded to the nearest integer.



2.2.1.1.4 Deliverables

The submission package for Task 2 includes several files and the table below provides a detailed description of the files that incorporate DLV 3 and DLV 4 under subtask 2.1.

Table 2-27: Detailed description of the files submitted as part of deliverables 3 and 4 (DLV3 and 4) for subtask 2.1: Mapping the distribution of coastal and freshwater wetlands and their protection level.

DLV number	Deliverable name	File name	Purpose/Significance
DLV 3	Digital maps in GeoTIFF format of the distribution of wetlands and potential changes in land cover	**Folder Inland Wetlands** including the GeoTIFF rasters and shapefiles for each inland wetland type identified within the EU Member States and Outermost regions: 1. CINEA_Inland_Flooded Flats 2. CINEA_Inland_Marsh 3. CINEA_Inland_Permanent Water 4. CINEA_Inland_Saline 5. CINEA_Inland_Swamp 6. CINEA_Inland_OutermostRegions A metadata file (Metadata_Inland_Wetlands) is also provided in this folder containing a general description of the spatial dataset.	Spatial files generated in sub-task 2.1 that map the distribution of inland wetlands, mangroves, tidal marshes and seagrasses across EU Member States and Outermost regions. The dataset can be used in future projects focusing on freshwater and coastal wetlands, including their conservation and restoration.
		Folder Mangroves including the shapefiles showing the mangrove distribution across the Outermost regions. A metadata file (Metadata_Mangroves) is also provided in this folder containing a general description of the spatial dataset.	
		Folder Seagrasses including the shapefiles showing the seagrass distribution within the EU Member States and Outermost regions: 1. CINEA_Seagrass_EU_MS 2. CINEA_Seagrass_OutermostRegions A metadata file (Metadata_Seagrasses) is also provided in this folder containing a general description of the spatial dataset.	
		Folder Tidal Marshes including the GeoTIFF rasters and shapefiles showing the distribution of tidal marshes within the EU Member States and Outermost regions: 1. CINEA_TidalMarshes_EU_MS 2. CINEA_TidalMarshes_OR A metadata file (Metadata_TidalMarshes) is also provided in this folder containing a general description of the spatial dataset.	
		Folder Maps including GeoTIFF maps for EU and outermostregions: 1. Habitat Maps 2. Extent Change	
		Additional file: Supplementary Tables containing supporting results (Tables S1 to 17) Format: Excel file	This file includes additional results cited in this Task.

DLV number	Deliverable name	File name	Purpose/Significance
DLV 4	Power point presentation summarising the results from the spatial assessment	DLV4_ Presentation on land use changes in wetlands and blue carbon habitats (.pptx)	Power Point file summarising the results found in Task 2.

2.2.1.2. Sub-task 2.2: Mapping the distribution change of coastal wetlands

For this sub-task, we used existing data to estimate distribution change of coastal wetlands across the EU and outermost regions (**Error! Reference source not found.**). Overall, there was a lack of temporal spatial data for mangroves, tidal marshes and seagrasses across the EU and outermost regions. For tidal marshes across the EU and outermost regions, we mapped the land cover change based on the long-term CORINE Land Cover (CLC) inventory dataset[27]. While for the EU region the data is available from 1990, 2000, 2006, 2012, and 2018, for the outermost regions, data is only available since 2006. For the purposes of this analysis, we focused on tidal marshes with the aim to quantitatively map gains and losses of the distribution of these ecosystems through land use changes over time. To assess the changes in tidal marsh distribution, we classified the land use classes used in the CORINE dataset in broader classes so we can also understand the different changes in land cover over time (Table 2-28). Then, we used the ArcGIS Pro tool 'Compute Change Raster' to compare the multiple digital maps to determine the type, magnitude, and location of tidal marsh change. For the outermost regions, tidal marshes were only identified in French Guiana and Mayotte.

For mangroves in the outermost regions, we used the long-term Global Mangrove Watch dataset (Bunting et al., 2022; **Error! Reference source not found.**) to estimate the gains and losses of mangrove forests over time. This dataset is available for 1996, 2007-2010 and 2015-2020, and different from the CORINE Land Cover dataset, it only shows the distribution of mangroves over time. In the case of mangroves, we estimated mangrove expansion and loss between two time periods: 1996 to 2010 and 2015 to 2020. While some data is available for tidal marshes, very limited data is available for seagrasses. For seagrasses, no publicly available spatial data was found. Therefore, here, we focus the seagrass analysis on the data compiled at site specific level across different sites in Europe by de Los Santos (2019). While the study conducted by de los Santos et al. (2019) focused on the entire Europe, our results are based only on data (i.e., area, trajectory, net change

[27] https://land.copernicus.eu/pan-european/corine-land-cover

and specific rate of change) extracted for the EU region. No data was publicly available to conduct the analysis for seagrasses in the outermost region.

For this sub-task, we used a combination of GIS operations for raster and vectors (such as select by location, merge, clip, intersect, erase, merge, union) in ArcGIS Pro version 3.3. Spatial data have been reprojected from their original projection into the WGS_1984_Albers. All spatial analyses were undertaken in ArcGIS Pro 3.3 through the Spatial Analyst, Geostatistical Analyst, and Image Analyst extensions.

Table 2-28: List of land use classes identified in the long-term CORINE Land Cover inventory dataset associated with tidal march changes over time, and the reclassified classes used in this study.

CORINE Classes	Reclassification applied in this study
Agro-forestry areas	Forest
Airports	Urban Area
Annual crops associated with permanent crops	Agriculture
Beaches, dunes, sands	Natural Environments
Broad-leaved forest	Forest
Coastal lagoons	Natural Environments
Complex cultivation patterns	Agriculture
Coniferous forest	Forest
Construction sites	Urban Area
Continuous urban fabric	Urban Area
Discontinuous urban fabric	Urban Area
Dump sites	Urban Area
Estuaries	Natural Environments
Fruit trees and berry plantations	Agriculture
Green urban areas	Urban Area
Industrial or commercial units	Urban Area
Inland marshes	Natural Environments
Intertidal flats	Natural Environments
Land principally occupied by agriculture, with significant areas of natural vegetation	Agriculture
Mineral extraction sites	Mineral extraction
Mixed forest	Forest
Moors and heathland	Agriculture
Natural grasslands	Natural Environments
Non-irrigated arable land	Agriculture
Olive groves	Agriculture
Pastures	Agriculture
Peat bogs	Peatlands

CORINE Classes	Reclassification applied in this study
Permanently irrigated land	Agriculture
Port areas	Urban Area
Rice fields	Agriculture
Road and rail networks and associated land	Urban Area
Salines	Agriculture
Sclerophyllous vegetation	Natural Environments
Sea and ocean	Natural Environments
Sparsely vegetated areas	Natural Environments
Sport and leisure facilities	Urban Area
Transitional woodland-shrub	Natural Environments
Vineyards	Agriculture
Water bodies	Natural Environments
Water courses	Natural Environments

2.2.1.2.1 Outcomes

Mangroves

As expected, we found that the distribution of coastal wetlands changed over time across the EU and their outermost regions. For example, for mangroves in the outermost regions, we found that French Guiana had the largest positive net change between 1996 and 2020, with mangrove extent increasing by 3,525 ha (Table 2-29 and Figure 2-10). In contrast, Mayotte was the only outermost region with a negative net change between 1996 and 2020 (Table 2-29 and Figure 2-10). Guadeloupe and Martinique also showed a positive net change over time, while mangroves in Saint Martin did not show any major change over time (Table 2-29 and Figure 2-10).

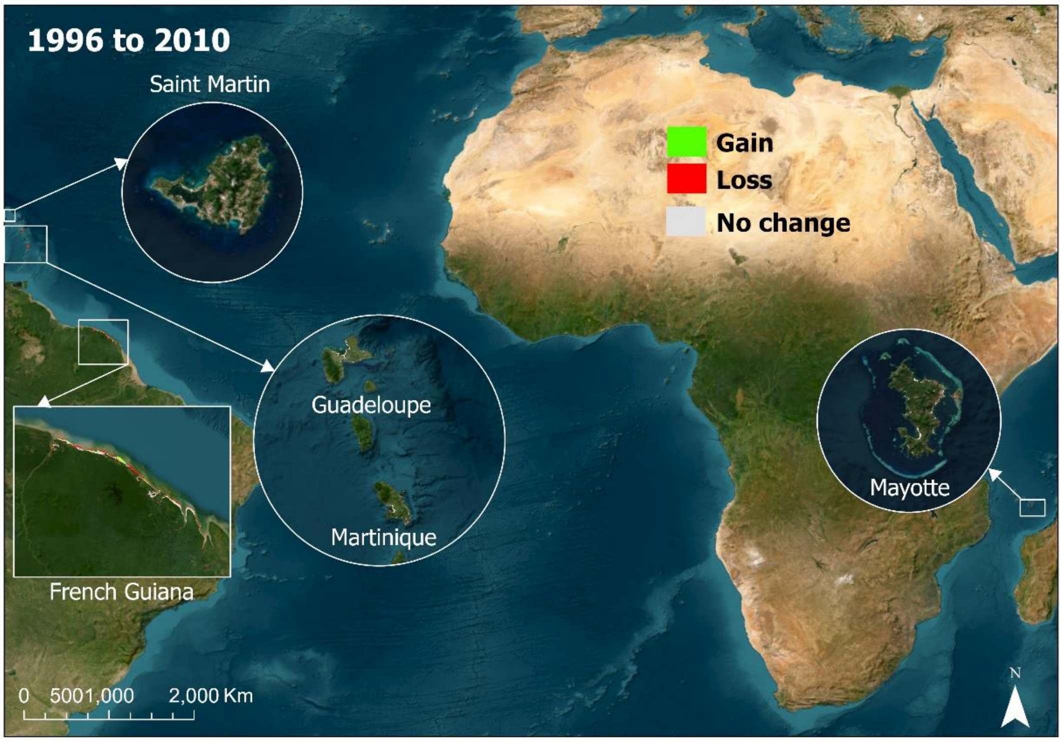
Table 2-29: Mangrove extent change (ha) during 1996 to 2020 across the outermost regions. Here, we estimated extent change in mangroves using the Global Mangrove Watch dataset (Bunting et al., 2022), which includes data from 1996, 2007 to 2010 and 2015 to 2020.

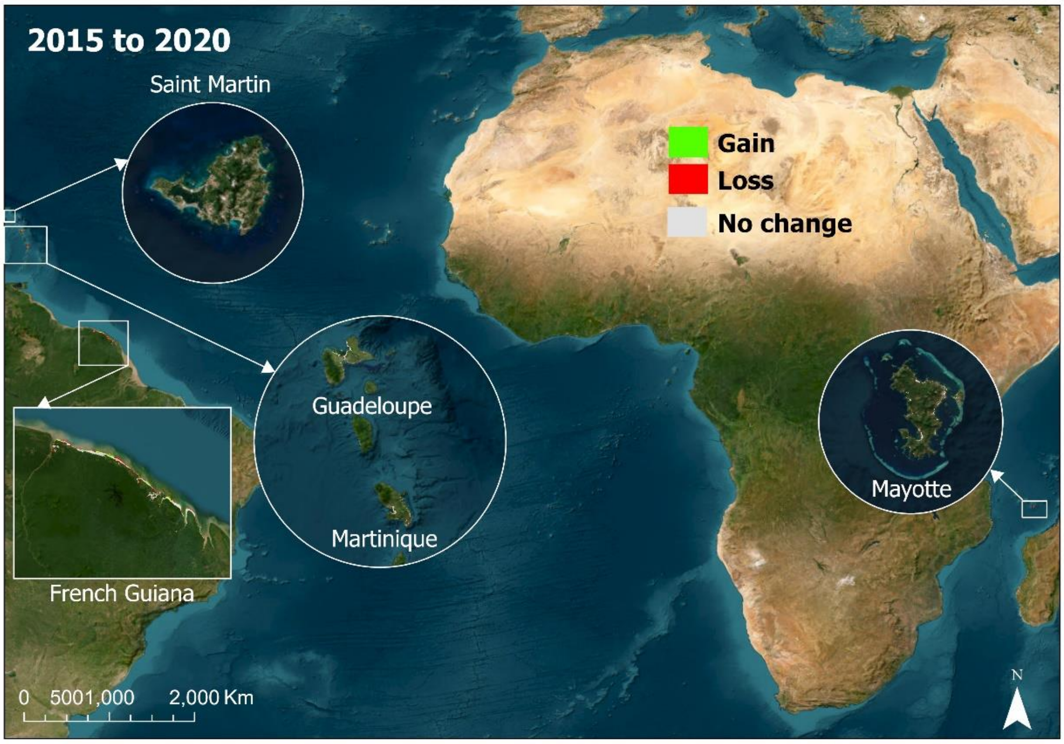
Year	Area (ha) in Outermost regions				
	French Guiana	Guadeloupe	Martinique	Mayotte	Saint Martin
1996	59,444	3,417	1,921	677	1.2
2007	58,661	3,424	1,920	686	1.2
2008	59,142	3,429	1,921	692	1.2
2009	59,760	3,441	1,930	692	1.3

Year	Area (ha) in Outermost regions				
	French Guiana	Guadeloupe	Martinique	Mayotte	Saint Martin
2010	60,045	3,432	1,926	689	1.3
2015	61,712	3,429	1,926	679	1.3
2016	62,538	3,431	1,910	675	1.3
2017	63,002	3,431	1,909	676	1.3
2018	62,910	3,432	1,915	681	1.2
2019	62,561	3,426	1,939	682	1.1
2020	62,970	3,420	1,941	676	1.1
Net change (ha) between 1996 and 2020	3,525	3	20	-1	0.1

Figure 2-10: Spatial patterns in mangrove extent change between 1996 and 2020 across the outermost regions.

Here, we estimated extent change in mangroves using the Global Mangrove Watch dataset (Bunting et al., 2022), which includes data from 1996, 2007 to 2010 and 2015 to 2020. The buffers around the polygons were increased for representation purposes.





Tidal marshes

In the EU region, we estimated that tidal marsh loss has decreased substantially in the 2012-2018 time period, varying from over 24,000 ha lost during the time period of 2006-2012 to just over 2,000 ha in the time period between 2012-2018 (Figure 2-11 and Figure 2-12). In contrast, when analysing the potential land conversion from other land use types to tidal marsh, we could estimate that the period between 2006 and 2012 was also the one with the highest expansion of tidal marshes across the EU Member States (i.e., > 67,000 ha of tidal marshes; Figure 2-11 and Figure 2-12). We also found that the period between 2012 and 2018 was the one with higher stability, with approximately 337,000 ha showing no changes in their distribution (Figure 2-11, Table 2-30 and Table S8). Overall, changes in tidal marsh were mainly associated with transition to other vegetation types and natural environments (Figure 2-12 and Tables S8 to S11). In addition, land use transitions between tidal marshes and agriculture were also responsible for large areas of extent change across the study region (Figure 2-12 and Tables S8 to S11). If we evaluate our results across each EU Member State, we found that the extent change in tidal varies substantially both spatially and temporally (Table 2-30 and Table S11). For example, we identified large areas of tidal marsh expansion in Denmark, France, Germany, Romania and Spain (Table 2-3030). In contrast, larger areas of tidal marsh loss were mainly identified on Greece and Italy (Table 2-30). Despite the larger changes in the distribution of tidal marshes, it is important to highlight that most of the mapped tidal marsh distribution have not shown changes in their distribution (Figure 2-11, Table 2-30 and Table S11).

For the outermost region, our results are focused on French Guiana and Mayotte only due to data availability. In this case, we estimate that while both outermost regions had a tidal marsh expansion of approximately 52 ha combined during 2006-2012, the tidal marsh loss in the same period was higher (i.e., ~89 ha; Table 2-30). In the following time period (i.e., 2012-2018), we have not identified any tidal marsh expansion, while there was a loss of approximately (17 ha; Table 2-30). Similar to EU Member States, changes in tidal marsh were mainly associated with transition to other vegetation types and natural environments (Table S12). In addition, land use transitions between tidal marshes and agriculture were also responsible for extent change on both outermost regions (Tables S12 – S14). While French Guiana showed higher tidal marsh loss over time, we did not find major spatial changes for most of the mapped tidal marsh distributed across both French Guiana and Mayotte (Figure 2-13 and Table 2-30). Furthermore, on both outermost regions, tidal marshes and their associated changes were limited to specific areas within their borders (for example, north of French Guiana and eastern coastline in Mayotte).

While the results based on the CORINE dataset shows an overall net increase in the tidal marsh extent between 1990 to 2018, a secondary dataset (Campbell et al., 2019; **Error! Reference source not found.**) shows an opposite trend for the EU. In this case, tidal marshes lost an area of approximately 31,543 ha between 2000 to 2019, while expanding their distribution to only 15,430 ha (Table S15). When assessing the changes in tidal wetlands (i.e., tidal marshes, mangroves and tidal flats) as a group (Murray et al., 2022), it has been estimated that EU Member States contributing ≥ 0.1% of global net change have lost 39,100 ha of tidal wetlands between 1999 and 2019, while gaining 53,400 ha during the same period (Table S16). In this case, the total wetland change has been estimated at 92,600 ha (Table S16). In this case, tidal flats were the tidal wetland with largest changes over time across the EU and outermost regions (Table S17). Similarly to the wetland maps in Task 2.1, the differences across the extent change maps can be associated with the methodological approaches, spatial resolution, inclusion of habitat-specific ground-truthing data, and the lack of a systematic protocol to monitor coastal wetlands in the region. See Blue Carbon Roadmap in DLV 4 for further details and recommendations on how to improve the monitoring of coastal wetland in the EU.

Figure 2-11: Spatial patterns in tidal marsh extent change between 1990 and 2018 across the EU.

Here, we estimated extent change in tidal marshes using the long-term CORINE Land Cover inventory dataset which includes data from 1990, 2000, 2006, 2012, and 2018. The buffers around the polygons were increased for representation purposes.

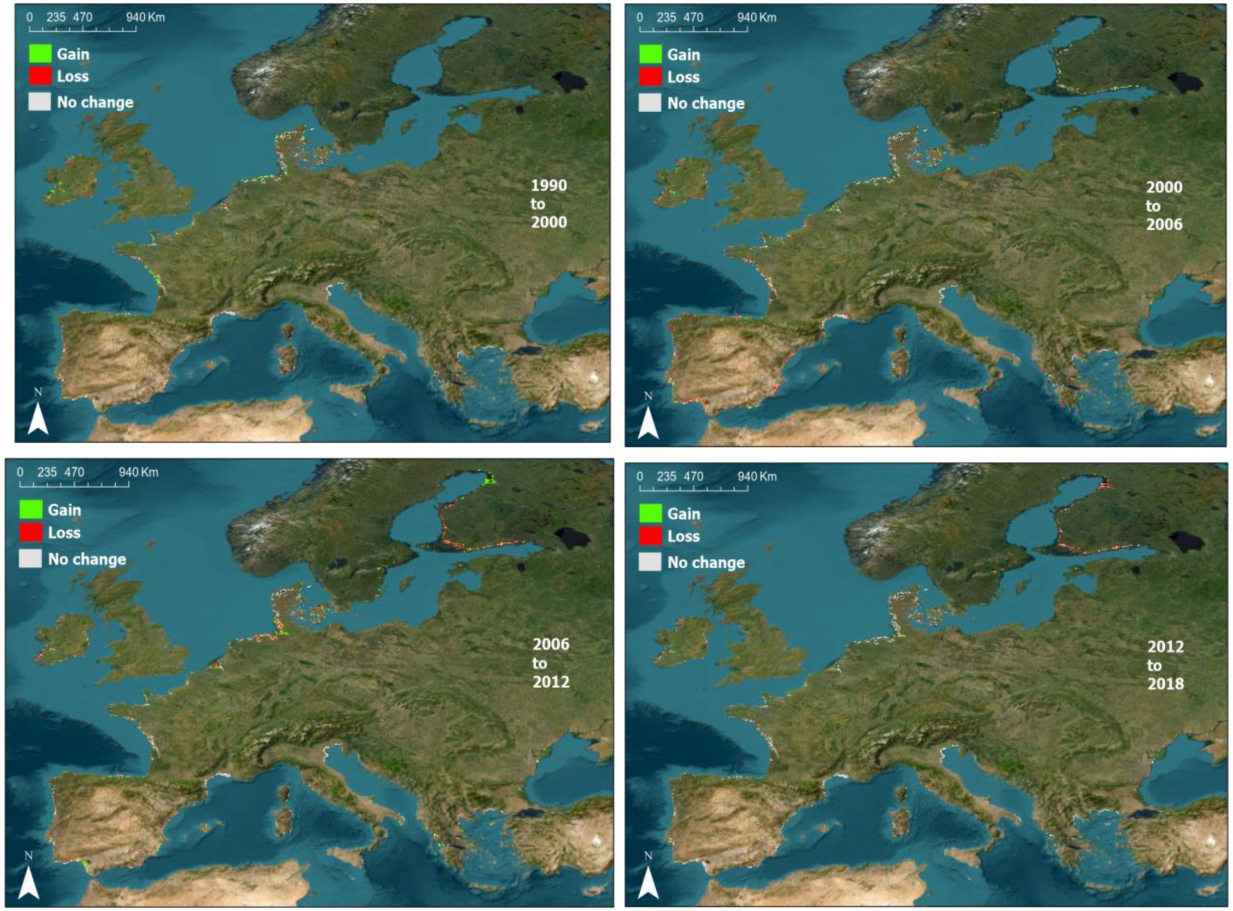


Figure 2-12: Changes in the distribution of tidal marshes (±SE) across the EU detailing the land use changes and its magnitude over time.

Tables S9 and S10 show the detailed changes in area (ha) for each land transition. Here, we estimated extent change in tidal marshes using the long-term CORINE Land Cover inventory dataset which includes data from 1990, 2000, 2006, 2012, and 2018.

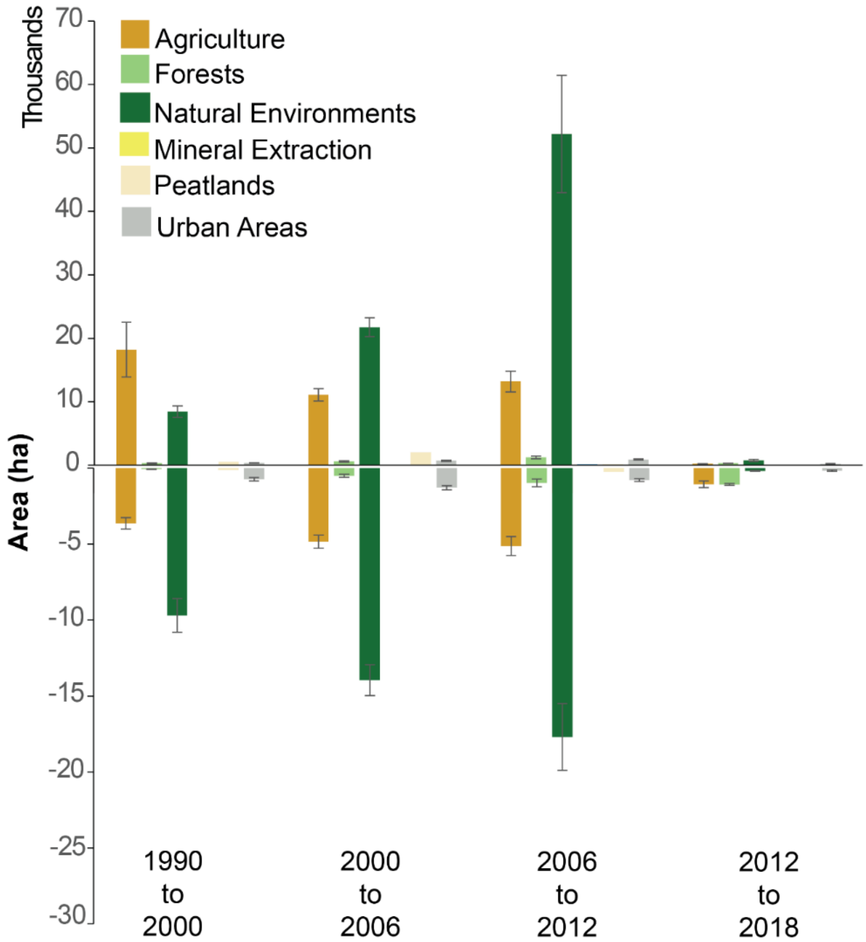


Table 2-30: Tidal marsh extent change (expansion – loss) during 1990 and 2018 across the EU Member States and outermost regions (French Guiana and Mayotte only due to data availability).

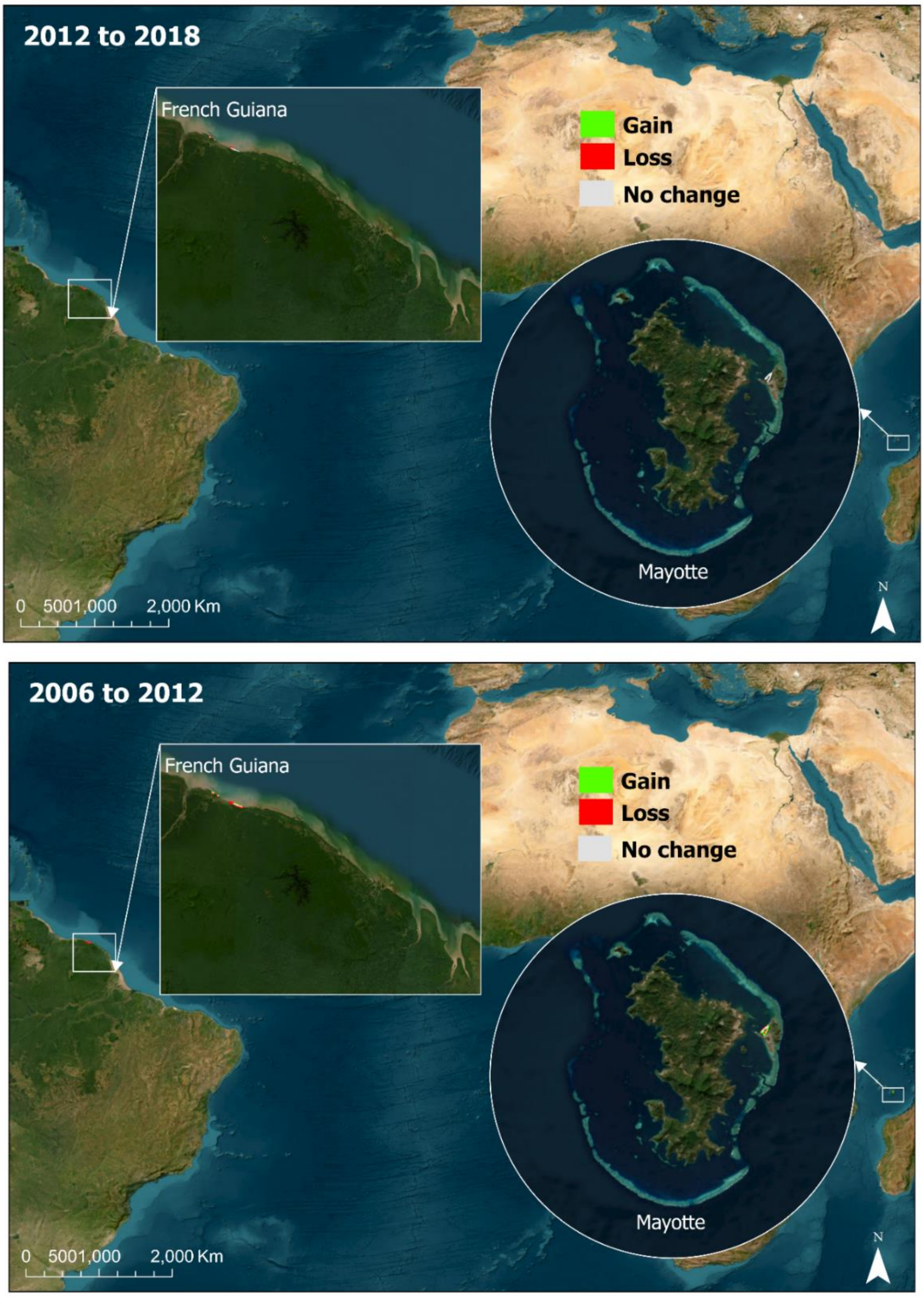
Here, we estimated extent change in tidal marshes using the long-term CORINE Land Cover inventory dataset which includes data from 1990, 2000, 2006, 2012, and 2018. Table S11 shows the tidal marsh expansion and loss for each EU Member State and time period. EU MS = EU Member State; OR: Outermost region.

Countries	Extent Change (expansion – loss)				No Change			
	1990 to 2000	2000 to 2006	2006 to 2012	2012 to 2018	1990 to 2000	2000 to 2006	2006 to 2012	2012 to 2018
Belgium (EU MS)	-12	23	161	181	524	536	558	721
Bulgaria (EU MS)		-35	488	-77	34	561		410
Croatia (EU MS)	26	-2	-1		547	826	570	570
Cyprus (EU MS)		11					839	839
Denmark (EU MS)	2,170	1,691	108		23,759	26,972	29,219	29,538
Estonia (EU MS)	-27	-28			305	278	278	277
Finland (EU MS)		831	1,191	-1,690		21,978	14,436	21,173
France (EU MS)	12,830	-112	-1,318	-71	63,904	78,084	77,261	78,816
Germany (EU MS)	871	402	7,923	-11	16,889	17,590	15,811	26,225
Greece (EU MS)	-477	-1,642	1,324	-55	33,837	29,605	30,292	33,545
Ireland (EU MS)	881	485	280		1,626	4,040	4,626	5,453
Italy (EU MS)	-1,972	2,259	-4,433	125	39,806	40,891	37,097	39,468
Latvia (EU MS)		8	-88		83	57		
Netherlands (EU MS)	109	339	246	217	8,926	9,711	9,680	10,365
Portugal (EU MS)	-683	-618	-103		18,012	17,038	17,975	18,238
Romania (EU MS)	2	5,906	2,151		815	381	6,647	8,874
Slovenia (EU MS)	114	-1	-50	-22	103	217	99	147

Countries	Extent Change (expansion – loss)				No Change			
	1990 to 2000	2000 to 2006	2006 to 2012	2012 to 2018	1990 to 2000	2000 to 2006	2006 to 2012	2012 to 2018
Spain (EU MS)	-443	5,983	35,240	55	29,873	20,286	33,264	71,270
Sweden (EU MS)		-4	341			1,823	1,794	2,177
French Guiana (OR)	NA	NA	-37	-17	NA	NA	664	686
Mayotte (OR)	NA	NA	0	0	NA	NA	40	51

Figure 2-13: Spatial patterns in tidal marsh extent change between 2006 and 2018 across the outermost regions (French Guiana and Mayotte only due to data availability).

Here, we estimated extent change in tidal marshes using the long-term CORINE Land Cover inventory dataset which includes data from, 2006, 2012, and 2018. The buffers around the polygons were increased for representation purposes.



Seagrasses

Based on the data available for changes in seagrass between 1869 and 2016 across the EU region, we found that most of the sites across all EU Member States showed a decline trend (50% of sites) compared to those reporting increase (20%) or no change (30%) (Table 2-31). From this decline trend, the highest number of sites reporting decline were associated with *Zostera marina*, while the lowest were reported for *Posidonia oceanica* (Figure 2-14 and Table 2-32). Overall, we estimated a net loss of 32,864 ha between 1869 and 2016, with the mean specific rate of change was higher on declining sites (10% yr^{-1}) than on increasing sites (8.9% yr^{-1}). Despite the overall decline trend found, de los Santos et al. (2019) found that European seagrasses have slowed down their decadal decline rate since 1980, followed by an increase in their decadal gain rates by 1990.

Figure 2-14: Distribution of seagrass sites across the EU region extracted from the database compiled by de los Santos et al. (2019), including their trajectories (i.e., decline, increase and no change) based on the available time series between 1869 and 2016. Pie charts show the overall and species-specific number of sites for each trajectory.

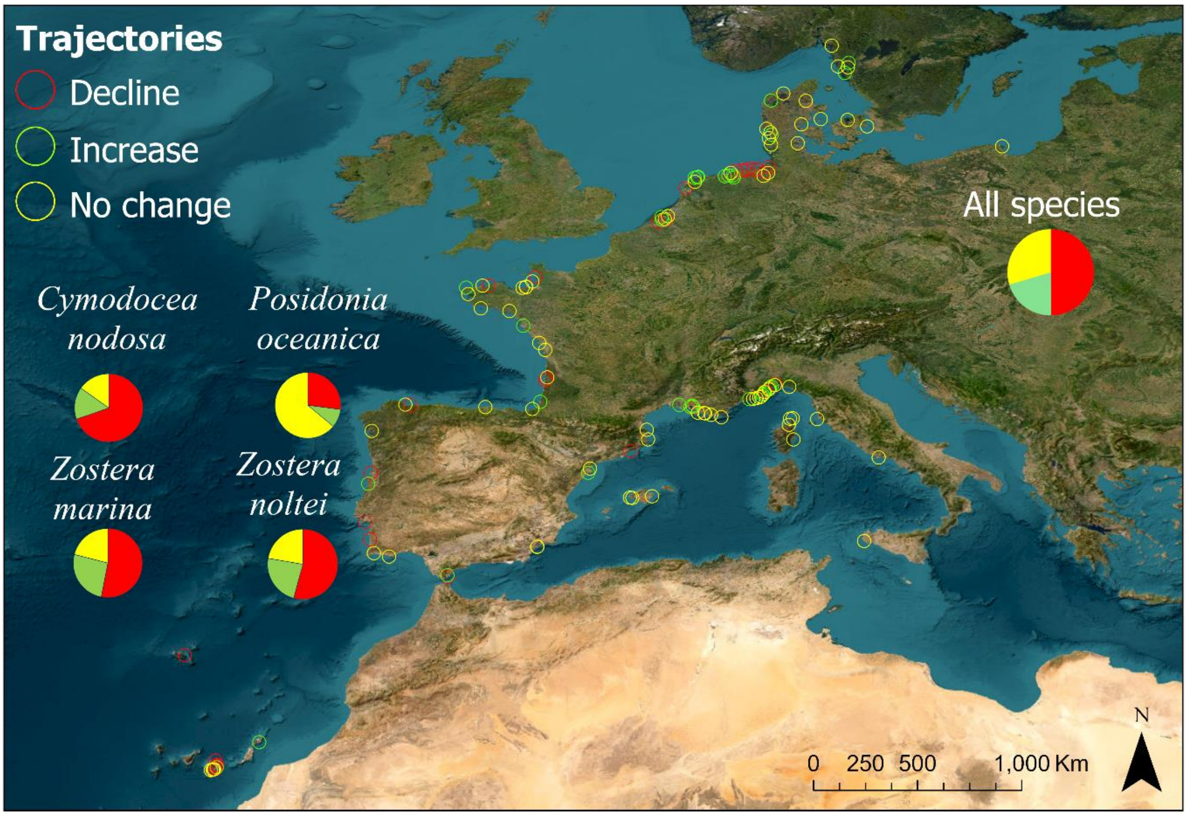


Table 2-31: Number of seagrass sites across the EU region and their trajectories and specific rate of change (% yr^{-1}). This data is based on the dataset compiled by de los Santos et al. (2019).

EU Member States	Trajectory		
	Decrease	Increase	No change
Denmark	31	22	23
France	91	42	71
Germany	31	4	7
Italy	21	11	20
Poland	2	3	1
Portugal	29	3	5
Spain	49	21	32
Sweden	7	2	6
Netherlands	32	13	9
Specific rate of change (% yr^{-1})			
	Mean	**Min**	**Max**
Denmark	-0.48	-39.5	26.3
France	-1.50	-48.5	40.3
Germany	-6.48	-16.3	10.1
Italy	-1.87	-22.1	24.9
Poland	-3.53	-41.5	13.6
Portugal	-6.49	-23.9	31.1
Spain	-5.76	-91.4	21.5
Sweden	-2.29	-10.8	5.5
Netherlands	-0.27	-44	67.1

Table 2-32: Net change (ha) in the distribution of seagrass species across the EU region. Values were rounded to their nearest integer. This data is based on the dataset compiled by de los Santos et al. (2019).

Species	Total net change (ha)	Min net change (ha)	Max net change (ha)	Mean net change (ha)
Cymodocea nodosa	-637	-400	197	-10
Posidonia oceanica	-6,072	-1,490	104	-50
Zostera marina	-20,395	-11,706	1,220	-84
Zostera noltei	-5,755	-1,814	9,018	-37

2.2.1.2.2 Deliverables

The submission package for Task 2 includes several files and the table below provides a detailed description of the files that incorporate DLV 3 and DLV 4 under subtask 2.2.

Table 2-33: Detailed description of the files submitted as part of deliverables 3 and 4 (DLV3 and 4) for subtask 2.2: Mapping the distribution change of coastal wetlands.

DLV number	Deliverable name	File name	Purpose/ Significance
DLV 3	Digital maps in GeoTIFF format of the distribution of wetlands and potential changes in land cover	**Folder Extent Change** including the GeoTIFF rasters and shapefiles showing the extent change of tidal marshes and mangroves within the EU Member States and Outermost regions: 1. Member States (tidal marshes only, in GeoTIFF): CINEA_CORINE_saltmarshchange_1990_2000_EU_MS CINEA_CORINE_saltmarshchange_2000_2006_EU_MS CINEA_CORINE_saltmarshchange_2006_2012_EU_MS CINEA_CORINE_saltmarshchange_2012_2018_EU_MS 2. Outermost regions (tidal marshes in GeoTIFF and mangroves in shapefiles) Tidal Marshes: CINEA_CORINE_saltmarshchange_2006_2012_FrenchGuiana CINEA_CORINE_saltmarshchange_2012_2018_FrenchGuiana CINEA_CORINE_saltmarshchange_2006_2012_Mayotte CINEA_CORINE_saltmarshchange_2012_2018_Mayotte Mangroves: CINEA_mangrovechange_1996_2010_expansion CINEA_mangrovechange_1996_2010_loss CINEA_mangrovechange_1996_2010_nochange CINEA_mangrovechange_2015_2020_expansion CINEA_mangrovechange_2015_2020_loss CINEA_mangrovechange_2015_2020_no change A metadata file (Metadata_Extent_Change) is also provided in this folder containing a general description of the spatial dataset.	Spatial files generated in sub-task 2.2 that map the extent change of tidal marshes and mangroves across EU Member States and Outermost regions. The dataset can be used in future projects focusing on the conservation and restoration of these ecosystems.
DLV 4	Power point presentation summarising the results from the spatial assessment	DLV4_ Presentation on land use changes in wetlands and blue carbon habitats (.pptx)	Power Point file summarising the results found in Task .2

2.2.1.3. Sub-task 2.3: Blue carbon roadmap – recommendations to improve blue carbon monitoring within EU

This roadmap is designed to improve the monitoring of coastal wetlands and their carbon storage capacities within EU Member States, supporting climate mitigation, biodiversity conservation, and sustainable development goals.

Building on insights from coastal wetland distribution mapping (Sub-Task 2.1) and the analysis of changes in wetland extent (Sub-Task 2.2), the **Blue Carbon Roadmap** (Roadmap) offers targeted recommendations to strengthen BCE monitoring across the EU.

Key components of the Roadmap include:

- **Addressing knowledge gaps**: Identify and address critical gaps in the distribution of BCEs within the EU, as highlighted by findings from Task 2.
- **Enhancing mapping accuracy**: Propose advanced methods and systematic protocols for accurately mapping and monitoring changes in BCE extent, integrating technologies like satellite imagery, drones, and field validation.
- **Standardising monitoring systems**: Establish consistent, interoperable monitoring systems across Member States to enable collaboration, data sharing, and alignment with EU-wide objectives.
- **Integration into policy frameworks**: Align monitoring efforts with the EU's climate and biodiversity strategies, including the European Green Deal, Biodiversity Strategy 2030, and Marine Strategy Framework Directive (MSFD).
- **Establishing objectives and actions**: Define short-, medium-, and long-term objectives and actionable recommendations to address monitoring challenges, ensuring progress over time.

This Roadmap aims to guide policymakers and stakeholders in enhancing and coordinating blue carbon monitoring efforts across the EU. It seeks to harmonize monitoring systems, address critical knowledge gaps, and align with the EU's climate and biodiversity objectives.

Structure of the Roadmap

The Roadmap is designed to enhance the mapping, monitoring, and integration of blue carbon ecosystems across EU Member States. It is structured around three key objectives, each addressing a crucial aspect of blue carbon monitoring: mapping and assessing ecosystem changes, enhancing monitoring of carbon and ecosystem services, and strengthening collaboration and data accessibility.

Each objective is further broken down into four or five actions, with specific sub-actions providing clear steps for implementation. These actions are designed to be implemented in a phased approach with short-term (1–3 years), medium-term (3–5 years), and long-term (5+ years) timelines. This structured approach ensures that efforts are practical, scalable, and aligned with EU climate, biodiversity, and marine conservation policies.

The Roadmap is provided as an individual file to this report, and included as an additional deliverable in DLV4.

2.2.1.3.1 Deliverables

The submission package for Task 2 includes several files and the table below provides a detailed description of the files that incorporate DLV 4 under subtask 2.3.

Table 2-34: Detailed description of the files submitted as part of the deliverable 4 (DLV 4) for subtask 2.3: Blue carbon roadmap – recommendations to improve blue carbon monitoring within EU

DLV number	Deliverable name	File name	Purpose/Significance
DLV 4	Power point presentation summarising the results from the spatial assessment	DLV4_Presentation on land use changes in wetlands and blue carbon habitats (.pptx)	Power Point file summarising the results found in Task .2
	Roadmap	**Additional file: Blue Carbon Roadmap for EU Member States**	This roadmap is designed to enhance the monitoring of blue carbon ecosystems (BCEs) and their carbon storage capacities within EU Member States.

2.2.2. Challenges encountered during implementation

No major challenge has been found in this Task; however, we did find limitations on how to collaborate with other researchers with relevant data that are not publicly available. This limitation was only clarified after we contacted local experts offering an opportunity to collaborate if they were willing to share non-publicly available datasets; message which was originally approved by CINEA. Therefore, to minimize the risks for this Task, we decided to only use publicly available datasets for the development of digital maps and completion of Task 2.

2.2.3. Lessons learned and recommendations for future work

A major gap identified in this task was the lack of spatial data publicly available for the different wetland types included in this study at the level of EU Member States and their outermost regions. This led the study to be based mostly on global datasets (**Error! Reference source not found.**). While such datasets are useful to develop large scale assessments such as the one presented in this Task, finer assessments will depend on consistent and comprehensive spatial datasets for the different types of coastal and inland wetlands. We provide detailed recommendations for further research into the Blue Carbon Roadmap included in DLV4.

During the implementation of this Task, we identified several ongoing projects with overlapping objectives. With the continued interest in coastal and inland wetlands and their role in climate change adaptation and mitigation, we suggest that ongoing projects should be mapped before the announcement of new proposals to avoid duplication of work. The Roadmap included in DLV4 also provides further recommendations on how to better facilitate effective and efficient collaboration across projects (e.g., clear instructions on collaboration opportunities from the start of the project; data sharing should be facilitated in both ways during the project; knowledge sharing across projects).

2.2.4. Key deliverables

Table 2-35 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 3	Digital maps in GeoTIFF format of the distribution of wetlands and potential changes in land cover	Draft: September 2024 Final: March 2025	Zipped file containing all spatial files (e.g., rasters in GeoTIFF, shapefiles, metadata)
DLV 4	Power point presentation summarising the results from the spatial assessment	Final: March 2025	Power Point

2.2.5. References

Berov Dimitar, Vasilev Vasil, Hiebaum Georgi, Biserkov Valko, Deyanova Diana, Klayn Stefania, Dimov Kuzman, Vrabcheva Yana, Karamfilov Ventzi (2022). Current distribution of *Zostera* seagrass meadows along the SW coast of the Black Sea, Bulgaria. SEANOE. Layer available for download from: https://www.seanoe.org/data/00684/79590/

Bunting, P.; Rosenqvist, A.; Hilarides, L.; Lucas, R.M.; Thomas, N.; Tadono, T.; Worthington, T.A.; Spalding, M.; Murray, N.J.; Rebelo, L.-M. Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. *Remote Sens.* 2022, *14*,

3657. https://doi.org/10.3390/rs14153657. Layers available for download from: https://data.unep-wcmc.org/datasets/45

Campbell, A.D., Fatoyinbo, L., Goldberg, L. et al. Global hotspots of salt marsh change and carbon emissions. Nature 612, 701–706 (2022). https://doi.org/10.1038/s41586-022-05355-z Layer available for download from: https://catalog.data.gov/dataset/global-salt-marsh-change-2000-2019-9e4b2

CORINE Land Cover – 2020 version. https://land.copernicus.eu/en/products/corine-land-cover

de los Santos, C.B., Krause-Jensen, D., Alcoverro, T. et al. Recent trend reversal for declining European seagrass meadows. Nat Commun 10, 3356 (2019). https://doi.org/10.1038/s41467-019-11340-4

DHI. (2024). Danish coastal submerged aquatic vegetation 2018 (Version 1) [Data set]. Zenodo. Layer available for download from: https://doi.org/10.5281/zenodo.10707800

European Environment Agency (2022). Extended wetland ecosystem layer. Layer available for download from: https://sdi.eea.europa.eu/catalogue/srv/api/records/b9399908-557a-47a8-954a-958dabeaf1b6

Flanders Marine Institute (2023). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 12. Available online at https://www.marineregions.org/. https://doi.org/10.14284/632

GADM data: 4.1 version released in 2022. https://gadm.org/data.html

Helsinki Commission. (2013) Seagrass meadows region. Layer available for download: https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/bda3d31d-bab2-4ff7-aad0-afeb19db18dc

IUCN, UNEP-WCMC. 2024. The World Database on Protected Areas (WDPA). [Insert month] release. Cambridge (UK): UNEP World Conservation Monitoring Centre. Available at: www.protectedplanet.net or https://data.unep wcmc.org/datasets/12

Jayathilake D.R.M., Costello M.J. 2018. A modelled global distribution of the seagrass biome. Biological Conservation. https://doi.org/10.1016/j.biocon.2018.07.009 Layer available for download from: https://data.unep-wcmc.org/datasets/46

Jia, M., Wang, Z., Mao, D., Ren, C., Song, K., Zhao, C., Wang, C., Xiao, X., & Wang, Y. (2023). Mapping global distribution of mangrove forests at 10-m resolution.

Science Bulletin, *68*(12), 1306–1316. https://doi.org/https://doi.org/10.1016/j.scib.2023.05.004 Layer available for download from: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PKAN93

Lucieer, V., Barrett, N., Butler, C., Flukes, E., Ierodiaconou, D., Ingleton, T., Jordan, A., Monk, J., Meeuwig, J., Porter-Smith, R., Smit, N., Walsh, P., Wright, A., & Johnson, C. (2019). A seafloor habitat map for the Australian continental shelf. *Scientific Data*, *6*(1), 120. https://doi.org/10.1038/s41597-019-0126-2

Murray, N.J., Worthington, T.A., Bunting, P., Duce, S., Hagger, V., Lovelock, C.A., Lucas, R., Saunders, M.I., Sheaves, M., Spalding, M., Waltham, N.J., Lyons, M.B., 2022. High-resolution mapping of losses and gains of Earth's tidal wetlands. Science, 76, 744–749. Available at: https://www.globalintertidalchange.org/data-viewer/tidal-wetland-change

Topouzelis, K., Makri, D., Stoupas, N., Papakonstantinou, A., & Katsanevakis, S. (2018). Seagrass mapping in Greek territorial waters using Landsat-8 satellite images. International journal of applied earth observation and geoinformation, 67, 98-113. Layer available for download: https://zenodo.org/records/1120338

UNEP-WCMC, Short FT (2021). Global distribution of seagrasses (version 7.1). Seventh update to the data layer used in Green and Short (2003). Cambridge (UK): UN Environment World Conservation Monitoring Centre. Data DOI: https://doi.org/10.34892/x6r3-d211

Worthington, T. A., Spalding, M., Landis, E., Maxwell, T. L., Navarro, A., Smart, L. S., & Murray, N. J. (2024). The distribution of global tidal marshes from Earth observation data. *Global Ecology and Biogeography*, 33, e13852. https://doi.org/10.1111/geb.13852 Layer available for download from: https://zenodo.org/records/8420753

Zhang, X., Liu, L., Zhao, T., Chen, X., Lin, S., Wang, J., Mi, J., & Liu, W. (2023). GWL_FCS30: a global 30 m wetland map with a fine classification system using multi-sourced and time-series remote sensing imagery in 2020. *Earth Syst. Sci. Data*, *15*(1), 265–293. https://doi.org/10.5194/essd-15-265-2023 Layer available for download from: https://zenodo.org/records/7340516

2.3. Task 3

2.3.1. Description of the Task

This task focused upon primarily seagrass and tidal marsh ecosystems, as they are the most prominent in Europe and the primary focus of much of the investigated literature, with the goal to establish knowledge on drivers influencing the status and distribution, and further the state-of-play on 'blue carbon' related research and initiatives at the European Level. This task established this knowledge by carrying out research in fulfilment of the following specific objectives:

- Investigating the pressures and drivers of loss in European blue carbon ecosystems, considering available scientific research and investigations (3.1);
- Synthesize findings on research results across the EU where blue carbon sequestration has been measured (3.2);
- Reporting on successful actions, projects, and strategies in EU Member States that have enhanced blue carbon sequestration, with a focus on where sequestration was measured or estimated (3.3);
- Assessing the cost and success rate of interventions designed to increase carbon sequestration in blue carbon ecosystems (3.4).

Each objective stood as an independent task that was conducted. As such we present the detailed breakdown per objective in the following.

2.3.1.1. Sub-Task 3.1: Pressures and drivers of loss in blue carbon ecosystems across the EU

A comprehensive review of EU literature was conducted to identify key drivers and pressures affecting blue carbon ecosystems. This analysis was complemented by an assessment of relevant EU legislation, particularly the Water Framework Directive and the Marine Strategy Framework Directive, to determine how Member States are required to report on pressures and drivers. This process allowed for the identification and classification of overarching driver groups and sub-drivers.

With this classification in place, the next step was to investigate which drivers of loss and pressures received the most attention in scientific literature. The underlying assumption was that the more frequently a driver is studied, the more urgent and relevant it is perceived to be for each blue carbon ecosystem. However, it is important to note that there was limited to no information available on outer regions, including mangroves. As a result, the focus of the analysis was primarily on seagrass and tidal marshes.

To validate this categorization, stakeholder consultations were conducted during workshop breakout sessions. Participants from various sectors provided feedback, confirming that the identified drivers and pressures accurately reflected the most pressing issues affecting seagrass and tidal marshes. This validation reinforced the idea that the prominence of a driver in scientific literature is a reasonable indicator of its significance in terms of ecosystem impact. However, stakeholders also highlighted an important nuance: differences in the prominence of drivers across Member States are not necessarily reflective of their actual significance in those locations. Instead, research patterns in the EU tend to be driven by political interest and funding opportunities rather than by the distribution of blue carbon ecosystems or the severity of specific drivers of loss.

The study successfully developed an overarching EU-wide categorization of drivers and pressures, aligning both with EU policy frameworks and prevailing scientific understanding. This categorization was broadly accepted through stakeholder validation and serves as a structured approach to assessing pressures on blue carbon ecosystems. Additionally, the analysis enabled the identification of the most significant drivers and pressures affecting seagrass and tidal marshes across the EU. For seagrass, the primary pressures were identified as human activity, land-use change, and climate change. For tidal marshes, the key pressures were climate change, land-use change, and human activity.

The key deliverable from this work is Deliverable 5, a report that provides a structured assessment of the pressures and drivers of loss across the EU. It presents the developed categorization, synthesizes findings from the reviewed scientific literature, and outlines the associated impacts on blue carbon ecosystems. The report offers a comprehensive overview of the predominant pressures and drivers affecting seagrass and tidal marshes in the EU, contributing to a clearer understanding of the threats these ecosystems face.

2.3.1.2. Sub-Task 3.2: Carbon stocks assessment in the EU

Initially, identifying publicly accessible data on carbon cores proved challenging. The literature reviewed in Task 3.1 did not provide any publicly available datasets on carbon stocks that could be extracted for further analysis. However, leveraging the diverse expertise within our consortium—comprising both consultants and academic specialists—we were able to establish contact with an ongoing EU-funded study that was compiling a comprehensive dataset of carbon core measurements across the EU. This dataset was made publicly available through an online repository, enabling us to access and utilize the data for our assessment.

Once the data was obtained, it was processed to ensure standardization and consistency. Following best practices outlined in the IPCC guidelines for GHG inventories for wetlands, we analysed carbon stocks at a depth of 30 cm across all

EU Member States. While 30 cm is a commonly used reference point, it is well recognized that blue carbon soils often sequester carbon down to much greater depths, often extending several meters. To align with recent scientific developments, we expanded our analysis to include carbon stocks at a depth of 100 cm. This approach required careful consideration of sample size variations, as extrapolation to 100 cm depth required core measurements reaching at least 50 cm, whereas 30 cm estimates could be derived from samples reaching 10 cm depth.

Our analysis aimed to identify differences in carbon stocks between habitat types, particularly between seagrass meadows and tidal marshes, as well as variations across Member States. The results confirmed significant differences in carbon stocks between these two ecosystems, with seagrass meadows showing higher average carbon stocks than tidal marshes. Additionally, as expected, there was a substantial increase in carbon stock estimates when comparing 30 cm to 100 cm depths across both ecosystem types.

By integrating these findings with spatial extent data from Task 2, we were not only able to estimate the average carbon stocks in specific Member States but also calculate the total estimated carbon stock at both 30 cm and 100 cm depths across the EU. This provided a more comprehensive assessment of blue carbon stocks at the regional and EU-wide scale.

The findings and results of this assessment were presented in two key deliverables. Deliverable 5 provides a detailed, granular assessment of carbon stocks, analysing regional variations and differences among Member States. Deliverable 8, developed under Task 5 as part of the scientific manuscript, presents overarching observations on carbon stocks at the Member State and EU levels. Additionally, the median carbon stock values derived from this study were used to assess both avoided emissions and total emissions from land-use change assessments conducted in Task 2.

These findings are significant, as they represent the first EU-wide mapping of blue carbon stocks, offering an initial estimate of the carbon currently stored in these ecosystems. This study underscores the critical role of blue carbon habitats in EU climate policies and highlights the importance of their protection as a means of securing carbon storage and mitigating climate change.

2.3.1.3. Sub-Tasks 3.3 and 3.4: Blue carbon ecosystem enhancement and cost aspects

An additional extensive literature review and stakeholder consultation were conducted in order to identify projects in the EU, and beyond, which focus on the enhancement of blue carbon ecosystems and the measurement of blue carbon sequestration.

The literature review built upon the review conducted in the previous sub-tasks and included additional project publications, news articles, governmental publications, and others. We also used stakeholder interviews and the workshop (see section 2.5) to complement and validate our findings, as well as for recommendations for further projects to include.

Having already anticipated a shortage of projects within the EU, the analysis was expanded to global restoration projects predominantly on seagrass habitats and tidal marshes. Accordingly, valuable insights were included from the UK and Australia. While the findings of the analysis are elaborated in Deliverable 5, the analysis has shown resulted in the following main findings:

- No formal blue carbon strategy exists at EU level, but several instruments aim to contribute to blue carbon sequestration enhancement. At national level, we were unable to identify strategies specifically targeting blue carbon ecosystem sequestration. The restoration of blue carbon ecosystems was sometimes addressed via strategies for the general protection of fragile ecosystems.28 There was a general agreement in literature that the protection of blue carbon ecosystems would be simplified if they would be classified as an endangered ecosystem.
- Restoration projects were mainly run by public stakeholders, mainly national governments, and research institutions. NGOs and multistakeholder collaborations are also common; projects run by businesses or other private stakeholders have so far been rare. Project owners often run multiple projects, also across different BCEs.
- Blue carbon sequestration rates were so far rarely considered as an indicator for success of restoration efforts, especially in seagrass restoration projects for which no before/after restoration measurement examples could be found in Europe. Restoration success was often reported in terms of item-based ecological indicators, such as the survival of planted transplants, seedlings, recruits, or propagules. Amongst others, this means that establishing a measurement of changes in blue carbon ex-post is hardly feasible. Commonly agreed and standardised indicators for measuring BC still need to be established.
- The measurement of blue carbon is currently not common practice in BCE restoration projects. In seagrass habitats, hardly any project in the EU currently conducts systematic long-term monitoring of carbon sequestration. Regarding tidal marshes, the measurement of blue carbon is more common, but often not labelled as such.

[28] France was the only Member State we identified with a National Maritime and Coastline Strategy (Stratégie nationale pour la mer et le littoral - SNML)

- BCE restoration projects are so far almost exclusively funded by public actors; private sector involvement was very limited. The current set-up and funding structures of restoration projects typically did not allow for the implementation of monitoring systems for at least 10 years which would be needed to generate meaningful results. Projects are mostly funded for shorter periods and the often-limited budget is rather spent on the restoration activities themselves than holistic monitoring systems. The lack of funding, the short-term oriented design of restoration projects, and a lack of standardised methodologies lead to a lack of comprehensive data on blue carbon sequestration in restoration projects.
- The development of a general cost framework for restoration projects was challenging due to a lack of good quality cost data on blue carbon ecosystem restoration projects within the EU and worldwide. Very little cost data on saltmarsh and seagrass restoration projects is available in public literature, with available data generally being of poor quality and lacking detail.
- Carbon revenues are currently treated as a means to attract private finance. However, it was mostly considered as a potential additional revenue stream rather than a primary one, also because few restoration projects in saltmarsh and seagrass ecosystems have measured changes in blue carbon sequestration so far. Additionally, a focus on carbon could overlook the importance of biodiversity and ecosystem services in the projects. Our analysis also suggests that blue carbon projects are not financially viable if financed by carbon crediting alone. As per end 2024, no European blue carbon restoration projects could be identified that have produced carbon credits.
- To make blue carbon projects self-sustaining in the long term, carbon-credit revenue could be paired with other sources of revenue. Potential other environmental credits to pair the carbon credits with could be through products, such as seaweed products, through properly valuing the co-benefits provided by blue carbon projects, the layering of government and philanthropic funds, or through direct payments from those who benefit from blue carbon projects, like insurers, tourism and aquaculture operators.29 It should be recognised that carbon is but one of many ecosystem services produced from blue carbon ecosystem restoration projects.

The analysis has contributed to a better understanding of the current approach towards considering blue carbon sequestration in restoration projects in the EU. The information can be considered in setting up effective support measures for such projects, which has shown to be an approach that is only just beginning to receive more attention.

[29] Macreadie, P., et al. (2022). Operationalizing marketable blue carbon.

2.3.2. Challenges encountered during implementation

2.3.2.1. Sub-task 3.1: Pressures and drivers of blue carbon habitats in the EU

One of the primary challenges faced in this study was the uneven distribution of information on pressures and drivers across EU Member States, with a complete lack of data for outermost regions. While some Member States had extensive investigations into pressures and drivers, others had little to no available research on these aspects. This inconsistency made it difficult to conduct a meaningful comparative analysis across Member States.

To address this issue, we focused on conducting an EU-wide assessment rather than attempting direct comparisons between Member States. Additionally, due to the absence of relevant data, mangroves were not included in the analysis.

Another significant challenge was identifying and categorizing the pressures and drivers being investigated in the literature. Research approaches vary considerably, with different studies using inconsistent terminology, grouping pressures in different ways, or investigating them as part of broader causal chains. For instance, climate change may be reported as leading to increased rainfall, which in turn causes higher nutrient runoff—meaning two distinct pressures are investigated simultaneously. This variability complicated efforts to determine which pressures should be considered the primary focus of each study.

To resolve this, we allowed each study to be categorized under up to three pressures, ensuring a more comprehensive and accurate representation of the issues investigated. As a result, the number of identified pressures exceeded the number of papers reviewed, reflecting the fact that many studies examined multiple interlinked pressures rather than isolated ones. This required a detailed and meticulous reading of the literature to ensure all relevant elements were correctly captured, often necessitating a deeper level of interpretation and analysis.

A related challenge was the categorization of pressures themselves. Some pressures were straightforward to classify (e.g., climate change leading to temperature increases), while others were more ambiguous. A common difficulty was distinguishing between pressures such as aquaculture and agriculture, both of which contribute to eutrophication, which is typically the primary focus of investigation. However, in other instances, these sectors were analysed in terms of land-use change rather than nutrient loading, leading to inconsistencies in how pressures were framed. This variation in how pressures were addressed across the literature complicated the development of a unified classification system.

To standardize our approach, we aligned our categorization with EU policy frameworks that require the reporting of pressures and drivers of loss, particularly the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD). By referencing these frameworks and incorporating insights from the literature, we developed a structured classification system for pressures and drivers. This categorization was further refined and validated during stakeholder consultations (Task 4), where experts confirmed its accuracy, with only minor adjustments needed.

The most significant limitation encountered in this study was extracting precise data on the impacts of specific pressures. Given that many studies analysed compounding pressures rather than individual ones, directly linking a single pressure to a specific impact on seagrass or tidal marshes proved difficult. In many cases, studies described broader ecosystem changes without isolating the direct effects of each pressure.

To address this, we separated the analysis of pressures from that of impacts, instead providing a systematic overview of the potential impacts identified in the literature. Where possible, we highlighted connections between specific pressures and their likely consequences, but due to the fragmented nature of the data, the full scope of impacts is likely broader than what could be systematically captured. Additionally, because our review focused on EU-based studies, we did not incorporate findings from the global research landscape. While international studies may offer valuable insights into pressures and impacts on blue carbon ecosystems, an expanded literature review of this scale was beyond the scope of this study.

Despite these challenges, the structured methodology employed ensured that key pressures and drivers were comprehensively identified, categorized, and validated, providing a valuable foundation for understanding the threats facing blue carbon ecosystems in the EU.

2.3.2.2. Sub-task 3.2: Carbon stocks assessment in the EU

One of the key challenges encountered in the carbon stock assessment was the need for extensive data cleaning to ensure consistency and accuracy across datasets. Some records contained extreme values—both unrealistically high and negative figures—which required removal based on expert-defined thresholds. Additionally, many carbon cores lacked essential parameters, such as dry bulk density (DBD), a crucial factor for carbon stock calculations. Another major issue was the uncertainty surrounding core compression, as some datasets did not indicate whether the cores had been compressed or decompressed during sampling. Hence, we implemented a structured approach to data standardization. First, missing dry bulk density values were replaced with mean DBD values by habitat type, allowing us to retain numerous otherwise-discarded data points. Second, we applied an estimated compression factor to translate all DBD values into a consistent, decompressed metric—albeit with a recognized margin of error. While this approach introduced some level of uncertainty, it allowed us to harmonize disparate datasets and ensure a more representative assessment of carbon stocks across Member States, even those with sparse measurements.

A further limitation was the uneven representation of Member States. While a few countries contributed multiple sampling locations for seagrass and tidal marsh habitats—providing more comprehensive national estimates—others relied on only a handful of data points or had no measurements at all. This imbalance posed a challenge when extrapolating results to unaccounted habitats. To mitigate these gaps, we employed habitat-specific median values for cases lacking direct carbon-core measurements, which introduced uncertainty given the broad variability in carbon storage across different regions.

Despite these challenges, we were able to maximize the available data to conduct an informed and methodologically sound analysis. By implementing systematic data-cleaning approaches, filling in critical gaps with well-reasoned assumptions, and applying consistent extrapolation techniques, we ensured that our assessment remained robust in a timely manner.

2.3.2.3. Sub-task 3.3 and 3.4: Blue carbon ecosystem enhancement and cost aspects

As for the other sub-tasks, data availability was the main issue encountered. While other tasks sometimes struggled with the accessibility of data, information on carbon sequestration in restoration projects was mostly simply not existent. However, the approach stakeholders were supportive and tried to provide us with the data they had. The analysis has hence furthermore contributed to uncovering further areas for future research and data collection.

Another challenge was the provision of generally applicable results. For example, the sequestration rates are often based on generalisations and estimations that are highly sensitive to site-specific circumstances. Furthermore, restoration costs appeared to be highly site-specific and variable, with historic costs potentially as an inaccurate guide for current and future costs. Costs varied per project and depended on factors such as necessary upfront investments, required labour, measurement, and monitoring. Nonetheless, the analysis has uncovered several challenges and considerations that are applicable to multiple projects, such as the currently too short funding periods.

2.3.3. Lessons learned and recommendations for future work

A critical challenge in implementation is the availability and aggregation of data on pressures, drivers, and carbon stocks and sequestration across the EU, particularly while accounting for the location-specific characteristics of blue carbon ecosystems. Data gaps and inconsistencies make it difficult to develop a comprehensive and harmonized assessment at the EU level.

At the same time, numerous ongoing EU initiatives are working to establish an overarching understanding of these issues at both the EU and national levels. This study encountered areas where similar work—such as carbon stock assessments—was already being undertaken by other projects. Through effective collaboration and leveraging our well-established network, we were able to align with these efforts, avoid duplication, and contribute to a more cohesive research landscape.

To maximize efficiency and impact, we recommend that future projects undertake a thorough mapping of ongoing EU initiatives at the outset. This will help ensure that efforts are complementary rather than duplicative, reducing competition over similar research objectives and fostering greater collaboration. Such an approach will not only enhance knowledge generation but also lead to more efficient and coordinated outcomes across the EU research and policy landscape.

2.3.4. Key deliverables

Table 2-36 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 5	Presentation on measures to enhance blue carbon sequestration	Draft: September 2024	Word document
		Final: March 2025	Word document

2.4. Task 4

2.4.1. Description of the Task

The main objective of this task was to test, validate, and further develop the current findings from Task 1, 2, and 3 through engagement with a broader stakeholder audience. To achieve this, a three-hour online workshop was conducted via Zoom, providing a platform for open exchange between the consultants and participants.

The potential participants were identified due to online research and making use of the network of the consultants. 150 practitioners and experts on the topic were identified and invited to the workshop. Eventually, the workshop was attended by 72 participants, including stakeholders from academia, practitioners, policy makers, and consultants.

In preparation for the workshop, relevant background materials and key findings from the previous tasks were compiled and shared with attendees to ensure an informed discussion.

The workshop itself featured a structured agenda, including a presentation of preliminary results to all attendees, and breakout sessions designed to gather insights and perspectives from the stakeholders due to interactive discussions. The breakout sessions (BS) were dedicated to one Task respectively and covered the following topic:

- BS 1: What are the barriers to including all wetland categories within the GHG inventory.
- BS 2: Blueprint for Blue Carbon: Building an EU-wide Monitoring Roadmap.
- BS 3: Blue carbon changes in Europe: Drivers, pressures, measurement, and restoration.

The participants were free to choose which breakout session to attend and a relatively even distribution across the sessions was achieved. During the breakout sessions, the consultants dived deeper into the Task-specific findings and presented topics that required further discussion and reflection.

The discussions benefitted from active participation and yielded valuable feedback, which helped to refine the initial findings, identify potential remaining gaps, and highlight key considerations for the finalisation of the overall project. A description of the feedback received can be found in the workshop report (Deliverable 6). The outcomes of the workshop were used to refine the findings per task.

As a deliverable, a workshop report was compiled, including a summary of the main feedback received per task, the background materials and the PowerPoint slides of the workshop. These will be publicly available at the Maritime Forum.

2.4.2. Challenges encountered during implementation

No significant challenges were encountered. The sufficient participation in the workshop had been assured due to sending out the first invites early enough in advance and following up with strategically placed emails to remind participants of the actual workshop day.

The active discussions in the breakout sessions benefitted from the background information that were provided to the participants in advance.

Technological issues that could have been caused due to the unfamiliarity with Zoom had been prevented due to practice session among the consultants in advance. Participants have been informed about the prerequisites to access the Zoom Meeting in advance.

2.4.3. Lessons learned and recommendations for future work

A critical point for data validation in workshops is ensuring the active and high participation of stakeholders. The chosen approach has shown to be effective. The high number of participants probably benefited from sending out the workshop invitation two months in advance which allowed participant to schedule in the time slot in their own planning.

The active participation was ensured due to sending out the background materials previous to the workshop. This enabled the participants to get more insights into our findings than could have been presented in the workshop itself.

Lastly, the practice sessions among the consultants to ensure familiarity with Zoom enabled a smooth execution of the actual workshops. Thereby, it was useful to have a smaller dedicated team that prepared the practice session and addressed concerns of the presenting consultants.

2.4.4. Key deliverables

Table 2-37 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 6	Workshop report	Draft: February 2025	Word document

DLV number	Deliverable name	Date of submission	Format of submission
		Final: March 2025	
DLV 7	Summary article for Maritime Forum (to accompany DLV6 upload)	Draft: February 2025 Final: March 2025	Word document

2.5. Task 5

2.5.1. Description of the Task

The objective of this task was to develop a manuscript that effectively synthesizes the key findings of the study while ensuring a coherent and engaging narrative on the blue carbon landscape and knowledge in the EU. The manuscript aimed to integrate insights from various aspects of the study, presenting them in a structured and compelling manner.

The scope of the task encompassed all project components; however, given the breadth of the study and the diverse range of findings generated, not all elements naturally lent themselves to a unified manuscript. Consequently, the final scope focused on selected elements from Tasks 1, 2, and 3, which were best suited for integration, allowing for a cohesive and informative narrative.

The manuscript development followed a structured and collaborative process:

- An initial outline was developed, identifying key ideas and central themes from each task.
- Task leads were invited to extract and contribute relevant data elements for the first draft.
- A structured outline was then refined, ensuring clarity in the overarching narrative and alignment with the study's objectives.
- The core purpose of the manuscript was defined, and guiding questions were formulated for each section, which were assigned to relevant lead authors for development in collaboration with their respective teams.
- Once the results section was drafted, the wider consortium convened to review and refine the manuscript's storyline, ensuring a logical flow of discussion points and a clear articulation of the main findings and observations.

- Following agreement on the structure and content, the discussion and results sections were finalized. The introduction, conclusion, and abstract were then refined to ensure consistency with the overall message.
- The methodology was placed in the annex to maintain focus on the main findings and results, aligning with common journal practices.

The primary outcome of this task was the successful development of a draft manuscript that synthesizes insights across multiple tasks, providing a holistic perspective on the blue carbon landscape in the EU. The manuscript effectively showcases how the study's findings contribute to a broader understanding of blue carbon ecosystems, reinforcing their significance within the EU research and policy framework.

2.5.2. Challenges encountered during implementation

One of the main challenges in developing the manuscript was ensuring that the selected elements worked together to form a coherent narrative. While the study produced a wealth of valuable insights across all tasks, many interesting findings had to be excluded to maintain a clear, focused storyline. The individual task reports, as well as this final report, reflect the breadth of work conducted, but including all findings in the manuscript would have diluted the central message, making it overly complex and unfocused. Impact on project timeline and deliverables

This also meant that certain highly relevant findings, while significant on their own, did not align well with the broader narrative and therefore could not be incorporated into the manuscript. In reality, almost every task could have resulted in a standalone manuscript, particularly the findings from Tasks 1 and 2, which each contained substantial independent contributions. However, due to time and resource constraints, as well as the overarching objective of Task 5, developing separate manuscripts within the scope of this project was not feasible.

Another challenge was the integration of findings from different tasks. Since the tasks were conducted largely independently for most of the project, coordination and alignment proved difficult. Each task had its own deliverables, timelines, and objectives, making it challenging to consolidate new findings in a way that maintained consistency across the manuscript.

Furthermore, the project did not allocate time for submitting the manuscript to a journal or for undergoing the peer-review process. As a result, the manuscript developed through this process is not yet publication-ready. Instead, it serves as an initial representation of what is possible with the generated data. As agreed with CINEA, it reflects the study's key findings but would likely require further refinement and peer review before being considered academically robust. In agreement with partners, one publication will be followed up on regarding the EU wide mapping of blue carbon habitats (primarily findings from Task 2) and other parts of the findings will be integrated into wider ongoing research studies (e.g. elements from Task 3).

To address these challenges, extensive collaboration was essential. The team engaged in frequent discussions, iterative reviews, and structured alignment meetings to ensure that the manuscript's storyline remained coherent and well-integrated. Through this process, careful selection of key findings was undertaken to balance comprehensiveness with clarity.

In addition, supplementary analyses were conducted beyond the initial scope of the tasks to strengthen the manuscript's narrative. For instance, the carbon stock assessment was significantly expanded to include emissions and avoided emissions from land use change, as well as an estimation of total carbon stock per Member State based on extent data. The assessment also incorporated data on carbon stored within protected areas. These additional analyses were made possible through close collaboration between Task 2 and Task 3 teams, enabling the integration of findings into a meaningful and cohesive storyline.

Another key strategy involved reaching an agreement with CINEA to treat this manuscript as a draft that captures the study's key findings while acknowledging the potential for further development. Given that several external partners contributed valuable data—largely stemming from other EU-funded initiatives—there is an opportunity to further refine the manuscript beyond the project's timeline. As a result, discussions have taken place to continue this work post-project, potentially developing multiple manuscripts to ensure that all significant findings are appropriately represented.

This approach impacts the deliverables and timelines, as the finalized manuscripts resulting from this study will be based on the current draft but further elaborated, refined, and potentially divided into multiple submissions. This ensures that the study's insights are presented comprehensively while allowing for continued collaboration and refinement beyond the project's formal scope.

2.5.3. Lessons learned and recommendations for future work

This study reinforced the significant value that research projects contribute to ongoing efforts in the EU. The volume of information generated is substantial, and much of it holds critical relevance for policy, scientific, and implementation work. Given this, the disclosure and publication of findings should be prioritized to maximize impact. The decision to pursue a scientific publication adds considerable value to a study of this nature, and such outreach and communication efforts should be more frequently integrated into project deliverables.

If the development of a manuscript is an intended outcome of a project, it is strongly recommended that structural coordination between tasks be established from the outset. Early alignment on manuscript objectives and integration of findings will facilitate a more seamless and efficient process. Tasks should be designed with the explicit intention of contributing to a coherent manuscript, ensuring that relevant data and insights are systematically compiled throughout the project.

For the best practices we recommend the following elements for future projects:

- Establish clear communication from the beginning regarding manuscript development, including which elements of the study are most suitable for inclusion.
- Facilitate frequent coordination meetings among authors to ensure consistency in messaging, narrative structure, and data integration.
- Promote cross-task collaboration early on to align methodologies, findings, and reporting formats, enhancing the efficiency of the manuscript-writing process.

By embedding these best practices into project planning and execution, future studies can improve the effectiveness of knowledge dissemination and ensure that valuable findings contribute meaningfully to broader EU research and policy initiatives.

2.5.4. Key deliverables

Table 2-38 List of deliverables

DLV number	Deliverable name	Date of submission	Format of submission
DLV 8	One original co-authored manuscript ready for submission to journal peer review	Final: April 2025	Word document

3. Management report

3.1. Overall progress against KPIs

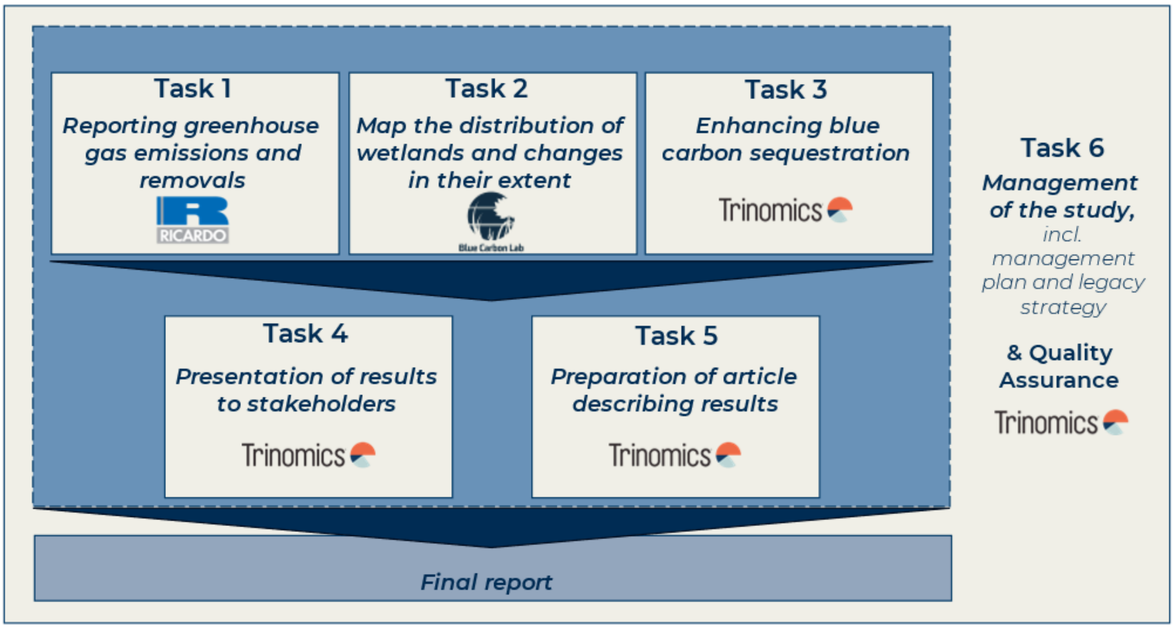
This project was structured around three main research tasks, each designed to improve our understanding of blue carbon ecosystems within the European Union (see Figure 3-1):

- **Task 1 – Reporting greenhouse gas emissions and removals**: This task focused on analysing how EU Member States currently report greenhouse gas (GHG) emissions and removals in wetlands. It was led by Ricardo.
- **Task 2 - Mapping distributions of wetlands and changes in their extent**: This task aimed to enhance understanding of wetland distribution and identify patterns in land-use changes that impact blue carbon ecosystems. It was led by Blue Carbon Lab.
- **Task 3 - Enhancing blue carbon sequestration**: This task reviewed past and ongoing projects to assess their effectiveness and identify best practices for scaling up blue carbon interventions. It was led by Trinomics.

In addition to these core research tasks, the project included two cross-cutting tasks:

- **Task 4** – Presentation of results to stakeholders, focused on organising an expert workshop with the aim to collect targeted feedback on the findings of the three research tasks, to generate more robust conclusions. This task was coordinated by Trinomics, with equal participation of all partners.
- **Task 5** – Preparation of article describing results, worked to develop a manuscript of a scientific publication which shares key results and recommendations. The task was also coordinated by Trinomics, with all partners engaging in its delivery.

Figure 3-1: Project structure and task leadership



To ensure the effective implementation and successful completion of the study, each task was assigned a dedicated Task Lead responsible for coordinating activities, meeting deadlines for draft and final deliverables, and maintaining quality and completeness. Task Leads also ensured that all deliverables incorporated relevant stakeholder feedback gathered during the workshop. A detailed list of deliverables and submission deadlines is provided in Table 3-1: .

To facilitate information exchange and timely communication, the project team held monthly internal meetings to monitor progress, address challenges, and ensure seamless coordination. Additionally, regular meetings with the Client were conducted to provide in-depth updates on implementation progress, present key findings and deliverables, and ensure project outputs aligned with expectations (see Table 3-1:).

Table 3-1: Reception list of deliverables, reports and meeting minutes

Activity and output indicators				
	Name	**Date**	**Content**	**Access link**
MEETINGS	Kick-off meeting	16-Jan-24	· Define scope, methodology, communication plan, and timeline · Introduce teams	Folder 'Meeting Minutes'
	Progress meeting 1	19-Mar-24	· Review project progress · Clarify implementation queries	
	Progress meeting 2	18-Jun-24	· Present draft DLV 1 · Present final DLV 2 · Address implementation queries	
	Interim meeting	01-Oct-24	· Assess progress and challenges · Present draft DLV 3 · Present draft DLV 5	
	Progress meeting 4	16-Dec-24	· Review progress · Discuss workshop planning · Clarify task-related queries	
	Transition meeting 1	12-Feb-25	· Confirm expectations for material handover	
	Final meeting	(Mar/Apr-25)	· Present key findings and recommendations · Discuss feedback on all project deliverables	
REPORTS	Inception report	Jan-24	Defines methodology, task organization, KPIs, and timeline	Folder 'Project reports'
	Progress report 1	19-Mar-24	Summarises project progress	Folder 'Progress reports'
	Progress report 2	18-Jun-24	Summarises project progress, including relevant deliverables	Folder 'Progress reports'
	Interim report	Oct-24	Provides updates on task execution, challenges encountered, and mitigation measures	Folder 'Project reports'
	Progress report 4	16-Dec-24	Summarises project progress	Folder 'Progress reports'
	Final report	Mar-25 Apr-25	Provides comprehensive overview of all tasks and deliverables, integrating progress reports, meeting minutes, and legacy strategy	Folder 'Project reports'
	DLV1	Jun-24 (d)	Relational database	Folder 'Deliverables

Activity and output indicators				
DELIVERABLES		Mar-25 (f)		
	DLV2	Jun-24 (f)	Presentation of reporting on blue carbon	
	DLV3	Sep-24 (d) Mar-25 (f)	Digital maps	
	DLV4	Mar-25 (f)	Presentation on land use changes in wetlands and blue carbon habitats	
	DLV5	Sep-24 (d) Mar-25 (f)	Presentation on measures to enhance blue carbon sequestration	
	DLV6	13-Mar-25	Workshop report	
	DLV7	13-Mar-25	Workshop report upload (to Maritime Forum)	
	DLV8	Mar-25	Peer-reviewed article	

3.2. Legacy strategy

In accordance with the requirements specified in the contract, this project required a robust legacy strategy to ensure an efficient handover and compliance with the European Commission's standards and regulations on information and knowledge transfer.

This final report serves as the official handover of all project materials delivered in the required format as stipulated in the contract. The complete list of materials produced, along with their designated formats, is detailed in Table 3-1.

A dedicated transition meeting was held with the Client to confirm specific handover requirements, with particular emphasis on the relational database (DLV 1). To ensure the Client can seamlessly take over and manage the database, the project team developed a short user guide, which is included within the database itself and is also annexed to this report (Annex A).

A second key element of this legacy strategy concerns intellectual property rights (IPR). The consortium was required to declare any pre-existing rights and ensure the transfer of IPR to the Client where applicable. However, all consortium members confirmed that no pre-existing rights applied to any of the materials used in the preparation of the project deliverables. As a result, all deliverables are fully transferred to the Client without any IPR constraints.

3.3. Risks and adaptive management

At the start of the project, we developed a comprehensive risk management framework tailored to address risks specific to each task and the overall project implementation. This framework played a crucial role in progress monitoring, enabling us to proactively identify challenges and implement solutions to mitigate risks or adapt our approach where necessary. The full framework is provided in Annex E.

Overall, the project was implemented smoothly, with no significant risks encountered that affected task execution or overall project objectives. All tasks were completed as planned, with effective implementation ensuring timely delivery.

One cross-cutting risk that did arise during the project was related to data privacy. This issue was identified during the preparation of the project's data protection notice, in accordance with CINEA requirements. The project's data protection compliance was governed by EU data privacy rules; however, two of the three project partners - Ricardo (UK) and Blue Carbon Lab (Australia) - were based outside the EU, necessitating careful handling of data privacy considerations.

- The UK, having a GDPR adequacy agreement with the European Economic Area (EEA), allowed for the free flow of data, and Ricardo was also registered with the UK Information Commissioner's Office (ICO), ensuring full GDPR compliance.
- Australia, in contrast, did not have a GDPR adequacy agreement with the EU. While Blue Carbon Lab followed Australian privacy laws, additional safeguards were required in case the organization engaged directly with stakeholders to ensure compliance with EU data protection standards.

To mitigate this risk and ensure compliance, the following safeguards were implemented:

- A Trinomics team member, typically the project manager, was always included in correspondence with stakeholders to oversee interactions.
- Any data collected or provided by stakeholders was stored securely on Trinomics' SharePoint, ensuring that no attribution to individual authors was made.
- No personal information (e.g., names, affiliations, contact details) of stakeholders was recorded or stored.

These safeguards were reviewed and confirmed as acceptable by the Client during the preparation of the data protection notice. Following this, the risk management framework was updated to formally document this risk and the implemented mitigation measures.

Through these proactive risk management strategies, the project successfully navigated potential challenges, ensuring compliance with data privacy regulations while maintaining effective stakeholder engagement and seamless project execution.

4. Annexes

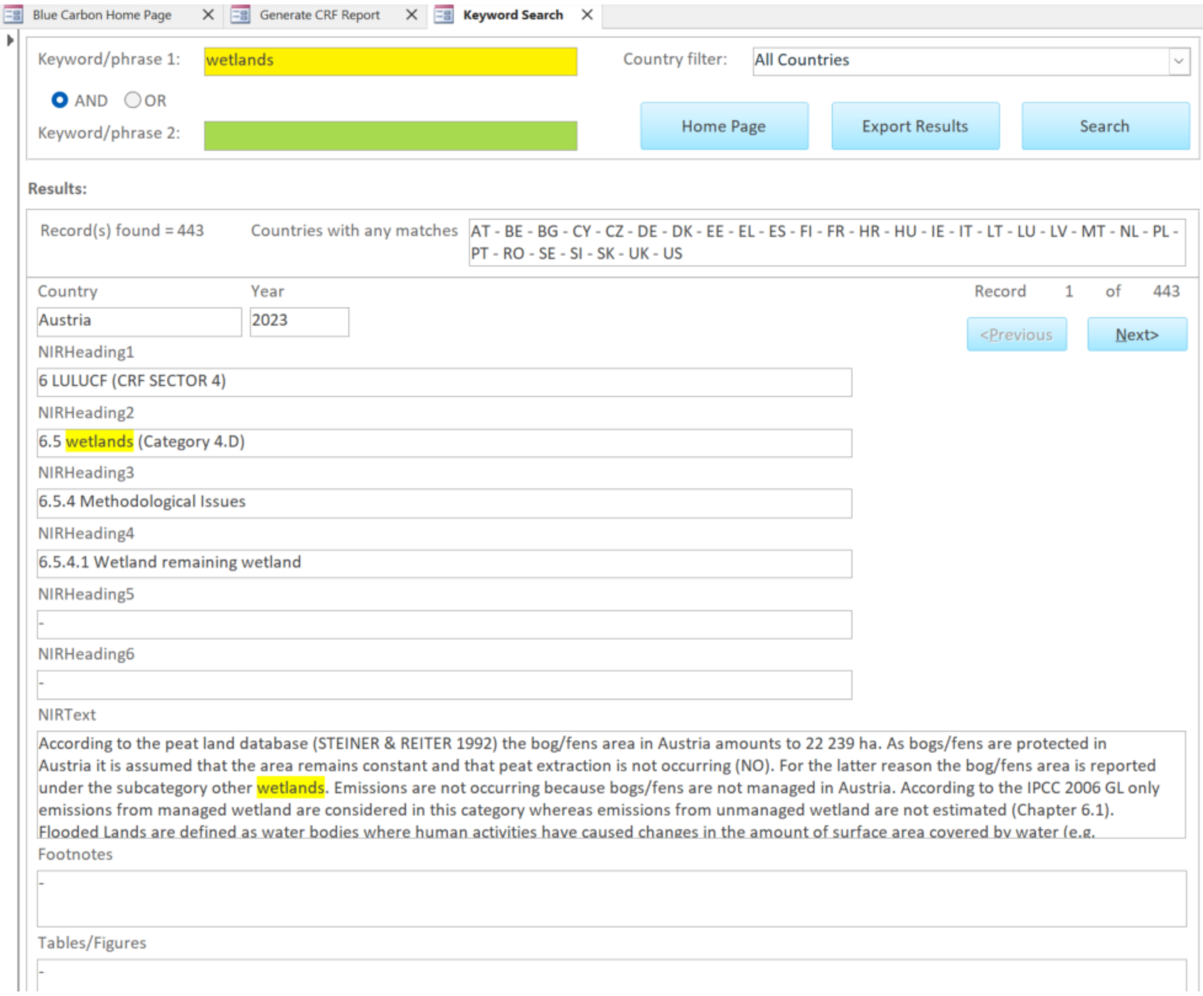
Annex A: User guide for the database

The database has three main queries on the home page (see **Error! Reference source not found.**). Each query has an option to export the search results to MS Excel:

1. **Database search:** Search keywords or phrases within the NIR data (see **Error! Reference source not found.**).
2. **Generate NIR report:** Select the country(ies) of interest to extract and view all the data from the NIRs that the database contains (see Figure 0-3).
3. **Generate CRF Report:** Select the country(ies) of interest to extract and view the data from the CRFs that matches the search criteria. A range of query criteria and filters are available (see Figure 0-4).

Figure 0-1: Database home page

Figure 0-2: Database search: Search keywords or phrases within the NIR data.

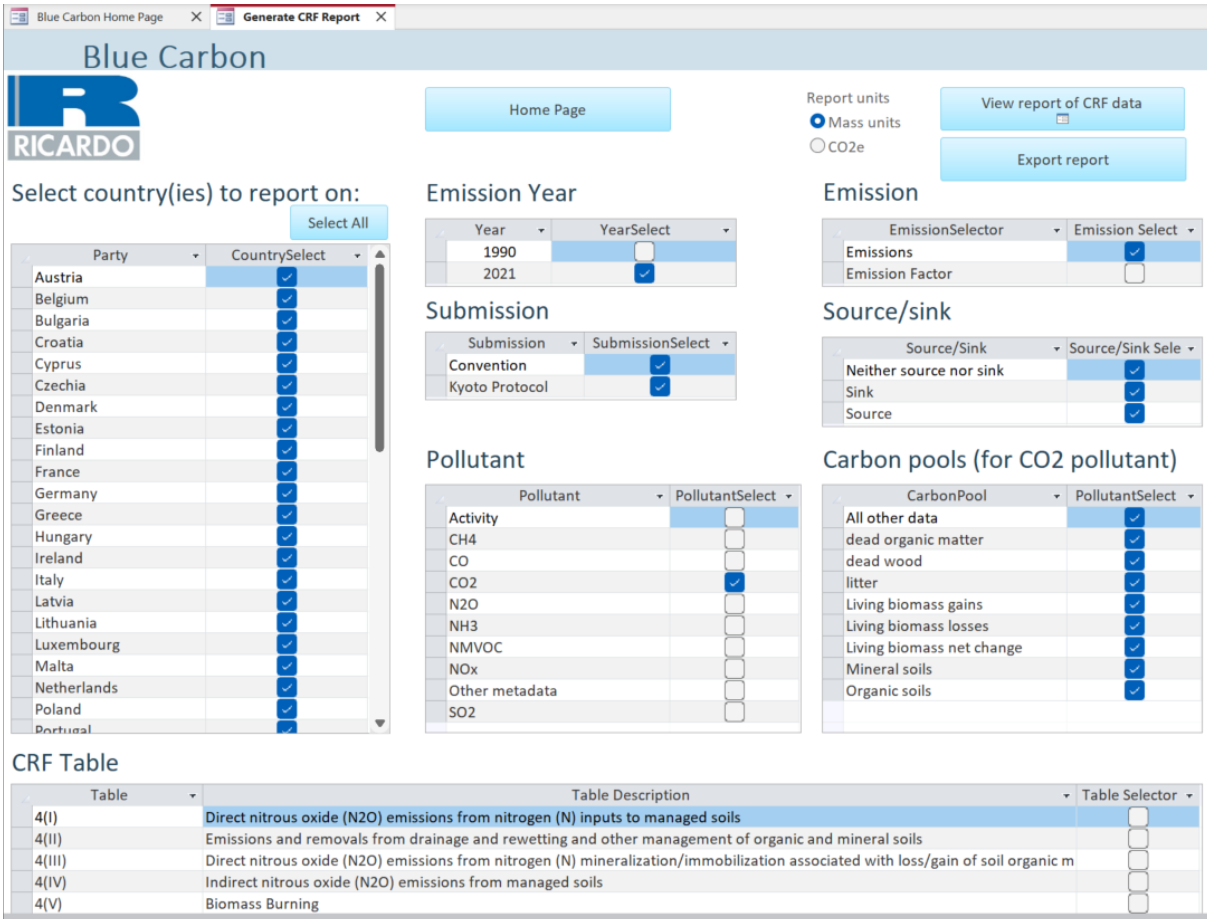


The database key word search is relatively self-explanatory, enter a word (or two) you are looking for within the NIRs in the yellow (in this example the key word searched is wetlands) and press search. The results will appear underneath, with the number of records found, and for which countries. Within the text boxes, the key word searched will be highlighted in yellow, for ease of understanding. You can scroll through the different results by pressing the next or previous buttons. The results can be exported by clicking on the "export results".

Figure 0-3: Generate NIR report: Select the country(ies) of interest to extract and view all the data from the NIRs.

Figure 0-4: Extract CRF data: Select the country(ies) of interest to extract and view all the data from the NIRs.

Running query at bottom right of screen shows it is processing the data, prior to the results opening in a new tab.



Annex B: Stakeholder consultation

The objectives of this stakeholder consultation were to 1) identify and engage with key GHG inventory practitioners (EU, UK, and USA) who have experience in compiling and reporting wetland inventories; 2) ask for their experience about creating and reporting these inventories, and to summarises the findings of "good practice" for the EU to consider.

Note: Some of the material in this section has been reproduced verbatim from email replies and from transcripts or notes of meetings. This has been done to ensure the reader can make their own judgement about the messages conveyed by the stakeholders. This means that some of the sentences will be colloquial.

Stakeholder identification

The project team used their greenhouse gas inventory connections, blue carbon project experience as well as their wide network of contacts to derive a selected list of key stakeholders to consult. The team attempted to ensure a representative spread of stakeholder types to ensure that well-rounded, objective analysis was conducted.

There were three types of stakeholder engagement:

- Email contact, followed up with a meeting to discuss in depth technical and inventory matters related to wetlands and blue carbon
- Email exchange only – facilitated by sending a standardised set of questions and requesting a response
- The main project stakeholder workshop in February 2025.

Approach to conducting interviews during meetings

The project team developed a semi-structured interview guide for each stakeholder type and/or individual interview. These interview guides served two key purposes:

- Allowed the interview to focus on key areas that are required to be explored during interviews (further data collection, refinement of analyses), to promote efficient information exchange.
- Identified where synergies could be achieved across (sub) tasks to assist in prioritising interviews.

One of the most important pieces of information we tried to acquire was the cost of creating and maintaining GHG inventories of wetlands. This cost data would not be normally reported in NIRs and is difficult to find.

It was not always possible to follow these interview guides strictly, but they still formed a useful “aide-memoir” during the discussions.

In some cases, the stakeholders were not able to respond because of work pressures.

Table 0-1. Stakeholders consulted

Stakeholder / MS/ Country	Function	Response
USA		
US Geological Survey. Lead, Environmental Geoscience Group.	Blue carbon research group	Yes. Meeting held
US EPA Agriculture/LULUCF inventory lead	Development/coordination of the GHG inventory interagency team	Yes. Meeting held
US. Silvestrum Climate Associates	Compile the estimates for the US GHG wetland’s inventory	Yes. Meeting held
UK		
UK CEH	Compilation of the UK’s LULUCF inventory	Yes. Email exchange

Stakeholder / MS/ Country	Function	Response
EU Member States		
Finland	LULUCF sector lead	No. Work pressure prevented engagement
Germany	LULUCF sector lead	No. Work pressure prevented engagement. Germany joined the stakeholder workshop and made a very valuable contribution
Ireland	LULUCF sector lead	No. Assumed work pressure prevented engagement
IPCC author	CLA for Chapter 4 “Coastal Wetlands” of the IPCC 2013 Wetlands Supplement	Yes. Email exchange, online meeting and stakeholder workshop
Stakeholder Workshop February 4th, 2025	Validation of the findings of Task 1 of this project, and further discussion of options to improve the wetlands inventory of the EU	

The sections below summarise the findings of each of the stakeholder engagements. Each section has a short paragraph at the end summarizing the key findings of the engagement, and what the implications of those findings are to help refine the current wetlands inventories of the MS and the EU as a whole.

The “USA series” of meetings

The US reports wetlands in their GHG inventory, and they have invested a lot of time and resources into generating the necessary maps of land use to underpin this inventory.

We therefore spent some time with the technical experts to understand the technical approaches that the US took to compiling the wetlands inventory, and to understand the lessons they had learnt, and the time and effort that they had invested. The conclusions from these meeting are important for the EU, and they provide “lessons learnt” and will help the EU identify cost and time efficient ways of compiling a complete and accurate GHG inventory for wetlands.

Three meetings were held with technical teams based in the USA.

- US Geological Survey. Lead, Environmental Geoscience Group. Blue carbon research group
- US EPA Agriculture/LULUCF inventory lead. Development/coordination of the interagency team
- Silvestrum Climate Associates. Compile the estimates for the US GHG wetland’s inventory.

Key messages from the “USA series meetings

The key messages have been split into thematic areas.

- Activity data:
  - The USA has invested in developing a set of land use data that can be used to help generate a GHG inventory for wetlands. They use Coastal Change Analysis Program [CCAP[30]] for each coastal county for the whole dataset for the NIR. Stratified into 22 land classes and enough data for a time series until 1996. As this is prepared by NOAA that is a large cost that the inventory does not have to bear. Very approximately, the cost of developing this data set for the US was 2 million USD and in addition another 2 million USD was spent in verification of the mapping data.
  - The CCAP time series goes back to 1996 so some work was needed to gap fill to 1990.
  - USA is developing some efforts to capture seagrass, but they are much more poorly mapped than other wetland types.
  - The views on whether to “start as granular as possible” (i.e. at MS level) or “have one large data set” (i.e. EU wide), in the context of the EU coastal wetlands, were possibly mixed. Both approaches seemed possible, but aggregating up inventories based on different sources of land use data might introduce uncertainties in comparison to aggregating up inventories based on a common set of land use data. The US GHG inventory team starts from the top; they start national and aggregate (disaggregate?) down to state level.
  - Critical thing is the improvements of mapping to be able to visualise where land management of wetlands is needed.
  - General IPCC definition of wetlands wasn’t used, but would usually, but not in this case.
  - The IPCC “managed land proxy” approach was used.
  - Land cover map [USA] corresponds to IPCC land use representation Approach 2.
  - Of all the time needed to collect and verify the remote sensing data, remote sensing data collection is “not much work”. Verifying is the hard part, and the time and effort needed for ground truthing.
  - The current pixel size is 30 m; some areas are 1 m now.
  - **Conclusions**: The US already had a set of land use data to work with, and this was a great help in developing the wetlands inventory. The

[30] https://coast.noaa.gov/ccapatlas/ ; https://coast.noaa.gov/digitalcoast/data/ccapregional.html

Commission could consider making a basic land use map of wetlands available to all MS. Some gap filling might be needed. The EU should consider how it can identify where (resolved spatially) land management of wetlands might be helpful to increase the carbon stocks of wetlands. The Commission could consider offering guidance to MS about how their definitions of wetlands could align with the IPCC definitions, to help ensure comparability between the inventories of MS – but acknowledging that the IPCC allows countries to have some flexibility in their definitions of land use. The IPCC "managed land proxy" approach can be used. The Commission should note that verification and ground truthing of the remote sensing data is likely to be time consuming and expensive and could perhaps consider supporting research into ways of doing verification efficiently and effectively. The likely achievable resolution of the land use maps now or in the very near future could be 1 m.

- Time and costs to develop and maintain wetlands inventory**:**
  - Is around a 2/3-year process to get things compiled and ready for the inventory.
  - Work for blue carbon estimates is paid for by NOAA, they subcontract Silverstrum Climate Associates. Rough estimate of around 50k USD annually to compile the NIR.
  - It takes 2 or 3 months a year to prepare the dataset [for the wetlands inventory], primarily because activity data are already processed.
  - Each year the inventory compilers try and do new improvements to the mapping.
  - **Conclusions**: The lead time to develop a full wetlands inventory might be 2 to 3 years. The cost of developing and verifying an initial land use / land-use change map for the EU might very approximately be in the order of 4 million USD or 4 million Euros. This map would then require periodic updates. For each MS, the cost of preparing the annual wetlands inventory might be very approximately 50 k Euros to compile the NIR, and 3 months of work, but only once the wetlands inventory is "well established". MS should create inventory improvement plans for their inventories of wetlands, and an improvement plan should be developed at the EU level also. Mapping the extents of seagrass should receive attention in the EU MS coastal waters because there is likely to be very little existing information.
- Periodicity of update of Activity Data (AD):
  - They look at the changes every 5 years and used that to look back in the time series. There are limitations with this data so with the

University of Connecticut they are looking back in time 1986-2020 to consider in greater detail the distribution of wetlands and tidal condition.

- **Conclusions**: The US does not update their land use maps of wetlands annually but update them every 5 years. The Commission could use the same frequency of update.

- Methodological issues:
  - The methodological strategy was to develop the inventory at Tier 1, and then improve over time.
  - Are different blue carbon inventories aggregated from USA states? No – that would be very difficult
  - The CCAP [Coastal Change Analysis Program] maps also don't define between salinity well and this is important as methane emissions are sensitive to levels of salinity. Methane is a "big issue" in terms of coastal wetlands in USA. Salinity levels cannot be determined from remote sensing and spectral information – or at least the US teams have not found a way of going this yet.
  - Other parts of the wetlands methodologies [the majority of the wetlands inventory] is now Tier 2.
  - Caution needed with the methodological treatment of mangroves; are these forests, or wetlands?
  - If the development of the wetlands inventory and the NIR is rushed and mistakes are made by using methods that are not "robust" or consistent then it could lead to a loss of confidence.
  - The US team don't know for sure what the depth of soil carbon stock to then determine what is lost and how this impacts emissions and removals. Assume a 1 m instantaneous loss [oxidation] in USA. But US [wetlands] not a metre deep everywhere and won't "disappear all at once". Some carbon might end up on the sea floor in areas of high deposition. This is a big uncertainty.
  - Implementing calculations in spreadsheet is not recommended; prefer to use models, such as "R".
  - The US is examining the effects of impoundments on emissions. They were hoping that the IPCC 2019 Refinement report was going to solve impounded water problem but consider that it has not done so.
  - The US is examining the tidal exchange of dissolved carbon exported to estuary and coastal ocean, may store in coastal ocean for a while.

The USA have an ambition to include that flux in the inventory- this is not represented in IPCC guidance

- **Conclusions**: The Commission should investigate if MS could report a full wetlands inventory using Tier 1 methods, rather than reporting Not Estimated – for example if MS consider that reporting Tier 1 estimates could be too inaccurate. MS achieving Tier 2 inventories seems feasible. The Commission could encourage MS to use a standard depth in their methodologies. The EU could offer guidance about how to treat mangroves in the wetlands inventory. The Commission should apply QA/QC very carefully to new and improved wetland inventories to ensure they meet the IPCC TACCC principles. The EU should suggest that MS implement their calculations in computer models, not spreadsheets. The EU should consider if it wishes to include the effects of tidal exchange of dissolved carbon exported to estuary and coastal ocean in its coastal wetland inventories

- Uncertainties:
  - Estimates of CH_4 are the most uncertain in the wetlands inventory. Tier 1 methods are used here as there is no country specific EFs available at this time. Some US States have more detailed mapping in some cases for methane. Palustrine estuaries are another source of uncertainty.
  - Another uncertainty concerns the depth of soil carbon lost via management activities or sea level rise, or natural impacts i.e. hurricanes- what is the lateral exchange and fate of carbon that erodes salt marsh
  - Lateral fluxes and residence times [of carbon] are areas of uncertainties.
  - **Conclusions**: The Commission should investigate if and how they might be able to help MS identify areas of different salinity in their wetlands, as this would greatly improve the accuracy of estimates of emissions of CH_4.
- Reporting issues:
  - The NIR (now the NID) doesn't say what the carbon stock is, only the change [in carbon fluxes annually].
  - **Conclusions**: The Commission could consider whether it wishes to report not just carbon stock changes in wetlands in its GHG inventory (mandatory reporting requirement), but also carbon stocks.

Dialogue with the EEA

The EEA lead the compilation of the EU GHG inventory.

- The work of the EEA is to do QA/QC of the inventory data we receive from Member States and then compile an EU inventory which is the sum of the MS. This means we are not involved in the monitoring and collection of field data, and are not sighted on questions regarding costs and time needed for collecting data.
- In the EU, MS report on all managed land including some of the land use [wetlands]. But they do not report on GHG fluxes from the sea. Fresh water lakes, rivers and streams are reported as wetlands but due to lack of IPCC guidance, countries are not reporting on GHG fluxes from natural water systems. In some cases, they will also be classified as unmanaged and therefore also not included in the GHG inventory. Artificial flooded areas or drained areas on the other hand are covered by the inventory.
- In the GHG inventory and following IPCC guidance, the EU GHG inventory reports by land use category. IPCC provides broad land use category definitions that countries use and adds some additional information to make it more meaningful in their national context. It can therefore sometimes be difficult to aggregate at the EU level.
- The IPCC 2013 Wetlands Supplement includes a chapter on coastal wetlands that refers to tidal freshwater and salt marshes, seagrass meadows, and mangroves. There is however no mentioning of blue carbon. Also, in the IPCC 2019 refinement this term is not used.
- The reporting tables (CRF tables, and now CRT tables) do not include any possibility to distinguish between different colour carbon. My guess it that some of the blue carbon you are interested in, are covered by what MS report today, but it is not possible to conclude how much as it is not separated from the rest of the inventory.
- MS report every year a full time series from 1990 to the latest year-2. And there should be timeseries consistency. The default approach for land use conversions is that a new steady state is reached after 20 years, which means MS should know the land use back to 1970. In some cases, this is of course not so easy, and we use the best information we can get. Member States use a mix of national data sets and EU data sets such as CORINE. Consistency also means applying the same land use definitions in all years.
- The land being reported [wetlands] is considered complete by the EEA and they assume the land is categorised according to the national definitions, but this latter point is not something we are able to confirm based on the information we have available. When Member States submit their annual greenhouse gas Inventory, they submit reporting tables (CRT) and national

inventory documents (NID). The NID serves partly to explain how countries have collected data and produced the estimates in the CRT.

- MS don't submit maps or georeferenced data. This means we have information on area of forestland, cropland, grassland, wetlands, settlements and other lands and any transition between these land use categories, but we don't have information on the geographic location of any of this land inside each country.
- Member States generally use their own information and according to the LULUCF regulation they shall use geographically explicit land-use conversion data in accordance with the 2006 IPCC Guidelines for national GHG inventories.
- We have developed a LULUCF instance using Copernicus and other datasets that map all land use in the EU according to some common definitions. We get however different results from MS partly because of different definitions and partly because we look at land cover and not land use. In our product [the EU GHG inventory], we use the IPCC land use categories, and we do not identify categories such as coastal wetlands - tidal freshwater and salt marshes, seagrass meadows, and mangroves.
- **Conclusions**: The EEA consider that the EU GHG wetlands inventory is complete, at least with respect to the IPCC methodologies that are mandatory for EU MS to use at this time. However, only Malta explicitly reports emissions from coastal wetlands. The default approach for land use conversions is that a new steady state is reached after 20 years, which means MS should know their land use back to 1970. This could prove difficult in some cases as reliable information on land use in the 1970s may be difficult to obtain. Might the Commission be able to help provide these data?

Dialogue with UK CEH

The UK has implemented the IPCC Wetlands Supplement.

- <u>Question</u>: How many work hours/days (in hours or days) would your organisation need to take to create the first complete wetlands inventory; How much would this cost in your currency?
    - <u>Response</u>: For the saltmarsh inventory compilation work, we're probably in the £200k GBP ballpark so far (for a range of band rates). As a rough estimate that's probably about 250 hours. But by the time we're finished, it could be another £100-150k with the mapping/EO work that's required for tracking LUC.

- But measuring saltmarsh emissions/removals with flux towers is many £100k more if you take into account cost of equipment, maintenance, staff time and continuity of measurements, but I'm not the expert there, so Annette may want to correct what I've just said.
- Additional information can be gained from these studies, some of which have yet to be published.
- Once these projects finish in the spring 2025 we'll be able to advise on whether we have enough data for Tier 1 or Tier 2 implementation of blue carbon in the GHGI (starting with saltmarsh first), and reassess where we are along the roadmap.
- **Conclusions**: The UK has demonstrated that it has been able to implement the Wetlands Supplement methodologies in its GHG inventory. For the saltmarsh inventories this has cost very approximately 350k GBP or 420k Euros. Note this is not the cost of implementing the full set of methodologies in the Wetlands Supplement.

Dialogue with IPCC Lead Author

The Lead Author for Chapter 4 "Coastal Wetlands" of the IPCC 2013 Wetlands Supplement.

- [In the UK] there have been numerous funded contracts to fill data gaps, procure new equipment (eddy covariance towers), development of nationally representative Tier 2 emission factors etc. The main saltmarsh contracts go to the Centre of Ecology and Hydrology and are funded through the environment agency with the original request from BEIS. Flux towers have now been installed and in some locations paired between natural and restored locations.
- For seagrass there is an intension to include it in the GHG inventory, but the meadows are not mapped, activity data not available and little data to provide a Tier 2 value, which is what UK would want to report.
- More generally some of the barriers to inclusion in the GHGI are
    - A reluctance to use the Tier 1 value as national value can to be significantly above or below this value, but with not enough national (or regional) data to provide a Tier 2 value.
    - Since the publication of the IPCC Wetlands Supplement there has been an explosion in new data. The Tier 1 values are often seen as inappropriate now and it is commented that they are waiting for a refinement of the coastal wetland chapter and "new" Tier 1 values.

- While there is all this new data related to stocks and accumulation rate, the values are from often from unmanaged habitats and there is a drive to get a focus more on managed sites. For example, the re-wetting Tier 1 is based on natural soil carbon accumulation rates and not restored (rewetted sites). The extraction Tier 1 assumes all organic carbon is emitted at time zero and a refinement of this to have a time dependent function is thought more appropriate.
- While locations and areal extent (for tidal marsh particularly) are known, the change in areal extent is not always available or if its conversion may have occurred prior to 1990.
- When including tidal marsh in the GHGI it often extends further than the current national boundary. It is asked, how much benefit is there in extending the national boundary and if so, how are the land areas that are not tidal marsh characterised (other land).
- The areal extent of seagrass determined by satellite is hindered in temperate regions by the turbidity of the water. Questions similar to (e) above are posed.
- The main management activity related to seagrass loss (and hence potential for seagrass restoration when impact is reduced) is eutrophication and there is no Tier 1 emission factor (although I guess some country may provide a Tier3 (2) factor if nationally important).
- I have heard " the GHGI for coastal wetlands is too expensive to implement" and "lack of intent to include as they would represent an additional source". USA assessed all coastal wetlands as managed and so a significant contribution to GHGI. Assigning coastal wetlands as managed may not be universally appropriate.
- Some countries in the EU and beyond still do not have the capacity in terms of technical knowledge, skills, and facilities to develop high-quality datasets.
- The collation and storage of data is spread amongst a plethora of databases and often is not accessible in a form that is needed for national GHGI.

- While there are barriers, the examples of USA, Australia, Japan etc are helping to show the way forward and hopefully will encourage our countries to include when circumstances allow.
- **Conclusions**: The UK has commissioned many projects to help implement the Wetlands Supplement in the UK GHG inventory. The Commission might consider the types of projects that UK has commissioned, and commission a fewer or perhaps just one project to deliver the same impact, with good efficiency. Mapping seagrass extent is a technical challenge. New scientific

data means that the IPCC Tier 1 values in the Wetlands Supplement are dated. Better data could be made available to MS in a coordinated way (perhaps via WG1?) to improve the accuracy of MS inventories. Land use (in wetlands) is better known that land use changes. The boundaries of coastal wetlands need to be clearly and carefully defined, and to ensure comparability, the boundary extents should be the same for all the coasts of MS. The EU could offer guidance to MS on defining the boundaries of their coastal wetlands, including those of any overseas territories. The Commission could have an important role in helping "upskill" the LULUCF sector experts in some MS to allow them to become more confident in creating complete and accurate wetland inventories. The Commission might consider creating a "datahub" of key activity data (land use and land-use change, according to MS) to help MS create and verify their wetland inventories. While there are barriers to the creation and reporting of complete and accurate wetland inventories, the examples of the UK, USA, Australia, Japan etc are helping to show the way forward and hopefully will encourage MS to include all wetland categories when their circumstances allow.

Key messages from the stakeholder workshop

The key messages of the workshop are summarised below. These messages reinforced many of the findings of the stakeholder consultations conducted before the workshop. The workshop was highly productive with a very high level of engagement from all participants.

Completeness

- Reporting of coastal wetlands is incomplete [in the EU GHG inventory].

Barriers

- Activity data (AD)
    - Difficulty with defining areas of wetlands.
    - Difficulty defining managed and unmanaged wetlands.
    - Helpful to have guidelines about how to differentiate the carbon sources and deal with that in the inventory, with a common approach.
- Emission factors (EFs)
    - Because of the large variabilities in carbon stocks and stock change between countries, IPCC Tier 1 EFs were not always suitable, and Tier 2 not always available.
    - IPCC Guidelines were "rather limiting", and often only based on a few sets of experimental data.

  - Differentiation of carbon source was very complicated – good to have guidance about how to handle this issue at EU level.
  - For Tier 1 data for carbon stocks – there is more data now.
  - Tier 1 is not changing much. There is large country variability, and a lack of Tier 2 data.

Resources

- Cost
  - The cost of generating country specific emission factors and using higher tier methods can be very large. Germany indicated that "costs are the problem". They started work 15 years ago with a huge interdisciplinary joint research program on organic soils, and the cost has been more than 10 million Euros.
  - France noted that flux towers are a "powerful method".
- Expertise and knowledge
  - IPCC lead author suggested that EU MS with non-key category (KC) categories could use Tier 1 methodologies to ensure completeness of their wetland inventories.
- Time
  - Some participants suggested prioritising the resources required to generate wetland inventories and using IPCC Tier 1 values for countries with relatively small areas of wetlands and where net emissions are likely to be small.

Improvements

- National boundaries defined for inventory
  - IPCC lead author raised important points about the geographical boundaries of emissions and whether coastal wetlands fall [or fully fall] within the national boundaries defined for GHG inventories – e.g. mean high water (of tides).[31] It is important to consider the implications of using different measures of boundaries – whilst complying with IPCC methodologies adopted under the UNFCCC. Boundary definitions could include: sovereign area, or sea territorial boundary (12 nautical miles).

[31] As an example, the areas used for the UK CRF submissions were based on the Standard Area Measurement to mean high water, providing a total area of the UK of 24,438.5 k ha.

- A member of EU COM noted that it is important not to conflate mitigation action with inclusion in a GHG inventory. Notes that [carbon fluxes] for soils are not well quantified. There need to be a prioritisation [of sources to include in a GHG inventory], and coastal wetlands might not be prioritised. Could imagine instruments [i.e. EU legislation] that address wetland issues without wetlands being in the GHG inventory. Gave an example of MS taking pride in forest expansion, but it was not necessary to create a GHG inventory to achieve this expansion; this is "a good lesson" [for the approach that could be taken to wetlands].

How can the EU support MS

- John Watterson raised a question of whether the EU should take the lead and provide support and perhaps even pre-calculate GHG emissions in the wetland sector.
- An attendee noted that the provision of support by the EU would be vital mainly for connecting researchers to calculate emissions. Guidance on methodology as well [would be useful].
- There was no strong or clear view about whether the Commission should provide precalculated values of emissions and removals from wetlands for MS to use.
- There is a need to understand the current quality of wetlands, not just the loss of wetland habitats.
- There was broad agreement about the Commission providing support [methodological] for EU MS inventory compilers to help them estimate wetland GHG inventories, including on how to use proxy data to go back to 1990. We should look at lessons learnt from supporting MS to create high quality inventories for other sectors such as the forest sector in the LULCUF sector.
- IPCC lead author thought that providing emission factors is good idea, but probably not the most useful advice that the Commission could provide. Activity data and how you can use proxies to go back to 1990 and the link between scientists and what scientists can give and what the inventory compilers need is far more important.

Supplementary material from the stakeholder consultation

Summary of discussions with GHG inventory related / blue carbon technical teams in the USA

Three meetings were held with technical inventory teams in the USA.

Meeting 1

Date and time of meeting: 04 June 2024 14:00-15:00 (UTC)

Attendees: US Geological Survey (USGS) and Ricardo

General

- USGS leads blue carbon research group, applied science, field research
- Need for good maps is essential for producing NIR
- Need to know extent and type of wetlands, and what is important is wetland condition i.e. the management condition
- In developed countries they [wetlands] are generally all managed at some point. The USA use managed lands proxy and assume all are managed and therefore capture all emissions and removals in the NIR

Impounded[32] wetlands

- Some wetlands are in bad condition with flow and hydrological functions restricted by transport or other built infrastructure. This impoundment in coastal areas can cause low salinity environments to occur, leading to significant methane sources. In higher salinity anaerobic environments microorganism use sulphate i.e. smell of saltmarsh. These wetlands are still considered tidal, but GHG behaviour is very different to what it would be in a more natural condition
- Removing these impoundments and restoring natural function of these wetlands can provide a big opportunity to reduce emissions - more CO_2 in soil through building soil carbon and ability to reduce methane emissions
- CCAP [Coastal Change Analysis Program] maps also don't define between salinity well and in most cases it is wrong or not the number needed to accurately determine if methanogenesis is occurring or not, i.e. estuarine

[32] Impounded wetlands represent areas where dikes, berms, ditches and culverts have been constructed to control the inflow and outflow of water through wetlands.

wetlands are currently assessed for methane emissions and removals in the NIR but may be contributing to methane emissions

- Methane is a big issue in terms of coastal wetlands in USA
- There have been incremental improvements since then, but methane is the largest uncertainty
- Need to address by accurately measuring natural methane emissions plus those enhanced through impoundment by better activity data
- But because it is short lived and significant gains can be made i.e. lower hanging fruit

Time series

- USA currently rely on the NOAA CCAP [Coastal Change Analysis Program[33]] maps. They look at the changes every 5 years and used that to look back in the time series. There are limitations with this data so with the University of Connecticut they are looking back in time 1986-2020 to consider in greater detail of the distribution of wetlands and tidal condition. They want to undertake a more sensitive analysis with annual maps-and also use capability to look at where impoundments and blockages of tidal areas have occurred or not
- They going to analysis past changes over the decades
- Want to improve management condition maps
- Improve model called "Peppermint"
- CCAP goes back to 1996 so they did have some time to gap fill to 1990.

Costs

- How much might the activity data mapping cost?
- Approximately 2 million USD. Maybe another 2 million USD for verification using measurement

Uncertainty

- Biggest uncertainty for the USA [from the wetlands sector] is methane. They are currently using tier 1 value as not enough data [to use higher tier methodologies]
- Aquaculture is also not great as no country specific data

[33] https://coast.noaa.gov/ccapatlas/ ; https://coast.noaa.gov/digitalcoast/data/ccapregional.html

- When considering conversion to open water (primarily around the loss of wetlands in the Mississippi Delta), they make an assumption that 1m of soil is remobilised. This is a big uncertainty though, so they really want to update that

Methane

- USA are still using the CCAP from memory and no additional mapping tools.
- Was not sure if there is a national level programme to support salinity data ground truthing.
- Destruction and restoration of wetlands does impact salinity and consequently methane.
- NOAA are starting to look at what the impact of warmer oceans will be on overall salinity and consequently methane emissions

Depth of soil carbon

- Another uncertainty concerns the depth of soil carbon lost via management activities or sea level rise, or natural impacts i.e. hurricanes- what is the lateral exchange and fate of carbon that erodes salt marsh
- We don't know for sure what the depth of soil carbon stock to then determine what is lost and how this impacts emissions and removals
- Assume a 1m instantaneous loss [oxidation] in USA. But it's [wetlands] not a metre deep everywhere and it won't disappear all at once. Some carbon might end up on the sea floor in areas of high deposition.
- This is a big uncertainty

Seagrass

- USA is developing some efforts to capture seagrass but they are much more poorly mapped than other wetland types. Hasn't been a focus for Kevin so hard to comment
- Seagrasses are hard to do, as more difficult to gather activity data through remote sensing. Some states in the US are developing programmes to gather activity data. USA is waiting to see how far these states get and then look to replicate

New areas to develop

- Lateral Flux
    - Lateral flux and net source of alkalinity is easier to model how long it will stay in the ocean

  - How particulate and dissolved organic carbon end up in ocean -will be hard to resolve in terms of how long they reside
  - Alkalinity or Dissolved inorganic carbon should be ok
- If we are going to design policy we need to know how change in future
- How are we accounting for sea level rise and the impact of that on wetlands and wetland reporting
- USA running some experiment in developing models considering these impacts for Herring river in Cape Cod.

Meeting 2

Date and time of meeting: 17 June 2024 13:00-14:00 (UTC)

Attendees:

US EPA GHG inventory and Ricardo

Arrangement and Costs

- In the USA they have a variety of institutional arrangements. EPA are the overall coordinators.
- Work for blue carbon estimates is paid for by NOAA, subcontracted to Silverstrum Climate Associates. Rough estimate of around 50k USD annually to compile the NIR annually 50k USD particularly as now undertaking Tier 2 for majority of the method.
- Is around a 2/3 years process to get things compiled and ready for the inventory
- Strategy was [develop inventory] at Tier 1 which could then be improved over time
- NOAA CCAP[34] programme – had a head start with respect to remote sensing data. Coastal wetland conversions

What are the largest challenges

- Seagrass and seagrass meadows, due [the difficulty] of identifying areas of seagrass

[34] https://coast.noaa.gov/ccapatlas/ ; https://coast.noaa.gov/digitalcoast/data/ccapregional.html

Aggregation

- Are different blue carbon inventories aggregated from USA states? No – that would be very difficult

Treatment of mangroves

- Caution needed with mangroves; are these forests, or wetlands?

Key points

- Key recommendation is that a first inventory should all be Tier 1 methods, no matter how good some of the data is. The USA did their first inventory at Tier 1 and then aim to improve over time. Need to crawl before we can walk. Then start moving into Tier 2 as there are bound to be growing pains and inconsistencies in activity data particularly initially. They had a lot of people claiming they had models etc to get them to Tier 2 and even now to Tier 3 but held off to make sure they get things right and consistent, even though they have relatively advanced data
- If NIR is rushed and mistakes are made by getting methods in that are not robust or consistent then it could lead to a loss of confidence. Particularly if decisions are made off estimates that turn out to be wrong (this will be particularly important in the political environment of the EU with 27 MS). Shouldn't rush things, start Tier 1 and build, and work together. (Canada looking at doing Tier 2/3? for wetlands and had a regulated timeframe which puts a lot of pressure on to get things done and could lead to mistakes)

Consistency in Activity Data (AD)

- Land representation in the US inventory not yet harmonised with the NOAA CCAP data
- They note that consistency of activity data and the methods undertaken is essential. May have to "cobble together" different data to get activity data. As long as methods are relatively similar or comparable then we can compare data across different areas, if not, then it's hard to compare and make estimates. ?The USA in their National emission Preparation? Say to US States, does this look correct for your state and if not, give us your data
- USA wondered if the EU space agency could play a role in activity data, or even as a QA measure. USA have been fortunate in having good CCAP data

Compilation of dataset

- Created a working group and different people from science departments in government agencies to map out what they wanted to include in the NIR
- For the EU- the biggest thing would be if it can establish classification scheme with common data set. US look at state level activities going to a single

product would be simpler- they started big then went granular to state level- that took a lot of time. It best to start at smallest level then aggregate up. You need a minimum unit, and get that sorted from the get go. Also try to start as granular as possible

- If we don't have consistent data unit and classification, particularly across multiple member states, processing data is going to be horrendous. Et the method similar.
- Another point the USA did is that once you get your units and classifications, then get your science community filling gaps in data. They will want to do it and help out. Easy way to mobilise people across a whole area i.e. methane saline ground truthing? They will also have a lot of data/consolidate/collaborate on projects?
- It takes 2 or 3 months a year to prepare the dataset, primarily because activity data are already processed
- The USA are happy with their approach. Getting everyone together early is key to get everyone on the same page and understanding, they gave clear orders, and they got agreement on some key issues early i.e. managed land, recognise conversion to open water (some say it's a natural process but no actually as it is rerouting sediment supply), clarifying sticky bits. Getting NOAA to provide remote sensing data for free is also a huge benefit. Starting at Tier 1 then updating when they could was also a good idea.
- From a technical standpoint, they say don't go to a spreadsheet approach as it is to difficult to QA and work in. Transition to coding approach so QA process better and so updates can be made all at once.

Mapping

- Map product doesn't cover tidal v non tidal areas
- USA do some field research to test concept of mapping
- They recently used a protected areas database to contact various professionals across the country to ground test coastal wetlands areas and do analysis to assess the accuracy of maps - found NIR only captures around 50% of impounded wetlands
- Improvements to mapping to identify areas with confidence is key
- Interesting that USA seen as leading as no national programme for mapping these features, mainly just individual researchers. There is no organised blue carbon programme specifically in the USA but they are developing that now
- Ideal mapping and on ground verification, and without assessing GHG fluxes would run into the couple million dollars to get useful info. Lots of programmes already looking at different aspects that would be needed in the USA

- Doesn't believe you can assess salinity differences using satellite data and spectral information
- Critical thing is the improvements of mapping to be able to visualise where land management of wetlands is needed

Definition, Boundaries, Overlap

- Boundary extent of coastal wetlands was something that had to be determined. USA looked at geographical extent of coastal areas in USA and eventually took the 'Howard' research line. Coastal wetlands are not in the general land representation used for the rest of the US NIR
- Definition used for Coastal wetlands is the CCAP data definition from memory as coastal wetlands are not harmonised in the land representation and are relying on CCAP data. General IPCC definition of wetlands wasn't used, but would usually, but not in this case
- It is key for EU to get a clear definition and boundary, and again so they use consistent methodology
- They do have some risk of double counting around forests and mangroves, due to mangrove height determining whether mangroves are forest or wetland. Many countries consider mangroves as forest. The activity data is not always clear, so it makes it difficult to actually determine the split
- Only intertidal wetlands are included, not seagrass yet
- CCAP mostly just clipped dataset at the extent of tidal area up to MHWS. They go out to vegetated wetlands extent, and just clipped some open water using the Lawson line (literature)
- Not everything included is truly tidal but that is what it is
- With capturing seagrass, it might be harder to consider what the appropriate extent of activity data should be. Do you go to the end of economic zone, on activity basis?

Unvegetated open water coastal wetlands

- USA consider unvegetated open water coastal wetlands as wetlands to capture as most that carbon loss that is lost in subsidence, as possible. There are a number of areas where has been a significant loss
- USA estimate emissions at fine spatial scale as much as possible then aggregate up. State then aggregate up to national. But state is doing that its, done by inventory team from top. They start national and aggregate down to state level.

Meeting 3

Date and time of meeting: 25 June 2024 16:00-17:00 (UTC)

Attendees: Silvestrum Climate Associates and Ricardo

CCAP (Coastal Change Analysis Program) data

- Silvestrum Climate Associates use CCAP[35] for each coastal county for the whole dataset for the NIR. Stratified into 22 land classes and enough data for a time series until 1996. As this is prepared by NOAA that is a large cost they don't have to worry about
- CCAP data gives intertidal data that is needed
- Do not have data on seagrass
- Each year they try and do new improvements of mapping

Managed land

- A large part of discussion focused on whether to use an activity or managed land proxy. They went for managed land because nearly every wetland in the USA can be considered managed. It makes accounting for emissions a lot easier as you are looking at land cover change everywhere then prescribing emission factors associated with that change. Suggest that for the EU a similar approach be taken. For EU everything should be managed.
- Features to remove water
- Soil carbon exposed to oxygen and oxidises-rapid emissions
- Lots of mapping is based on elevation- so USA look at an area that would have been tidal otherwise – they look at land that is not a coastal wetland but might have been or that could be restored to salt marsh
- These would likely capture more carbon in soil if restored
- These may be on privately owned land, used by others, so hard to change
- IPCC guidance does cover this

How did the US start work, and what were the key issues? What lessons are there for the EU to learn from the US?

- Getting community and scientists together at the beginning [of the creation of the wetlands inventory] is key. Agree approach
- Issues: 1) managed land proxy; 2) do we recognise conversion to open water

[35] https://coast.noaa.gov/ccapatlas/ ; https://coast.noaa.gov/digitalcoast/data/ccapregional.html

- Started stratifying at climate level and then improved to state level. This took a long time. So, [recommends] starting out at a granular level as possible

Effort needed

- How long to generate the CCAP [data set]? Considerable effort – ground truthing and verification [needed]
- 2 or 3 months person time – BUT – have received processed data to use

What inventory calculation approaches should be used?

- Better to move away from spreadsheets. Recommend taking a coding approach [to estimating emissions/removals]
- A lot of people are using the “R” language
- Land cover map [USA] is IPCC Approach 2
- Inland wetlands – US government starting to look at this now

Remote Sensing Data

- European Space Agency might be the agency to generate wetlands maps for the EU
- They clip from the highest astronomical tide/time? They call that coastal land area. Then there are 22 classes (settlement, crop etc). They look at the change and if it gets recognized as a wetland class, they track as restoration.
- Restoration is not really tracked- land cover mapping is only way to track it
- Unvegetated to vegetated is considered restoration
- Remote sensing data collection is not much work. Verifying is the hard part, and they do ground truthing. At the moment CCAP have over 85 % accuracy on pixel.
- Most recent cover in 2016 they took advantage of computer power using updated software looking back in time-they use Landsat. They are talking about machine learning to produce product every year, and using 1 m pixels instead of 5 m
- Current pixel size is 30 m, some areas are 1 m now.
- An update to for 2019 is planned but they are still waiting for it come out
- They rely on NASA data. Therefore, we wonder if ESA can help in this space. It makes a big difference having someone collect and give you consistent activity data

Other

- Have 15,000 data points of carbon stocks from around the world
- Silvestrum Climate Associates also helped establish the coastal carbon network- 15,000 data points around the world on soil carbon stocks to help share information and link reporting together
- Terrestrial wetlands- US just really kicking off activity data on this?
- Land cover map is Tier 2 – stratifying
- States have more detailed mapping in some cases for methane. They can account for more but not all states the same. They are just about to engage in Washington, so can get better classification of saline brackish freshwater

Uncertainties

- What are the highest uncertainties? CH_4 emissions and palustrine estuaries. Use a Tier 1 approach – don't have country specific values

Additional thoughts

- Experience of IPCC [guidance] - Emission factors very incomplete
- A 2017 opportunity to increase salinity by opening tidal restrictions to reduce methane release not a factor included in IPCC methodology– so bad for GHG estimates
- USA used freshwater emission factors instead for impounded waters
- IPCC 2019 Refinement report was going to solve impounded water problem but it didn't
- EPA is analysing impoundments- but are looking at big ones such as dams, drinking water reservoirs etc whereas the issue for coastal wetlands are smaller impoundments and wetlands across larger areas and impounded by various smaller infrastructure
- Australia may have done more work in this space regarding carbon markets and California is focused on it.
- Salinity and methane considerations might to be interesting for Europe in terms of the Mediterranean with less currents and flows and areas of higher and lower salinity. These differences across the Mediterranean may be initially difficult to accurately map along the coast at the level we need for a solid NIR? Assume the USA would have similar challenges in the Gulf of Mexico along the coast but potentially more pronounced in areas of Europe?
- Uncertainties going to be similar for Europe
- NIR doesn't say what is the stock, only the change [in carbon fluxes annually]

NIR

- For the NIR you want to look at carbon stock and stock changes in soil, methane changes but also want to look at lateral flux.
- This is the tidal exchange of dissolved carbon exported to estuary and coastal ocean, may store in [carbon] coastal ocean for a while.
- The USA have an ambition to include that flux in the inventory- this is not represented in IPCC guidance

Climate Zones

- They USA do stratify wetlands emissions/removals estimates by climate zones. Is important to consider temperature, particularly for Europe. Key thing is that 'it's consider' and wetlands stratified somehow

Change from NIR 22 - NID 23

- Changes were pretty minimal for coastal wetlands

Additional information from discussions with UK CEH

- Additional information can be gained from these studies, some of which have yet to be published:
  - the newly published Defra report: Defining saltmarsh for inclusion in the LULUCF Inventory - ME5325 and Moving towards inclusion of coastal wetlands in the UK LULUCF inventory (https://naei.energysecurity.gov.uk/reports/moving-towards-inclusion-coastal-wetlands-uk-lulucf-inventory)
  - Synthesis of GHG and C flux data from published work applicable to and collected from UK saltmarsh habitat, and compilation of database (completed, but report will be published with follow-on project below)
  - Visualization of the UK saltmarsh GHG flux and carbon database (to be published online in spring 2025)
  - Assessment of Tier 1 and Tier 2 emission factors for saltmarsh (project just started using outputs from the synthesis project– to be completed in Spring 2025)
  - UKBCEP Greenhouse Gases Inventory – 1990 saltmarsh basemap (project just started – Phase 1 scoping of data runs until March 2025)
  - There is an expanding network of UKCEH GHG flux towers on saltmarsh, you can find all the project details here: https://www.ceh.ac.uk/our-science/projects/uk-saltmarsh-code/saltmarsh-blue-carbon.
- Once these projects finish in the spring 2025 we will be able to advise on whether we have enough data for Tier 1 or Tier 2 implementation of blue carbon in the GHGI (starting with saltmarsh first), and reassess where we are along the roadmap.

Additional information from dialogue with IPCC Lead Author

Resources that may be useful:

- Saltmarsh Blue Carbon in UK and NW Europe - evidence synthesis for a UK Saltmarsh Carbon Code
- The link below goes to the contract "Assessment of Tier 1 and Tier 2 emission factors for saltmarsh" (with cost) and on this page there are further links to Environment agency - Assessment tier emission factors
- Global dataset of soil organic carbon in tidal marshes | Scientific Data

- The distribution of global tidal marshes from Earth observation data - Worthington - 2024 - Global Ecology and Biogeography - Wiley Online Library
- aao1de1.pdf
- A New Coupled Biogeochemical Modeling Approach Provides Accurate Predictions of Methane and Carbon Dioxide Fluxes Across Diverse Tidal Wetlands - Oikawa - 2024 - Journal of Geophysical Research: Biogeosciences - Wiley Online Library
- Murray Global Tidal Wetland Change v1.0 (1999-2019) | Earth Engine Data Catalog | Google for Developers
- Global Ecology and Biogeography - Wiley Online Library
- Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0
- Global Mangrove Distribution, Aboveground Biomass, and Canopy Height
- Global mangrove soil organic carbon stocks dataset at 30 m resolution for the year 2020 based on spatiotemporal predictive machine learning - ScienceDirect
- Global mangrove soil organic carbon stocks dataset at 30 m resolution for the year 2020 based on spatiotemporal predictive machine learning - ScienceDirect
- CARBON SEQUESTRATION RATES IN COASTAL BLUE ...
- Dipòsit Digital de Documents de la UAB
- https://ddd.uab.cat › tesis › hdl_10803_667139
- (PDF) Outlining a methodological pathway to improve the global seagrass map

Annex C: Methodology in USA Coastal Wetlands Emissions Reporting

This annex outlines the methodologies undertaken by the USA in coastal wetland GHG emissions and removals reporting.

What emissions and removals do the USA assess?

In assessing emissions and removals from coastal wetlands, the USA look at the biomass, dead organic material (DOM; including litter and dead wood stocks) and soils of coastal wetlands. They account for emissions and removals from five different emission pools:

- Biomass Carbon Stock Exchanges
- Soil Carbon Stock Changes
- Soil Methane Emissions
- DOM (dead wood & litter)
- Nitrogen Aquaculture

There are two chapters of the inventory that coastal wetlands fall under:

- Wetlands Remaining Wetlands
- Land Converted to Wetlands

Under Wetlands Remaining Wetlands there is a Coastal Wetlands Remaining Coastal Wetlands section. They define coastal wetlands into four wetland categories based on changes in land use:

- Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands
- Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands
- Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands
- N_2O Emissions from Aquaculture in Coastal Wetlands

Under Land Converted to Wetlands they define coastal wetlands into one wetland category based on changes in land use:

- Land Converted to Vegetated Coastal Wetlands.

Each change in land use will result in the reporting of certain emissions and removals based on the nature of the environment, land use change, and availability of data. The following emissions and removals are quantified:

- Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands - Carbon stock changes, and CH_4 emissions
- Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands - Carbon stock changes
- Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands - Carbon stock changes
- Aquaculture in Coastal Wetlands - Nitrous Oxide Emissions
- Land Converted to Vegetated Coastal Wetlands - Carbon stock changes and CH_4 emissions

The Wetlands Supplement provides specific guidance on quantifying emissions and removals on organic and mineral soils that are covered or saturated for part of the year by tidal fresh, brackish or saline water and are vegetated by vascular plants and may extend seaward to the maximum depth of vascular plant vegetation. The Wetlands Supplement provides methodologies to estimate N_2O Emissions from Aquaculture in Coastal Wetlands.

What definition of wetlands does the USA use?

As described in further detail in this report, the USA source activity data from the National Oceanic and Atmospheric Administration (NOAA) – Coastal Change Analysis Program Atlas (C-CAP). Therefore, the definition used for coastal wetlands under C-CAP is effectively what is used in the inventory (Personal communication, Steller, 2024). Within C-CAP the EPA defines wetlands as:

- ‘Lands that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation (i.e., hydrophytes) typically adapted for life in saturated soil conditions (i.e., hydric soils). Wetlands generally include swamps, marshes, bogs, and similar areas (NOAA n.d.a)’
- All privately- and publicly owned coastal wetlands (i.e., mangroves and tidal marsh) on federal and non-federal lands along the oceanic shores of the conterminous United States are considered.
- Mangrove forests that are less than 5 m in height, and all other non-drained, intact coastal marshes are reported under Coastal Wetlands.

- There are a variety of exclusions from coastal wetlands and land classification methods in the USA inventory:
- Seagrasses are not currently included in the mapping and therefore calculations, due to insufficient data on distribution, change through time and C stocks or C stock changes as a result of anthropogenic influence.
- Mangroves that are 5 m or greater (or if there is evidence that trees can obtain that height,) are reported under the Forest Land category so are excluded from coastal wetlands reporting.
- Soil carbon is released over-time from drainage through conversion to settlements, croplands and grasslands. These emissions continue until the soil carbon stock is depleted or soil water management changes. However, estimates of conversion of coastal wetlands to these other land-use categories are covered under other AFOLU categories, and therefore they are not included under coastal wetlands (Green, et al, 2021)
- The Wetlands Supplement provides methodologies to estimate N_2O Emissions from Aquaculture in Coastal Wetlands. The N_2O emissions from aquaculture result from the N derived from consumption of the applied food stock that is then excreted as N load available for conversion to N_2O. While N_2O emissions can also occur due to anthropogenic N loading from the watershed and atmospheric deposition, these emissions are not reported here to avoid double-counting of indirect N_2O emissions with the Agricultural Soils Management, Forest Land and Settlements categories in the inventory.
- Other open water shellfisheries for which no food stock is provided, and thus no additional N inputs, are not applicable for estimating N_2O emissions (e.g., clams, mussels, and oysters) and have not been included in the analysis.
- Some lands can be classified into one or more land cover categories due to multiple uses that meet the criteria of more than one definition. However, a ranking has been developed for assignment priority in these cases. The ranking process is from highest to lowest priority based on the following order: Settlements > Cropland > Forest Land > Grassland > Wetlands > Other Land.

Wetlands are considered lower priority generally because in the other categories the land is being used for an anthropogenic activity whereas in wetlands it is less likely. For example, if land is potentially either wetland and cropland, then the land is considered to be used as a crop i.e. wetlands used for rice or cranberry production. The assignment priority does not reflect the level of importance for reporting GHG emissions and removals on managed land but is intended to classify all areas into a discrete land-use category.[36]

[36] Delineating Vegetated Coastal Wetlands from ephemerally flooded upland Grasslands represents a particular challenge in remote sensing. Moreover, at the boundary between wetlands and uplands, which may be gradual on low lying coastlines, the presence of wetlands may be

- Land is treated as remaining in the same category (e.g., Wetlands Remaining Wetlands) if a land-use change to another land category has not occurred in the last 20 years

What emissions and removals do the USA not assess?

A variety of emissions and removals from certain activities related to coastal wetlands are not assessed:

- The lateral flux of C to or from any land use.
  - Lateral transfer of organic C to coastal wetlands and to marine sediments within U.S. waters is the subject of ongoing scientific investigation; there is currently no IPCC methodological guidance for lateral fluxes of C.
- 4.D.1 Wetlands Remaining Wetlands
  - Biomass Burning: Controlled Burning, Wildfires- CO_2, CH_4, and N_2O
  - Data are not currently available to apply IPCC methods to estimate emissions from biomass burning in Wetlands.
- 4.D.2 Land Converted to Wetlands
  - Biomass Burning: Controlled Burning, Wildfires- CO_2, CH_4, and N_2O
  - Data are not currently available to apply IPCC methods to estimate emissions from biomass burning in Wetlands.
- 4.A Forest Land
  - Emissions and Removals from Rewetting of Organic and Mineral Soils- CO_2 and CH_4
  - Not required based on the 2006 IPCC Guidelines. Emissions from this source may be estimated in future Inventories using guidance from the Wetlands Supplement when data necessary for classifying the area of rewetted organic and mineral soils become available.
- 4.B Cropland
  - Emissions and Removals from Rewetting of Organic and Mineral Soils- CO_2 and CH_4.

ephemeral depending upon weather and climate cycles and as such, impacts on the emissions and removals will vary over these time frames.

  - Not required based on the 2006 IPCC Guidelines. Emissions from this source may be estimated in future Inventories using guidance from the Wetlands Supplement when data necessary for classifying the area of rewetted organic and mineral soils become available, except for CH_4 emissions from drainage and rewetting for rice cultivation.

- 4.C Grassland
  - Emissions and Removals from Rewetting of Organic and Mineral Soils- CO_2 and CH_4.
  - Not required based on the 2006 IPCC Guidelines. Emissions from this source may be estimated in future Inventories using guidance from the Wetlands Supplement when data necessary for classifying the area of rewetted organic and mineral soils become available.

Preparation of the Annual Inventory

This section describes the EPA's approach to preparing the annual inventory. The inventory coordinator at EPA, with support from the cross-cutting compilation staff, is responsible for coordinating aggregation of all emission and removal estimates, conducting the overall uncertainty analysis of inventory emissions and trends over time, and ensuring consistency and quality throughout the inventory and CRTs. Emission and removal calculations, including associated uncertainty analysis for individual sources and/or sink categories are the responsibility of individual source and sink category leads, who are most familiar with each category, underlying data, and the unique national circumstances relevant to its emissions or removals profile. Using the IPCC methodological decision trees and suggested good practice guidance, the individual leads determine the most appropriate methodology and collect the relevant activity data to use in the emission and removal calculations, based upon their expertise in the source or sink category, as well as coordinating with researchers and expert consultants familiar with the sources and sinks. Each year, the coordinator oversees a multi-stage process for collecting information from each individual source and sink category lead to compile all information and data for the inventory.

Because the EPA has been leading preparation of the inventory for many years, for most source and sink categories, the methodology for the previous year is applied to the new "current" year of the inventory, and inventory analysts collect any new data or update data that have changed from the previous year. If estimates for a new source or sink category are being developed for the first time, or if the methodology is changing for an existing category (e.g., implementing improvement efforts to apply a higher tiered approach for that category), then the source and/or sink category lead will develop and implement the new or refined methodology, gather the appropriate activity data and other information (e.g., emission factors or in some cases direct emission measurements) for the entire time series, and conduct any further category-specific review with involvement of relevant experts from industry, government, and universities. Once the methodology is in place and the data are collected, the individual source and sink category leads calculate emission and removal estimates. The inventory is prepared to align with the Paris Agreement and UNFCCC reporting guidelines for national inventory reports while also reflecting national circumstances.

Discussion with USA experts in the development of the inventory have provided insights into how the inventory is developed and prepared. While the EPA are the overall coordinators or the inventory, work for coastal wetlands estimates is paid for by NOAA, who currently contract out with Silverstrum Climate Associates (Personal communication, EPA, 2024). Some key matters to note are outlined below:

- It is around a two to three year process to get the coastal wetlands section of the inventory compiled and ready for the inventory and a two to three month process to prepare the dataset, primarily because activity data are already compiled by NOAA (Personal communication, EPA, 2024).
- Remote sensing data development does not require much effort and resourcing for the inventory team because it is already complied by NOAA. Verifying, including ground truthing, is more difficult and requires more effort (Personal communication, Silvestrum Climate Associates, 2024).
- Rough estimates of the relevant cost of preparing the coastal wetland section of the inventory given by experts sit at approximately US $50,000?? (Personal communication, EPA, 2024). They noted that this is in the context that they are now undertaking Tier 2 methodology for the majority of the inventory, and that base activity data is largely supplied to them free of charge from NOAA.

Initial Development of Coastal Wetland Reporting in the Inventory.

In our discussions with USA experts, discussion included focus on the approach and process undertaken in the initial development of coastal wetland reporting in the inventory.

The USA initially developed a working group of interested parties and experts (particularly from science departments in government agencies) to map out what they wanted to include in the inventory, set methods and establish how the inventory would be prepared.

Key matters noted by USA experts, from the initial discussions in the development of the inventory, included the following:

- Key to early discussions was getting agreement on the methods, definitions, units, classifications, etc used across inventory reporting. This was particularly true in the development of activity data and the methods undertaken in processing. This was to ensure consistency and clarity when making estimates across the country. USA experts noted that as long as methods were similar or comparable then they can compare data across different areas of the country. If there is no consistency, processing data and making estimates is extremely difficult.

- The USA gained consensus that the first inventory would be undertaken using Tier 1 approaches with the aim to then improve over time. At the time of the development there were several differing views and claims around the methods used to estimate emissions, particularly in relation to models that had been developed to assess certain emission pools i.e. soil stock changes. Many claimed they could get to a Tier 2 and Tier 3 methodology right away. While that may have been true in some cases, and they did have some relatively advanced data available, the USA made the decision to only use Tier 1 initially to ensure methods were correct and consistent and to build trust in the process.
- Getting agreement on other key matters required in the development of an inventory was also central to discussions. This included:
    - Gaining consensus on whether to recognise all coastal wetlands as managed and therefore report on all areas
    - Recognising the conversion of vegetated coastal wetlands to unvegetated open water coastal wetlands in reporting. Some views were that it was a natural process via coastal processes or hurricanes, but they settled on the view that this is not strictly the case as wetlands are often impacted by rerouted sediment supply.
    - Confirming the boundary extent of coastal wetlands and consequently the extent of activity data.
    - The definition used for wetlands.
    - Sourcing activity data from a consistent and central source. The NOAA was able to provide remote sensing data for free via C-CAP.
- Once the USA had confirmed methods, definitions, units, classifications, etc they were able to utilise their science community to address gaps in data for reporting purposes. They found many experts across the country had useful data and knowledge and were happy to assist in ensuring good quality data. They found them easy to mobilise once parameters were set and it ensured clarity in roles.

Activity Data Sources

In sourcing activity data for the purposes of coastal wetland emissions and removals reporting, the USA use the NOAA Coastal Change Analysis Program (C-CAP) (NOAA, n.d.b).

For other land uses in the USA inventory, a national land use representation system is used in order to assess land use and land-use changes and the associated GHG fluxes over the inventory time series. At the stage of inventory development, coastal wetlands are not incorporated in the land representation analysis until a planned improvement is undertaken for future inventories to reconcile coastal wetlands data from C-CAP with the wetlands area data provided in the National Resource Inventory (NRI) used to compile the land representation.

How are C-CAP change maps produced?

C-CAP products are developed by NOAA using multiple dates of remotely sensed imagery to produce nationally standardized land cover and land change information for the coastal regions of the USA. NASA satellite imagery is combined with, tide station data, and national soil survey databases to provide high resolution land cover mapping and land use histories recorded every 5 years from 1996. C- CAP areas are calculated at the state/territory level and summed according to climate zone to national values. Change detection analysis compares the two dates of imagery to identify the areas that have likely changed during this time frame. These areas are then classified through a combination of models, use of ancillary data, and manual edits. Data is stratified into 22 different land classes (i.e. settlement, cropping, etc) (Personal communication, Silvestrum Climate Associates, 2024).

A wetland "gain" refers to pixels that changed from a developed (i.e., high intensity, medium intensity, low intensity, and open space), agricultural (i.e., cultivated crops and pasture/hay), barren-land, or open-water class in the early date to a wetland class in the late date. Conversely, a wetland "loss" refers to pixels that changed from a wetland class in the early date to a developed, agricultural, barren land, or open water class in the late date.

The mapped data does not capture changes between wetland types, and as such changes do not represent a true "gain" or "loss" of wetlands, but instead a transition from one wetland type to another (e.g., forested wetland that is harvested and becomes emergent wetland, or re-grows to scrub/shrub or mature forest). Such changes are however, included in the numerical data reported on the sidebar of the application (NOAA, n.d.a).

The team preparing the inventory clip the area relevant to coastal wetland reporting and assess the changes between the different 5-year periods (Personal communication, Silvestrum Climate Associates, 2024). In addition, checks are undertaken to confirm that coastal wetlands recognized by C-CAP represented a subset of wetlands recognized by the NRI for marine coastal states. They also do undertake some field research and ground truthing to test concept of mapping (Personal communication, Silvestrum Climate Associates, 2024; Personal communication, US Geological Survey, 2024). The US Geological survey representative, (2024) noted that the USA recently used a protected areas database to contact various professionals across the country to ground test coastal wetlands areas and undertake analysis to assess the accuracy of maps.

This high-resolution mapping provides data to support IPCC Approach 2 methods for tracking land cover change.

Notes and Limitations:

- Maps produced do not include a distinction between tidal and non-tidal areas (Personal communication, US Geological Survey, 2024)
- Delineating Vegetated Coastal Wetlands from ephemerally flooded upland Grasslands represents a particular challenge in remote sensing. Moreover, at the boundary between wetlands and uplands, which may be gradual on low lying coastlines, the presence of wetlands may be ephemeral depending upon weather and climate cycles and as such, impacts on the emissions and removals will vary over these time frames.

Mapping Extent of Coastal Wetland Activity data

Remote sensing data is clipped via an area called the ‘coastal land area’ (Personal communication, Silvestrum Climate Associates, 2024). Coverage extends from land below the elevation of high tides (from mean high water spring tide elevation) and as far seawards to the maximum depth of vascular plant vegetation or a boundary called the ‘Lawson line’ which was developed from literature (Personal communication, Silvestrum Climate Associates, 2024; Personal communication, EPA, 2024).

Sub categorising Wetland Data

As mentioned, C-CAP data is stratified (Personal communication, EPA, 2024; Personal communication, Silvestrum Climate Associates, 2024). In C-CAP base data coastal wetlands are considered in both palustrine (freshwater) and estuarine (saline) marshes categories (NOAA, n.d.a.). The NOAA then subcategorise wetlands based on climate zone and vegetation height based on availability of data (NOAA, n.d.a.):

- Palustrine Forested Wetland - Pixels include tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to five meters in height, as well as all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Palustrine Scrub/Shrub Wetland - Pixels include tidal and non-tidal wetlands dominated by woody vegetation less than five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5%. Total vegetation coverage is greater than 20 percent.
- Palustrine Emergent Wetland - Pixels include tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses, or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent.
- Estuarine Forested Wetland - Pixels include tidal wetlands dominated by woody vegetation greater than or equal to five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Scrub/Shrub Wetland - Pixels include tidal wetlands dominated by woody vegetation less than five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Emergent Wetland - Pixels include all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). This classification includes all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for the majority of the growing season in most years. Total vegetation cover is greater than 80 percent.
- Unconsolidated Shore - Pixels include material (such as silt, sand, or gravel) that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favourable.

Activity Data Time Coverage

- The current USA reporting of emissions from coastal wetland covers land use changes from 1990 to 2022. C-CAP data covers land use change from 1996 with updates made every 5 years. When the USA started compiling the inventory, they used C-CAP data to look back in the time series however they still had a shortfall of 6 years to cover until 1990. Here they used literature to develop rough estimates of total area (Personal communication, EPA, 2024).

- Time series consistency can be difficult to achieve, especially as activity data in earlier years can be much harder to locate and with much higher associated uncertainties. Improvements are implemented consistently across the previous inventory's time series (i.e., 1990 to 2021) to ensure that the trend is accurate.
- Ideally, USA would like to be undertaking annual mapping updates (Personal communication, US Geological Survey, 2024).

Other Key Considerations of the USA Coastal Wetland Inventory

Managed and Unmanaged Land

The IPCC (2006) outlines that all countries reporting should describe the methods and definitions used to determine areas of managed and unmanaged lands in the country and account for GHG fluxes on all managed lands. Managed land serves as a proxy for anthropogenic emissions and removals in reporting. In the USA, wetlands are not differentiated between managed and unmanaged as it is too difficult due to limited data availability, because of anthropogenic influence and level of regulatory oversight. Therefore, all emissions/removals on managed land are estimated regardless of whether the driver was natural.

This decision was made when developing the initial inventory, because nearly every wetland in the USA could be considered managed (Personal communication, Silvestrum Climate Associates, 2024). Wetlands are highly connected systems that are influenced by indirect landscape-scale human activities, such as upstream water diversions and sediment supply disruptions. This makes on-site attribution of emissions and removals to a specific management practice difficult to include in inventories (Green et al, 2021). The USA considers all wetlands as managed as it makes accounting for emissions simpler as you are looking at land cover change everywhere and then prescribing emission factors associated with that change irrespective of the driver/s (Personal communication, Silvestrum Climate Associates, 2024).

Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands

The United States recognizes both vegetated wetlands and unvegetated open water as coastal wetlands. As per guidance provided by the Wetlands Supplement, sequestration of C into biomass, DOM and soil C pools is recognized only in

Vegetated Coastal Wetlands and does not occur in Unvegetated Open Water Coastal Wetlands. The United States takes the additional step of recognizing that C stock losses occur when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands. This way they capture as much carbon that is lost in subsidence and erosion (i.e. subsidence from changes in river hydrology, hurricanes, sediment supply disruption, oil and gas extraction), as possible. The USA particularly in the southern states, has had significant losses of wetlands in this manner across a number of areas (Personal communication, EPA, 2024).

Time Coverage Assumptions

Some specific assumptions relating to time are applied to the different wetland categories and changes as outlined below:

- Lands are treated as remaining in the same category (e.g., Wetlands Remaining Wetlands) if a land-use change has not occurred in the last 20 years, consistent with the IPCC guidelines (2006).
    - Wetlands Remaining Wetlands includes all wetlands in an inventory year that have been classified as a wetland for the previous 20 years.
    - Land Converted to Vegetated Coastal Wetlands is assumed to remain in this category for up to 20 years before transitioning to Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands as per Wetland Supplement guidance.
- For Land Converted to Coastal Wetland, soil C removal factors and CH_4 emissions were multiplied by activity data of land area for these wetland types for a given year in addition to the previous 19-year cumulative area because Land Converted to Vegetated Coastal Wetlands is assumed to remain in this category for up to 20 years before transitioning to Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands.
- For extraction activities i.e. Vegetated Coastal Wetlands converted to Unvegetated Open Water Coastal Wetlands, Wetland Supplement assumptions are followed where CO_2 emissions and removals are estimated for the initial change in carbon stocks that occur during the year the extraction activities take place. Once the activity/activities is/are completed, these lands are continually tracked but CO_2 emissions and removals are reported as zero at Tier 1. Tracking of such lands requires spatially and temporally explicit activity data (i.e., Approach 3).
- Land Converted to Vegetated Coastal Wetlands Guidance from the Wetlands Supplement is followed which allows for the rate of soil C accumulation to be instantaneously equivalent to that in natural settings and that soil C accumulation is initiated when natural vegetation becomes established. All soil C accumulation is assumed to occur in the first year of conversion. The

difference between the stocks for biomass and DOM is reported as the stock change under the assumption that the change occurred in the year of the conversion. The biomass and DOM stock is assumed to be in steady state once established in the year of conversion; therefore, no interannual changes are calculated during the remaining years it is in the category.

- Biomass, DOM and soil C accumulation on Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands begins with vegetation establishment. While this is the case, the assumption applied is that total biomass, DOM and soil C accumulation is reached in the year of conversion.
- For Land Converted to Vegetated Coastal Wetlands, and for soil carbon stock change assessment, it is mentioned that since the C-CAP coastal wetland area dataset begins in 1996, the area converted prior to 1996 is assumed to be the same as in 1996. Similarly, the coastal wetland area data for 2017 through 2022 is assumed to be the same as in 2016.

Other Assumptions

There are some other minor assumptions that apply in the USA reporting to be aware of:

- Vegetated Coastal Wetlands converted to Unvegetated Open Water Coastal Wetlands. The USA follows the Wetlands Supplement for a number of assumptions:
    - This land conversion can be classed as an excavation and the USA adopts the Tier 1 methodological guidance from the Wetlands Supplement for estimating emissions following the methodology for excavation. They assume a 1 m depth of disturbed soil. This 1m depth is consistent with estimates of wetland C loss provided in the Wetlands Supplement and literature.
    - A Tier 1 assumption that all mobilized C is immediately returned to the atmosphere, rather than redeposited in long-term C storage.
- Land Converted to Coastal Wetlands
    - This inventory does not include Land Converted to Unvegetated Open Water Coastal Wetlands

Emission Pool Activity Data, Emission Factors and Methodology

These sections outlined the specific methodology for calculating emissions and removals from the different emission pools for coastal wetlands that are reported on in the US inventory.

Biomass Carbon Stock Exchanges

Activity Data

C-CAP is used to source activity data.

When calculating biomass, it is important to note that biomass is not sensitive to soil organic matter content but is differentiated based on climate zone.

Emissions Factors (biomass C stocks)

Biomass C stocks are developed from a series of sources:

- Aboveground biomass:
  - Across all wetland categories
    - For non-forested wetlands, derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al. 2017; Byrd et al. 2018; Byrd et al. 2020).
    - For (subtropical)/estuarine forested wetlands (dwarf mangroves that are not classified as forests due to their stature), derived from a meta-analysis by Lu and Megonigal (2017).
  - Across all wetland categories except for Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands in addition to those sources above
    - Aboveground biomass C stock/removal data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment of a C stock to a disaggregation of a community class
  - For Land converted to Vegetated Coastal Wetlands in addition to those sources above
    - Forest Land, Cropland, and Grassland that are lost with the conversion to Vegetated Coastal Wetlands are derived from Tier 1 default values (IPCC 2006; IPCC 2019)."
- Belowground biomass:
  - Across all wetland categories
    - Root to shoot ratios from the Wetlands Supplement were used.

Methodology to Estimate Emissions

In assessing biomass emission/removals the USA use the gain loss method across all categories of coastal wetlands. It is not entirely clear whether the USA undertake a Tier 2 or Tier 1 approach. The NIR indicates a mix depending on the wetland category. They use some country specific emission factors as noted above but follow IPPC guidance (default emission factors) for some of the Land converted to Vegetated Coastal Wetlands factors and for belowground biomass factors for all categories. They derive stock changes and activity data for aboveground biomass, below ground biomass, then calculate total biomass, followed by the change in biomass stock.

- Aboveground Biomass C stocks: are developed from the series of sources noted above
- Belowground Biomass C stocks: are developed from the source above. These ratios were then multiplied by the aboveground C stock to get below ground biomass
- Total biomass C stock: is calculated by summing the two values of above and below ground biomass

Change in Biomass Stock: is determined by calculating the difference in area between that year and the previous year to calculate gain/loss of area for each climate type. This is then multiplied by the mean biomass for that climate type

An additional consideration is required for Land converted to Vegetated Coastal Wetlands. Biomass C stock changes are calculated by subtracting the biomass C stock values of each land-use category (i.e., Forest Land, Cropland, and Grassland) from those of Vegetated Coastal Wetlands in each climate zone and multiplying that value by the corresponding C-CAP derived area gained that year in each climate zone. The difference between the stocks is reported as the stock change

Soil Carbon Stock Exchanges

Activity Data

C-CAP is used to source activity data.

It is noted that no differentiation is made for soil type (i.e., mineral, organic) when considering soil carbon stock exchange

Emissions Factors

Country-specific soil C emission/removal factors are developed from a synthesis of peer-reviewed literature ((Lynch 1989; Orson et al. 1990; Kearny & Stevenson 1991; Thom 1992; Roman et al. 1997; Craft et al. 1998; Orson et al. 1998; Merrill 1999; Weis et al. 2001; Hussein et al. 2004; Church et al. 2006; Köster et al. 2007; Drexler et al. 2009; Boyd 2012; Callaway et al. 2012 a & b; Bianchi et al. 2013; Drexler et al.

2013; Watson and Byrne 2013; Crooks et al. 2014; Breithaupt et al. 2014; Weston et al. 2014; Smith et al. 2015; Villa & Mitsch 2015; Boyd and Sommerfield 2016; Marchio et al. 2016; Noe et al. 2016; Arriola and Cable 2017; Boyd et al. 2017; Gerlach et al. 2017; Giblin and Forbrich 2018; Krauss et al. 2018; Abbott et al. 2019; Drexler et al. 2019; Poppe and Rybczyk 2019; Ensign et al. 2020; Kemp et al. 2020; Lagomasino et al. 2020; Luk et al. 2020; McTigue et al. 2020; Peck et al. 2020; Vaughn et al. 2020; Weston et al. 2020; Arias-Ortiz et al. 2021; Baustian et al. 2021; Allen et al. 2022; Miller et al. 2022).

There were some additional sources for certain categories:

- Land converted to Vegetated Coastal Wetlands: soil C removal data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment to a disaggregation of a community class.
- For Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands a single soil C stock of 270 t C ha^{-1} was applied to all classes. This is because Holmquist et al., (2018) analysis demonstrated that it was not justified to stratify based upon mineral or organic soil classification, climate zone, or wetland classes.

Methodology to Estimate Emissions

To estimate emissions from Soil Carbon, the USA uses the stock change method for soil carbon (C).

To estimate soil C stock changes/removals associated with annual soil C accumulation, a Tier 2 level estimate and Eq. 4.7, Chapter 4 of the *Wetlands Supplement* are followed. Country-specific soil C removal factors are multiplied by activity data or land area remaining or converted for each wetland category. This is applied to the area remaining or converted of each wetland category on an annual basis.

For Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands the Tier 1 approach for extraction activities in the Wetland Supplement is used with Eq. 4.6 followed. As outlined above, a single soil C stock of 270 t C ha^{-1} is applied to all classes. This is multiplied by activity data or area of Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands. Soil C loss with conversion of Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands is assumed to affect soil C stock to one-meter depth (Holmquist et al. 2018).

Soil Methane Emissions

Activity Data

C-CAP is used to source activity data.

Following *Wetlands Supplement* methodologies for estimating CH_4 emissions, coastal wetlands in salinity conditions greater than 18 parts per thousand have little to no CH_4 emissions compared to those experiencing lower salinity brackish and freshwater conditions. Some estuarine wetlands may have salinity less than 18 ppt, where methane can be produced, while others may have salinity greater than 18 ppt (where negligible to no CH_4 is produced). However, the current dataset for the USA does not differentiate estuarine wetlands based on their salinities and, therefore it cannot be determined which are emitting CH_4 and which are not. As a result, CH_4 emissions from estuarine wetlands are not included at this time[37]. In higher salinity anaerobic environments microorganism use sulphate i.e. smell of saltmarsh (Personal communication, US Geological Survey, 2024).

Conversion of Vegetated Coastal Wetlands to or from Unvegetated Open Water Coastal Wetlands are conservatively assumed to not result in a change in salinity conditions and are assumed to have no impact on CH_4 emissions.

Therefore, for the assessment of soil methane emissions in the inventory, only palustrine wetlands within Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands and Land converted to Vegetated Coastal Wetlands, are assumed to emit CH_4 and therefore are the only wetland subcategories assessed.

Emission Factors

To estimate CH_4 emissions the USA follows the Tier 1 approach of the Wetlands Supplement and therefore sources emission factors from those provided in Table 4.14 of the supplement.

Methodology to Estimate Emissions

To estimate CH_4 emissions the USA follows the Tier 1 approach and Equation 4.9, Chapter 4 of the Wetlands Supplement. Tier 1 emissions factors provided in Table 4.14 are multiplied by the area of palustrine coastal wetlands.

Dead Organic Matter

Activity data

C-CAP is used to source activity data.

[37] The C-CAP the USA split palustrine and estuarine wetlands by salinity below, or, equal to or greater than, 0.5 percent, rather than 18ppt. However as the dataset currently does not differentiate estuarine wetlands based on their salinities, CH_4 emissions from estuarine wetlands are not included at this time.

When calculating DOM C stock, only DOM C stocks in subtropical estuarine forested wetlands emissions are assessed. This is because:

- The Wetlands Supplement includes Tier 1 default values for Litter and Dead wood carbon stocks in mangroves, only for tropical/subtropical mangroves.
- Tier 1 default or Tier 2 data on DOM are not currently available for either palustrine or estuarine scrub/shrub wetlands for any climate zone.
- Data for estuarine forested wetlands in climate zones, other than subtropical, are not included since there is no estimated loss of these forests to unvegetated open water coastal wetlands across any year based on C-CAP data.
- Changes in DOM are assumed to be negligible for other land-use conversions (i.e., other than Forest Land) to coastal wetlands based on the Tier 1 method in IPCC (2006).

For estuarine emergent wetlands no reason is given as to why these are excluded, but we assume that this is because the Tier 1 assumption for both dead wood and litter pools for all land-use categories is that their carbon stocks are not changing over time if the land remains within the same land-use category.

Emission Factors

To estimate DOM C stock in subtropical estuarine forested wetlands the USA use Tier 1 estimates

- Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands
    - Tier 1 estimates of mangrove DOM were used (Wetlands supplement)
- Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands
    - Tier 1 estimates of subtropical estuarine forested wetland DOM were used (Wetlands supplement).
- Land to Vegetated Coastal Wetlands
    - Tier 1 estimates of mangrove DOM C stocks were used for subtropical estuarine forested wetlands (Wetlands supplement).
    - Tier 1 DOM C stocks for Forest Land converted to Vegetated Coastal Wetlands were derived from (IPCC 2019) to account for the loss of DOM that occurs with conversion.

Methodology to Estimate Emissions

To estimate emissions/removals from DOM the USA use the gain loss method.

- For vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands and Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands
  - Tier 1 DOM C stock are multiplied by the area of Vegetated Coastal Wetlands lost, or gained, that year to or from Unvegetated Open Water Coastal Wetlands.
- For Land converted to Vegetated Coastal Wetland
  - DOM removals are calculated by multiplying the area gained that year by the difference between Tier 1 DOM C stocks for Vegetated Coastal Wetlands and Forest Land. This is the area change by the change in DOM C stocks.

Other Assumptions

No DOM calculations are undertaken for Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands since this stock is considered to be in a steady state when using Tier 1 methods (Wetlands supplement).

N_2O Emissions from Aquaculture in Coastal Wetlands

Activity data

N_2O Emissions from Aquaculture in Coastal Wetlands result from the N derived from consumption of the applied food stock that is then excreted as N load available for conversion to N_2O. While N_2O emissions can also occur due to anthropogenic N loading from the watershed and atmospheric deposition, these emissions are not reported here to avoid double-counting of indirect N2O emissions with the Agricultural Soils Management, Forest Land and Settlements categories in the inventory

Activity data for this analysis is derived from NOAA Fisheries annual report- Fisheries of the United States (U.S. recreational catch and commercial fisheries landings and values.) Data are reported on U.S. aquaculture production, the U.S. seafood processing industry, imports and exports of fish-related products, and domestic supply and per capita consumption of fisheries products. The mass of production for catfish, striped bass, tilapia, trout, crawfish, salmon and shrimp are reported. Some of these fisheries are produced on land and some in open water cages within coastal wetlands.

All have data on the quantity of food stock produced, and this is the activity data that is applied.

While some aquaculture occurs on coastal lowland floodplains, the USA considers this a likely minor component of tidal aquaculture production because of the need for a regular source of water for pond flushing.

Other open water shellfisheries for which no food stock is provided, and thus no additional N inputs, are not applicable for estimating N_2O emissions (e.g., clams, mussels, and oysters) and have not been included in the analysis.

The estimation of N_2O emissions from aquaculture is not sensitive to salinity using IPCC approaches, and as such, the location of aquaculture ponds within the boundaries of coastal wetlands does not influence the calculations.

Emission Factors

Emissions factors come from the IPCC Tier 1 default emission factor of 0.00169 kg N_2O-N per kg of fish/shellfish produced (Wetlands Supplement).

Methodology to Estimate Emissions

The methodology to estimate N_2O emissions from aquaculture in coastal wetlands follows the Tier 1 guidance in the Wetlands Supplement by applying the IPCC Tier 1 default emission factor to the country-specific fisheries production data.

Uncertainty

Approach

For the inventory, uncertainty analyses are conducted for each source and sink category as well as for the uncertainties associated with the overall emission (current and base year) and trends estimates. These analyses reflect the quantitative uncertainty in the emission (and removal) estimates associated with uncertainties in their input parameters (e.g., activity data and EFs) and serve to evaluate the relative contribution of individual input parameter uncertainties to the overall inventory, its trends, and each source and sink category.

The overall level and trend uncertainty estimates for total U.S. GHG emissions was developed using the IPCC Approach 2 uncertainty estimation methodology (assuming a Normal distribution for Approach 1 estimates), which employs a Monte Carlo stochastic simulation technique. The IPCC provides good practice guidance on two approaches—Approach 1 and Approach 2—to estimating uncertainty for both individual and combined source categories. Approach 2 quantifies uncertainties based on a distribution of emissions (or removals), built-up from repeated calculations of emission estimation models and the underlying input parameters, randomly selected according to their known distributions. Approach 2 methodology is applied to each individual source and sink category wherever data and resources are permitted and is also used to quantify the uncertainty in the overall inventory and its

Trends. For Coastal Wetlands remaining Coastal wetlands Approach 1 Quantitative Uncertainty Estimates were undertaken.

The overall uncertainty surrounding the Total Net Emissions is estimated to be -6 to +6 percent in 1990 and -5 to +6 percent in 2022. When the LULUCF sector is excluded from the analysis the uncertainty is estimated to be -3 to +4 percent in 1990 and -2 to +4 percent in 2022.

Consistent with IPCC (IPCC 2006), the United States has ongoing efforts to continue to improve the overall inventory uncertainty estimates.

What Uncertainties Apply?

A range of uncertainties have been applied to the USA coastal wetland reporting.

- Uncertainties across all of the wetland categories:
  - uncertainties associated with Tier 2 literature values of soil C stocks, biomass C stocks, DOM
  - assumptions that underlie the methodological approaches applied
  - uncertainties linked to interpretation of remote sensing data
  - differentiation of palustrine and estuarine community classes, which determines the soil C stock and CH_4 flux applied
  - uncertainty for root to shoot ratios
- Other uncertainties apply to some categories of wetland and not others:
  - For Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands and Land converted to Vegetated Coastal Wetlands
    - Uncertainties for CH_4 flux, and significant uncertainty in salinity ranges for tidal and non-tidal estuarine wetlands and activity data used to apply CH_4 flux emission factors (delineation of an 18 ppt boundary) that will need significant improvement to reduce uncertainties
    - Uncertainties for CH_4 flux assumptions
  - For Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands
    - Uncertainties for soil and biomass C stock data for all subcategories.
  - For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands,
    - Depth of soil erosion

- For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands, and Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands
  - uncertainties with Tier 1 estimates of subtropical estuarine forested wetland DOM stocks
- For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands, and Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands
- For aboveground biomass C stocks, the mean standard error was very low and largely influenced by the uncertainty associated with the estimated map area (Byrd et al. 2018).
- For N_2O Emissions from Aquaculture in Coastal Wetlands
  - uncertainties with Tier 1 estimates for N_2O emissions
  - NOAA Fisheries of the United States fisheries production data

How have uncertainties been calculated?

In the inventory uncertainties have been calculated in a variety of methods as outlined below.

- Uncertainties across all the wetland categories:
  - uncertainties associated with Tier 2 literature values of soil C stocks, biomass C stocks, DOM, and CH_4
  - assumptions that underline the methodological approaches applied
  - uncertainties linked to interpretation of remote sensing data- Overall uncertainty of the NOAA C-CAP remote sensing product is 15 percent- in the range of remote sensing methods (±10 to 15 percent; IPCC 2003).
  - differentiation of palustrine and estuarine community classes, which determines the soil C stock and CH_4 flux applied
  - uncertainty about root to shoot ratios are derived from the 2013 Wetlands Supplement
- Other uncertainties apply to some categories of wetland and not others:
  - For Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands and Land converted to Vegetated Coastal Wetlands
    - Uncertainties for CH_4 flux assumptions are the Tier 1 default values reported in the *Wetlands Supplement*

- For Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands

  - Uncertainties for soil and biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment of a C stock to a disaggregation of a community class.

- For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands

  - Depth of soil erosion- The IPCC default assumption (consistent with estimates of wetland C loss provided in the Wetlands Supplement and literature) of 1 m of soil erosion with anthropogenic activities was adopted to provide standardization in U.S. tidal C accounting (Holmquist et al. 2018).

- For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands, and Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands

  - Uncertainty for subtropical estuarine forested wetland DOM stocks were derived from those listed for the Tier 1 estimates

- For Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands, Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands and Land converted to Vegetated Coastal Wetlands

  - For aboveground biomass C stocks, the mean standard error was very low and largely influenced by the uncertainty associated with the estimated map area (Byrd et al. 2018).
  - Because mean soil and biomass C stocks for each available community class are in a fairly narrow range, the same overall uncertainty was assigned to each, respectively (i.e., applying approach for asymmetrical errors, the largest uncertainty for any soil C stock value should be applied in the calculation of error propagation; IPCC 2000).

- For N_2O Emissions from Aquaculture in Coastal Wetlands

  - Tier 1 default 95 percent confidence interval provided in Table 4.15, chapter 4 of the Wetlands Supplement for N_2O emissions
  - expert judgment of the NOAA Fisheries of the United States fisheries production data

Note: The inventory notes that given the overestimate of fisheries production from coastal wetland areas due to the inclusion of fish production in non-coastal wetland areas, this is a reasonable initial first approximation for an uncertainty range.

- Combined uncertainty for each wetland category

- calculated using the IPCC Approach 1 method of summing the squared uncertainty for each individual source (i.e. C-CAP, soil, DOM, biomass and CH_4) in each wetland category and taking the square root of that total.

Quality Assurance and Quality Control and Verification

The United States has developed a quality assurance (QA) and quality control (QC) plan designed to check, document, and improve the quality of its inventory over time. QA/QC activities on the inventory are undertaken within the framework of the U.S. *Quality Assurance/Quality Control and Uncertainty Management Plan* (QA/QC plan) *for the U.S. Greenhouse Gas Inventory: Procedures Manual for QA/QC and Uncertainty Analysis*. Key attributes are included within the inventory.

QC—in the form of both good practices (such as documentation procedures) and checks on whether good practices and procedures are being followed—is applied at every stage of inventory development and document preparation.

QA occurs in 3 stages of review

- Expert Review: During the first stage of review, i.e., the 30-day expert review period, a first draft of updated sectoral chapters are sent to technical experts who are not directly involved in preparing estimates
- Public Review: Following expert review, a second draft of the document, including cross-cutting synthesis chapters, is released for a 30-day public review through a notice in the U.S. Federal Register. The entire draft inventory document is published on the EPA website. The public review period is open to the entire U.S. public. This is also essential for promoting the openness of the inventory development process and the transparency of the inventory methods and underlying input data sources
- UNFCCC Technical Review: Following completion and submission of the inventory under the UNFCCC and the Paris Agreement, the inventory also undergoes review by an international team of independent experts for adherence to UNFCCC/Paris reporting guidelines and consistency with IPCC methodological guidance

For each GHG emissions source or sink category included in this inventory, a minimum of general or Tier 1 QC analysis has been undertaken. Where QC activities for a particular category go beyond the minimum general checks and include category-specific checks (Tier 2) or include verification, further explanation is provided within the respective source or sink category text. EPA publishes responses to comments received during both expert and public reviews with the publication of the final inventory on its website. Feedback from all review processes that contribute to improving inventory quality over time is also addressed within each planned improvement section.

Specific QA/QC and Verification steps in relation to Coastal Wetlands remaining Coastal wetlands include:

- Activity data
  - The C-CAP programme is subject to agency internal QA/QC assessment consistent with the general QC checks outlined in the inventory QA/QC Plan. Acceptance of final datasets is contingent upon the product compilation being compliant with mandatory QA/QC requirements
  - As another QC step, a check was undertaken confirming that coastal wetlands recognized by C-CAP represent a subset of wetlands recognized by the NRI for marine coastal states
- Soil carbon stock datasets
  - the Smithsonian Environmental Research Center and coastal wetland inventory team leads reviewed summary tables against reviewed sources
- Biomass carbon stocks
  - are derived from peer-review literature,
  - reviewed by the U.S. Geological Survey prior to publishing,
  - reviewed by the peer-review process during publishing, and
  - reviewed by the coastal wetland inventory team leads before inclusion in the inventory.
- A team of two evaluated and verified there were no computational errors within the calculation worksheets.

Unvegetated open water coastal wetlands to vegetated coastal wetlands & vegetated coastal wetlands to unvegetated open water coastal wetlands

- Land cover estimates
  - were assessed to ensure that the total land area did not change over the time series in which the inventory was developed, and
  - were verified by a second QA team.

Vegetated coastal wetlands to unvegetated open water coastal wetlands

- For subtropical estuarine forested wetlands
  - Tier 1 estimates of mangrove DOM were used (Wetlands Supplement).

Unvegetated open water coastal wetlands to vegetated coastal wetlands

- Root to shoot ratios and DOM data
  - are derived from peer-reviewed literature
  - undergo review as per IPCC methodology.
- Two biogeochemists at the USGS, also members of the NASA Carbon Monitoring System Science Team, corroborated the simplifying assumption that where salinities are unchanged CH_4 emissions are constant with conversion of unvegetated open water coastal wetlands to vegetated coastal wetlands.

Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands & Land to Vegetated Coastal Wetlands

- Soil and biomass carbon stock change data
  - are based upon peer-reviewed literature
- CH_4 emission factors
  - derived from the Wetlands Supplement

N_2O Emissions from Aquaculture in Coastal Wetlands

- NOAA provided internal QA/QC review of reported fisheries data. The coastal wetlands inventory team consulted with the coordinating lead authors of the coastal wetlands chapter of the Wetlands Supplement to assess which fisheries production data to include in estimating emissions from aquaculture. It was concluded that N_2O emissions estimates should be applied to any fish production to which food supplement is supplied be they pond or coastal open water and that salinity conditions were not a determining factor in production of N_2O emissions.

USA Identified Improvements

Each year, several emission and sink estimates in the inventory are recalculated and revised, through the use of better methods and/or data with the goal of improving inventory quality and reducing uncertainties, including the transparency, completeness, consistency, and overall usefulness of the inventory. In this effort, the United States follows the 2006 IPCC Guidelines (IPCC 2006) and its 2019 Refinement, which state, “Both methodological changes and refinements over time are an essential part of improving inventory quality. It is good practice to change or refine methods when available data have changed; the previously used method is not consistent with the IPCC guidelines for that category; a category has become key; the previously used method is insufficient to reflect mitigation activities in a transparent manner; the capacity for inventory preparation has increased; improved inventory methods become available; and/or for correction of errors." The EPA's Office of Atmospheric Programs coordinates improvement planning across all sectors and also cross-cutting analyses based on annual review and input from the technical teams leading compilation of each sector's estimates, including continuous improvements to the overall data and document compilation and QA/QC processes. Planned improvements are identified through QA/QC processes (including completeness checks), the key category analysis, and the uncertainty analysis. The inventory coordinator, with input from EPA source and sink category leads, maintains a log of all planned improvements, by sector and cross-cutting, tracking the category significance, specific category improvement, prioritisation, anticipated time frame for implementation of each proposed improvement, and status of progress in implementing improvement. Improvements for significant or key categories are usually prioritised across all improvements unless effort would require disproportionate levels of effort and resources relative to improvements for other key categories to address.

The USA has identified a range of planned improvements to the inventory. These include:

- General Activity Data Improvements
    - The C-CAP product is not used directly in the land representation analysis that is undertaken to assess emissions from other land uses. A planned improvement for future Inventories is to reconcile the coastal wetlands data from the C-CAP product with the wetlands area data provided in the other databases used in the inventory.
    - NOAA is currently working to phase in the next generation of high-resolution land cover, which is being produced through advanced deep learning artificial intelligence combined with expert-based analysis, review, and editing. This will be more useful at the local level in ways not previously possible with national-level data. These will aim to be at new 1-meter pixel products (Personal communication, Silvestrum Climate Associates, 2024)
    - As noted above the current inventory does not include a classification of managed and unmanaged wetlands, except for remote areas in Alaska. Consequently, there is a planned improvement to classify managed and unmanaged wetlands for the conterminous United States and Hawaii, and more detailed wetlands datasets will be evaluated and integrated into the analysis to meet this objective.
    - Although most of the managed land in the United States is included in the current land use data for the conterminous United States, Alaska, and Hawaii, a planned improvement is to fully incorporate area data by land use type for U.S. Territories

  - Other general improvements to the accuracy of activity data as occurs at a regular basis (Personal communication, Silvestrum Climate Associates, 2024). Particularly as the biggest uncertainty for the USA is the inventory is methane emissions due to difficulties in assessing salinity conditions between palustrine and estuarine wetlands when developing activity data.

- Impounded Water
  - Investigation into quantifying the distribution, area, and emissions resulting from impounded waters (i.e., coastal wetlands where tidal connection to the ocean has been restricted or eliminated completely) is underway.
  - Many coastal wetlands in the USA are noted as being in bad condition with flow and hydrological functions restricted by transport or other built infrastructure i.e. causeways and roads. This impoundment in coastal areas can cause low salinity environments to occur, leading to significant methane sources. These wetlands are still considered tidal but GHG behaviour is very different to what it would be in a more natural condition. As noted above, C-CAP maps do not define salinity very well and mostly it cannot be accurately determined if methanogenesis is occurring or not. US Geological Survey, 2024 noted that the USA recently undertook ground truthing of coastal wetlands areas to assess the accuracy of maps and found the inventory only captures around 50% of impounded wetlands. The USA notes they need to address this by accurately measuring natural methane emissions plus those enhanced through impoundment by better activity data. Removing these impoundments and restoring natural function of these wetlands can provide a big opportunity to reduce methane emissions and build soil carbon (Personal communication, US Geological Survey, 2024).

- Seagrass
  - The inventory includes both mangroves and tidal marsh but not seagrasses due to insufficient data on distribution, change through time and carbon stocks or carbon stock changes as a result of anthropogenic influence. Work is currently underway to examine the feasibility of incorporating seagrass soil and biomass carbon stocks.

- Extractions
  - Soil depth accuracy
    - The depth of soil C affected by conversion of Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands will be updated from the IPCC default assumption of 1 m of soil erosion when mapping and modelling advancements can

quantitatively improve accuracy and precision. Improvements are underway to address this, first conducting a review of literature publications. Until the time where these more detailed and spatially distributed data are available, the IPCC default assumption that the top 1 m of soil is disturbed by anthropogenic activity will be applied. This is a longer-term improvement.

- Remobilized coastal wetland soil C
  - An approach for calculating the fraction of remobilized coastal wetland soil C returned to the atmosphere as CO_2 during conversion of Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands is currently under review and may be included in future inventories.
  - Currently, the only coastal wetland conversion that is reported in the inventory is Lands Converted to Vegetated Coastal Wetlands. The next submission is expected to include C stock change data for Lands Converted to Unvegetated Open Water Coastal Wetlands.
- Improve the quantification of conversation to open water
  - More detailed research is in development that provides a longer-term assessment and more highly refined rates of wetlands loss across the Mississippi Delta (e.g., Couvillion et al. 2016). The Mississippi Delta is the largest extent of coastal wetlands in the United States. Higher resolution imagery analysis would improve quantification of conversation to open water, which occurs not only at the edge of the marsh but also within the interior. Improved mapping could provide a more refined regional Approach 2-3 land representation to support the national-scale assessment provided by C-CAP.

- Other
  - Lateral Flux
    - The USA have an ambition to include lateral carbon flux (the tidal exchange of dissolved carbon exported to estuary and coastal ocean, that may store in ocean for a while) in the inventory in the future (Personal communication, US Geological Survey, 2024). Lateral transfer of organic carbon to coastal wetlands and to marine sediments within U.S. waters is the subject of ongoing scientific investigation. There is currently no IPCC methodological guidance for lateral fluxes of carbon.
  - Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands & Land to Vegetated Coastal Wetlands
    - The USGS is investigating higher resolution mapping approaches to quantify conversion of coastal wetlands. Such approaches may

form the basis for a full Approach 3 land representation assessment in future years.

- Other activities considered important, but not yet included, are CH_4 emissions from forestry activities on tidally influenced forests

Deviations from IPCC Guidance

There are number of matters that are specific to the USA and that deviate from IPCC guidance. These are explained throughout the different sections above but summarised below.

- As per guidance provided by the Wetlands Supplement, sequestration of C into biomass, DOM and soil C pools is recognized only in Vegetated Coastal Wetlands and does not occur in Unvegetated Open Water Coastal Wetlands. The United States takes the additional step of recognizing that C stock losses occur when Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands.
- In the USA, wetlands are not differentiated between managed and unmanaged as it is too difficult due to limited data availability, because of anthropogenic influence and level of regulatory oversight, thus all are considered managed and included.

Where the USA has used Tier 1 and Tier 2 approaches is outlined in the below table copied from the CRF table 3s2

Summary Report for Methods and Emission Factors Used (Sumarry3s2)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
3. Agriculture	T1,T2	CS,D	M,OTH,T1,T2	CS,D,M,OTH	M,OTH,T1,T2	CS,D,M,OTH
A. Enteric fermentation			M,T1,T2	CS,D,M		
B. Manure management			M,T1,T2	CS,D,M	M,T1,T2	CS,D,M
C. Rice cultivation			OTH	OTH		
D. Agricultural soils(3)					OTH,T1	D,OTH
E. Prescribed burning of savannas						
F. Field burning of agricultural residues			OTH	OTH	OTH	OTH
G. Liming	T2	CS				
H. Urea application	T1	D				
I. Other carbon-containing fertilizers						
J. Other						
4. Land use, land-use change and forestry	CS,OTH,T1,T2,T3	CS,D,OTH	OTH,T1,T2	D,OTH	OTH,T1,T2	D,OTH
A. Forest land	T2,T3	CS	T2	D	T1,T2	D
B. Cropland	OTH,T2	CS,OTH				
C. Grassland	OTH,T2	CS,OTH	OTH	OTH	OTH	OTH
D. Wetlands	T1,T2	CS,D	T1	D	T1	D
E. Settlements	CS,OTH,T2,T3	CS,OTH			T1,T2	D
F. Other land						
G. Harvested wood products	T3	CS				
H. Other					OTH	OTH
5. Waste			CS,D,T1,T2	CS,D	CS,D,T1,T2	CS,D
A. Solid waste disposal			CS	CS		
B. Biological treatment of solid waste			D,T1	D	T1	D
C. Incineration and open burning of waste						
D. Waste water treatment and discharge			CS,D,T2	CS,D	CS,D,T2	CS,D
E. Other						
6. Other *(as specified in summary 1.A)*						

Key: T1 (IPCC Tier 1), T2 (IPCC Tier 2), D (IPCC Default), CS (Country Specific)

Key Categories

The 2006 IPCC Guidelines (IPCC 2006) and 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) define key categories as “inventory categories which individually, or as a group of categories (for which a common method, emission factor and activity data are applied) are prioritised within the national inventory system because their estimates have a significant influence on a country’s total inventory of GHG in terms of the absolute level, the trend, or the level of uncertainty in emissions or removals. Whenever the term key category is used, it includes both source and sink categories.’ A key category analysis identifies source or sink categories for focusing efforts to improve overall inventory quality, including additional review when feasible.

Coastal wetlands are not a key category in any of the approaches used to conduct a key category analysis and identify key categories by the USA in this inventory. The disaggregation of categories presented in CRF Table 7 and annex of the inventory vary but the results of the key category analysis are consistent.

Neither Net CO_2 Emissions from Coastal Wetlands Remaining Coastal Wetlands, CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands, N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands, and CH_4 Emissions from Land Converted to Coastal Wetlands are identified as key categories.

Although Net CO_2 Emissions from Land Converted to Coastal Wetlands are not mentioned in the annex

UNFCC Review

The United Nations Framework Convention on Climate Change, 2024 completed a 'Report on the individual review of the inventory submission of the United States of America submitted in 2022'. This presents the results of the individual review of the 2022 inventory submission of the USA inventory, by an expert review team in accordance with the "Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual GHG inventories".

This report was assessed to see if any issues of note regarding coastal wetlands were raised by the review team. Nothing of note was raised around coastal wetlands. For general reporting matters, again no major issues of relevance for this inventory, i.e. C-CAP mapping, were raised.

Other notable Gaps in Data and Limitations

Land converting back from open water to vegetated wetland is not assessed for methane emission. However, this type of wetland may eventually become palustrine and produce methane.

Forested wetland under C-CAP is defined as having greater than or equal to 5m in height. However, the USA says in the inventory that -Mangroves that are 5 m or greater (or if there is evidence that trees can obtain that height,) are reported under the Forest Land category so are excluded from Coastal Wetlands coverage. Therefore, it is unclear whether estuarine or palustrine wetland will be counted as forested wetlands and therefore not included in coastal wetland reporting.

The NGGI also assumed that 100% of the carbon released by conversion from coastal wetlands to open water is lost to the atmosphere. However (Lovelock *et al* 2017) reviewed available studies and estimated 25%–50% of terrestrial carbon delivered to the marine environment was buried in ocean sediments (Baldock *et al* 2004, Cai 2011, Blair and Aller 2012).

References and bibliography

Abbott, K. M., Elsey-Quirk, T., and DeLaune, R. D. (2019) Factors influencing blue carbon accumulation across a 32-year chronosequence of created coastal marshes. Ecosphere, 10(8): e02828.

Allen, J. R., Cornwell, J. C., and Baldwin, A. H. (2021) Contributions of organic and mineral matter to vertical accretion in tidal wetlands across a Chesapeake Bay subestuary. Journal of Marine Science and Engineering 9(7): 751.

Arias-Ortiz, A., Oikawa, P. Y., Carlin, J., Masqué, P., Shahan, J., Kanneg, S., ... and Baldocchi, D. D. (2021) Tidal and nontidal marsh restoration: a trade-off between carbon sequestration, methane emissions, and soil accretion. Journal of Geophysical Research: Biogeosciences, 126(12): e2021JG006573.

Arriola, J. M., and Cable, J. E. (2017) Variations in carbon burial and sediment accretion along a tidal creek in a Florida salt marsh. Limnology and Oceanography 62(S1): S15-S28

Baustian, M. M., Stagg, C. L., Perry, C. L., Moss, L. C., and Carruthers, T. J. (2021) Long-term carbon sinks in marsh soils of coastal Louisiana are at risk to wetland loss. Journal of Geophysical Research: Biogeosciences 126(3): e2020JG005832.

Bianchi, T. S., Allison, M. A., Zhao, J., Li, X., Comeaux, R. S., Feagin, R. A., & Kulawardhana, R. W. (2013) Historical reconstruction of mangrove expansion in the Gulf of Mexico: linking climate change with carbon sequestration in coastal wetlands. Estuarine, Coastal and Shelf Science 119: 7-16.

Boyd, B. (2012) Comparison of sediment accumulation and accretion in impounded and unimpounded marshes of the Delaware Estuary. Doctoral dissertation, University of Delaware.

Boyd, B. M. and Sommerfield, C. K. (2016) Marsh accretion and sediment accumulation in a managed tidal wetland complex of Delaware Bay. Ecological Engineering, 92: 37-46.

Boyd, B. M., Sommerfield, C. K., and Elsey-Quirk, T. (2017) Hydrogeomorphic influences on salt marsh sediment accumulation and accretion in two estuaries of the US Mid-Atlantic coast. Marine Geology, 383: 132-145.

Breithaupt, J. L., Smoak, J. M., Smith III, T. J., and Sanders, C. J. (2014) Temporal variability of carbon and nutrient burial, sediment accretion, and mass accumulation over the past century in a carbonate platform mangrove forest of the Florida Everglades. Journal of Geophysical Research: Biogeosciences, 119(10): 2032-2048.

Byrd, K. B., Ballanti, L. R., Thomas, N. M., Nguyen, D. K., Holmquist, J. R., Simard, M., Windham-Myers, L., Schile, L. M., Parker, V. T., … and Castaneda-Moya, E. (2017) Biomass/Remote Sensing dataset: 30m resolution tidal marsh biomass samples and remote sensing data for six regions in the conterminous United States: U.S. Geological Survey data release, https://doi.org/10.5066/F77943K8.

Byrd, K. B., Ballanti, L., Thomas, N., Nguyen, D., Holmquist, J.R., Simard, M., and Windham-Myers, L. (2018) A remote sensing-based model of tidal marsh aboveground carbon stocks for the conterminous United States. ISPRS Journal of Photogrammetry and Remote Sensing 139: 255-271.

Byrd, K. B., Ballanti, L., Thomas, N., Nguyen, D., Holmquist, J.R., Simard, M., and Windham-Myers, L. (2020) Corrigendum to “A remote sensing-based model of tidal marsh aboveground carbon stocks for the conterminous United States”. ISPRS Journal of Photogrammetry and Remote Sensing 166: 63-67.

Callaway, J. C., Borgnis, E. L., Turner, R. E. & Milan, C. S. (2012a) Carbon sequestration and sediment accretion in San Francisco Bay tidal wetlands. Estuaries and Coasts 35(5): 1163-1181.

Callaway, J. C., Borgnis, E. L., Turner, R. E., Milan, C. S., Goodfriend, W., & Richmond, S. (2012b) "Wetland Sediment Accumulation at Corte Madera Marsh and Muzzi Marsh". San Francisco Bay Conservation and Development Commission.

Church, T. M., Sommerfield, C. K., Velinsky, D. J., Point, D., Benoit, C., Amouroux, D. & Donard, O. F. X. (2006) Marsh sediments as records of sedimentation, eutrophication and metal pollution in the urban Delaware Estuary. Marine Chemistry 102(1-2): 72-95

Couvillion, B. R., Fischer, M. R., Beck, H. J. and Sleavin, W. J. (2016) Spatial Configuration Trends in Coastal Louisiana from 1986 to 2010. Wetlands 1-13.

Craft, C. B., & Richardson, C. J. (1998) Recent and long-term organic soil accretion and nutrient accumulation in the Everglades. Soil Science Society of America Journal 62(3): 834-843.

Crooks, S., Rybczyk, J., O’Connell, K., Devier, D. L., Poppe, K., Emmett-Mattox, S. (2014) Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary: The Climate Benefits of Estuary Restoration. Report by Environmental Science Associates, Western Washington University, EarthCorps, and Restore America’s Estuaries.

Drexler, J. Z., de Fontaine, C. S., and Brown, T. A. (2009) Peat accretion histories during the past 6,000 years in marshes of the Sacramento–San Joaquin Delta, CA, USA. Estuaries and Coasts 32: 871-892.

Drexler, J. Z., Krauss, K. W., Sasser, M. C., Fuller, C. C., Swarzenski, C. M., Powell, A., ... and Orlando, J. (2013) A long-term comparison of carbon sequestration rates in impounded and naturally tidal freshwater marshes along the lower Waccamaw River, South Carolina. Wetlands 33: 965-974.

Drexler, J. Z., Woo, I., Fuller, C. C., and Nakai, G. (2019) Carbon accumulation and vertical accretion in a restored versus historic salt marsh in southern Puget Sound, Washington, United States. Restoration Ecology 27(5): 1117-1127.

Ensign, S. H., Noe, G. B., Hupp, C. R., and Skalak, K. J. (2015) Head-of-tide bottleneck of particulate material transport from watersheds to estuaries. Geophysical Research Letters 42(24): 10-671.

EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022.

Gerlach, M. J., Engelhart, S. E., Kemp, A. C., Moyer, R. P., Smoak, J. M., Bernhardt, C. E., and Cahill, N. (2017) Reconstructing Common Era relative sea-level change on the Gulf Coast of Florida. Marine Geology 390: 254-269.

Giblin, A., Forbrich, I., & LTER, P. I. E. (2018) PIE LTER high marsh sediment chemistry and activity measurements, Nelson Island Creek marsh, Rowley, MA.

Green. C, Lovelock C.E, Sasmito. S, Hagger. V, Crooks. S. 2021. Coastal Wetlands in National Greenhouse Gas Inventories Advice on reporting emissions and removal from management of Blue Carbon ecosystems. Coastal-Wetlands-in-National-Greenhouse-Gas-Inventories.pdf (bluecarbonpartnership.org)

Holmquist, J. R., Windham-Myers, L., Bliss, N., Crooks, S., Morris, J. T., Megonigal, J. P. & Woodrey, M. (2018) Accuracy and Precision of Tidal Wetland Soil Carbon Mapping in the Conterminous United States. Scientific reports 8(1): 9478.

Hussein, A. H., Rabenhorst, M. C. & Tucker, M. L. (2004) Modeling of carbon sequestration in coastal marsh soils. Soil Science Society of America Journal 68(5): 1786-1795.

IPCC (2000) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Quantifying Uncertainties in Practice, Chapter 6. Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. and Tanabe, K. (eds). Institute of Global Environmental Strategies (IGES), on behalf of the Intergovernmental Panel on Climate Change (IPCC): Hayama, Japan.

IPCC (2003) *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. LUCF Sector Good Practice Guidance, Chapter 3. Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. and Wagner, F. (eds). Institute of Global Environmental Strategies (IGES), on behalf of the Intergovernmental Panel on Climate Change (IPCC): Hayama, Japan.

IPCC (2006) *IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan.

IPCC (2014) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds.). Published: IPCC, Switzerland.

IPCC (2019) *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4: Agriculture, Forestry, and Other Land Use. Calvo Buendia, E., Tanabe K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P., & Federici, S. (eds). IPCC, Switzerland.

Kearney, M. S. & Stevenson, J. C. (1991) Island land loss and marsh vertical accretion rate evidence for historical sea-level changes in Chesapeake Bay. Journal of Coastal Research 7(2): 403-415.

Kemp, A. C., Sommerfield, C. K., Vane, C. H., Horton, B. P., Chenery, S., Anisfeld, S., and Nikitina, D. (2012) Use of lead isotopes for developing chronologies in recent salt-marsh sediments. Quaternary Geochronology 12: 40-49.

Köster, D., Lichter, J., Lea, P. D., & Nurse, A. (2007) Historical eutrophication in a river–estuary complex in mid-coast Maine. Ecological Applications 17(3): 765-778.

Krauss, K. W., Noe, G. B., Duberstein, J. A., Conner, W. H., Stagg, C. L., and Jones, M. C. (2018) Carbon budget assessment of tidal freshwater forested wetland and oligohaline marsh ecosystems along the Waccamaw and Savannah Rivers, USA (2005–2016). US Geological Survey Data Release. https://doi.Org/10.5066/F7TM7930.

Lagomasino, D., Corbett, D. R., and Walsh, J. P. (2013) Influence of wind-driven inundation and coastal geomorphology on sedimentation in two microtidal marshes, Pamlico River Estuary, NC. Estuaries and Coasts 36: 1165-1180.

Lu, M & Megonigal, J. P. (2017) Final Report for RAE Baseline Assessment Project. Memo to Silvestrum Climate Associates by Smithsonian Environmental Research Center, Maryland.

Luk, S. Y., Todd-Brown, K., Eagle, M., McNichol, A. P., Sanderman, J., Gosselin, K., and Spivak, A. C. (2021) Soil organic carbon development and turnover in natural and disturbed salt marsh environments. Geophysical Research Letters 48(2): e2020GL090287.

Lynch, J. C. (1989) Sedimentation and nutrient accumulation in mangrove ecosystems of the Gulf of Mexico. M.S. thesis, Univ. of Southwestern Louisiana, Lafayette, LA.

Marchio, D. A., Savarese, M., Bovard, B., & Mitsch, W. J. (2016) Carbon sequestration and sedimentation in mangrove swamps influenced by hydrogeomorphic conditions and urbanization in Southwest Florida. Forests 7: 116-135.

McTigue, N., Davis, J., Rodriguez, A. B., McKee, B., Atencio, A., and Currin, C. (2019) Sea level rise explains changing carbon accumulation rates in a salt marsh over the past two millennia. JGR Biogeosciences.

Merrill, J. Z. (1999) Tidal Freshwater Marshes as Nutrient Sinks: particulate Nutrient Burial and Denitrification. Ph.D. Dissertation, University of Maryland, College Park, MD, 342 pp

Miller, C. B., Rodriguez, A. B., Bost, M. C., McKee, B. A., and McTigue, N. D. (2022) Carbon accumulation rates are highest at young and expanding salt marsh edges. Communications Earth & Environment 3(1): 173

NOAA (n.d.a) Coastal Change Analysis Program (C-CAP Landcover Atlas. National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management. Data accessed at; CCAP Atlas (noaa.gov)

NOAA (n.d.b) Coastal Change Analysis Program (C-CAP) C-CAP High-Resolution Land Cover. Data collected 1995-present. National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management. Data accessed at: C-CAP High-Resolution Land Cover (noaa.gov)

NOAA Fisheries annual report (multiple years) - Fisheries of the United States (U.S. recreational catch and commercial fisheries landings and values.) https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-reports#:~:text=According%20to%20the%20Fisheries%20of,200%20million%20trips%20in%202022.

Noe, G. B., Hupp, C. R., Bernhardt, C. E., & Krauss, K. W. (2016) Contemporary deposition and long-term accumulation of sediment and nutrients by tidal freshwater forested wetlands impacted by sea level rise. Estuaries and Coasts 39(4): 1006-1019.

Ocean Conservation Trust 92024). Blue Carbon: The Ocean's hidden carbon solution?. Data accessed at: https://oceanconservationtrust.org/blue-carbon-the-oceans-hidden-carbon-solution/. [Accessed on 01/04/2025]

Orson, R. A., Simpson, R. L., & Good, R. E. (1990) Rates of sediment accumulation in a tidal freshwater marsh. Journal of Sedimentary Research 60(6): 859-869

Orson, R., Warren, R. & Niering, W. (1998) Interpreting sea level rise and rates of vertical marsh accretion in a southern New England tidal salt marsh. Estuarine, Coastal and Shelf Science 47(4): 419-429.

Peck, E. K., Wheatcroft, R. A., and Brophy, L. S. (2020) Controls on sediment accretion and blue carbon burial in tidal saline wetlands: insights from the Oregon Coast, USA. Journal of Geophysical Research: Biogeosciences 125(2): e2019JG005464.

Poffenbarger et al. 2011

Poppe, K. L., and Rybczyk, J. M. (2021) Tidal marsh restoration enhances sediment accretion and carbon accumulation in the Stillaguamish River estuary, Washington. PloS one 16(9): e0257244.

Roman, C., Peck, J., Allen, J., King, J. & Appleby, P. (1997) Accretion of a New England (USA) salt marsh in response to inlet migration, storms, and sea-level rise. Estuarine, Coastal and Shelf Science 45(6): 717-727.

Smith, K. E., Flocks, J. G., Steyer, G. D., and Piazza, S. C. (2015) Wetland Paleoecological Study of Southwest Coastal Louisiana: Sediment Cores and Diatom Calibration Dataset. US Department of the Interior, US Geological Survey.

Thom, R. M. (1992) Accretion rates of low intertidal salt marshes in the Pacific Northwest. Wetlands 12: 147-156.

United Nations Framework Convention on Climate Change (2024) Report on the individual review of the inventory submission of the United States of America submitted in 2022. United Nations Framework Convention on Climate Change

Vaughn, D. R., Bianchi, T. S., Shields, M. R., Kenney, W. F., and Osborne, T. Z. (2020) Increased organic carbon burial in northern Florida mangrove-salt marsh transition zones. Global Biogeochemical Cycles 34(5): e2019GB006334

Villa, J. A. & Mitsch W. J. (2015) Carbon sequestration in different wetland plant communities of Southwest Florida. International Journal for Biodiversity Science, Ecosystems Services and Management 11: 17-28

Watson, E. B., and Byrne, R. (2013) Late Holocene Marsh Expansion in Southern San Francisco Bay, California. Estuaries and Coasts 36: 643-653.

Weis, D. A., Callaway, J. C., and Gersberg, R. M. (2001) Vertical accretion rates and heavy metal chronologies in wetland sediments of the Tijuana Estuary. Estuaries 24: 840-850.

Weston, N. B., Neubauer, S. C., Velinsky, D. J., & Vile, M. A. (2014) Net ecosystem carbon exchange and the greenhouse gas balance of tidal marshes along an estuarine salinity gradient. Biogeochemistry 120: 163-189.

Weston, N. B., Rodriguez, E., Donnelly, B., Solohin, E., Jezycki, K., Demberger, S., ... and Craft, C. B. (2023) Recent acceleration of wetland accretion and carbon accumulation along the US East Coast. Earth's Future 11(3): e2022EF003037.

Personal Communications

Discussions were held with:

- Environmental Geoscience Group Member, US Geological Survey;
- Ag/LULUCF lead, Environmental Protection Agency (EPA);
- Two members of Silvestrum Climate Associates - This company compiles the estimates for the inventory.

Annex D: Sub-task 1.5C supplementary information

Sensitivity analysis for coastal wetlands reporting

Following the Better Regulation Guidelines and Toolbox, particularly 'Chapter 8 – Methodologies for analysing impacts in impact assessments, evaluations, and fitness checks,' a sensitivity analysis of the effects of the applied discount factor was conducted. This analysis included alternative calculations with sufficiently higher and lower values (up to +/- 1% at least).

This appendix presents the net present value of Blue Carbon reporting cost estimates at higher and lower social discount rates, specifically 2% and 4%.

Table 0-1 Total costs NPV (2% and 4% discount rates)

Value	Tier 1	Tier 2	Tier 3
2% discount rate			
One-off costs (EUR million, NPV) (Low – High)	2 (1 – 3)	12 (10 – 15)	140 (112 – 168)
Recurring costs (EUR million, NPV) (Low – High)	19 (16 – 23)	37 (30 – 44)	137 (110 – 164)
Total Costs (EUR million, NPV) (Low – High)	**22** **(17 – 26)**	**49** **(39 – 59)**	**277** **(222 – 332)**
4% discount rate			
One-off costs (EUR million, NPV) (Low – High)	2 (1 – 3)	11 (9 -13)	122 (98 – 147)
Recurring costs (EUR million, NPV) (Low – High)	17 (13 – 20)	32 (25 – 38)	118 (94 – 141)
Total Costs (EUR million, NPV) (Low – High)	**19** **(15 – 23)**	**43** **(34 -51)**	**240** **(192 – 288)**

Source: Ricardo analysis.

Annex E: Risk Management Framework

Project tasks	Risk	Severity	Probability	Contingency
Task 1 – Reporting greenhouse gas emissions and removals	Team are unfamiliar with the legislative context of the work. Poor understanding of the relevant EU legislation and reporting requirements under the UNFCCC.	H	L	Our team have spent many years working on LULUCF related projects for the EU. Our team includes UNFCCC GHG inventory lead reviewers and IPCC lead authors of the 2006 GLs and the 2019 Refinement (John Watterson) who have outstanding knowledge of the relevant legislation.
	Team is unfamiliar with the structure of the UNFCCC reporting – the National Inventory Reports (NIRs) and the CRF tables – and hence cannot locate all the necessary data.	H	L	Our team includes GHG inventory compliers, at national level (John Watterson; Peter Brown). We know exactly where to look and what data to look for. Work will therefore be accurate and efficient. We have already started to assess the information provided by MS; see information in the Boxes in sub-Task 1.2. Should any information be unclear, we have contacts with many of the MS GHG inventory teams which we can use.
	Lack of understanding of the LULUCF sector, and the wetlands sector.	H	L	John Watterson and Jeremy Wiltshire both have detailed knowledge of the LULUCF sector. John Watterson sits on the UK GHG inventory LULUCF Steering Committee and has helped guide the UK work to introduce the Wetlands Supplement into the UK GHG inventory. Manuela de Mendonca will support. Bradley Ginns is a land use and data expert. Lea Herold (PM for sub-contract) is a soil expert.
	No contacts at the European Environment Agency. Hinders any queries about data at EU and MS level	L	L	John Watterson and Peter Brown have both worked with the EEA in the past and know several of the members of staff who lead the compilation of the EU GHG inventory (Ricardo Fernandez, Bernd Gugele). If there are technical questions, it will be easy to ask them.
	Creation of a sub-standard database.	M	L	Peter Brown and Dom Ingledew have very good technical knowledge of MS Access, and regularly use it during compilation of the UK National Atmospheric Inventory (NAEI). If necessary, they will call on the Ricardo Digital Services Team to help with specific database queries.
	Lack of experience developing data collection templates	M	L	Our team for Task 1 is highly experienced at developing templates for data collection. John Watterson and Jeremy Wiltshire have done this many times before.
	Team not sufficiently experienced to locate and assess the data sets in the NIRS and CRFs, and other scientific literature	M	L	Our team for Task 1 are taken from the Ricardo teams involved in national GHG inventory compilation and QA and/or GHG accounting related to land use.

Project tasks	Risk	Severity	Probability	Contingency
	Insufficient data are available to make new estimates for all Wetlands Supplement (WS) categories for some MS, or, for some MS at all.	M	H	Estimates will not be made where data are lacking or where data are highly uncertain. We are confident that we will be able to make estimates of emissions and removals for coastal wetlands, where these exist in MS. It may be harder to make estimates for some of the other WS categories. We expect Task 2 will provide data to allow Tier 1 estimates to be made for some or most, perhaps all MS.
	Poor QA/QC leading to inaccurate estimates of emissions and removals. This would then have "knock on" implications for any assessment of the changes in reporting, and accounting – for example accounting under the LULUCF Regulation.	H	L	Our team includes GHG inventory compliers, at national level (John Watterson; Peter Brown). Both have experience of QA/QC at national GHG inventory level.
	Team is unfamiliar with the structure of the UNFCCC reporting for the USA – the National Inventory Reports (NIRs) and the CRF tables – and hence cannot locate all the necessary data. No channels of communication with the USA GHG inventory team exist.	L	L	Our team includes GHG inventory compliers, at national level (John Watterson; Peter Brown). We know exactly where to look and what data to look for. Work will therefore be accurate and efficient. We have already started to assess the information provided by the USA; see the preliminary analysis already provided in the text describing our approach in sub task 1.4. Should any information be unclear, we know several members of the USA GHG inventory team as we have worked with them during the UNFCCC review process or have worked with them on international capacity building projects. This will allow us to talk to them easily.
	For some MSs there will be no reporting to assess	L	M	We are sure that some MSs will not report coastal wetlands, but we expect most or all will report some wetland data and emissions. We will assess the reporting that has been done, and report on gaps (completeness) for all MS.
	Poor quality literature review of work at EU and international level.	L	M	We have already started the literature review; see table in the section describing Sub-Task 1.5b. We have access to Science Direct, the world's leading source for scientific, technical, and medical research. Our team have successfully undertaken many literature review and assessments. Our team can write well and clearly.
	Inaccurate estimate of costs and feasibility of reliable EU wide reporting of blue carbon	L	M	Our team includes economists, Brais Louro, and Inge Kukla who will advise on the data we need to capture to estimate the likely costs, and who will perform the economic calculations.
	Poor quality control resulting poor quality assessment of country calculations	M	L	John Watterson is an UNFCCC GHG inventory Lead Reviewer and is highly experienced at checking complex calculations. He will QC all the work.

Project tasks	Risk	Severity	Probability	Contingency
	Team unable to judge the quality of the data sets	M	L	Our team for Task 1 is taken from the Ricardo teams involved in inventory compilation and QA and/or GHG accounting related to land use. They are "detail people" and are used to critically assessing data quality.
	Poor ability to interpret complex calculations	H	L	John Watterson is an UNFCCC GHG inventory Lead Reviewer and is highly experienced at checking complex calculations. He will QC all the work.
	Poor quality outputs – written, visual and database and spreadsheets.	M	L	Ricardo has a strict QA/QC policy. All material is peer reviewed before external release. Trinomics will further peer review material before it is released to the Commission.
Task 2 – Map the distribution of wetlands and changes in their extent	Difficulties in identifying relevant digital maps	H	L	We have already identified several digital maps that are relevant to the spatial assessment and we anticipate that any additional data identified during the systematic search will be available publicly or through contacting the corresponding contact.
	Lack of response from the contact person for specific digital maps	H	L	Most of the data already identified in the task 2 proposal is publicly available. Furthermore, we will be working closely with Dr Serrano, who has 10+ years' experience in blue carbon ecosystems, globally and in Europe. Dr Serrano has a well-established collaboration network within the EU and will be supporting the project team to contact any relevant expert identified in Task 2.
	Lack of enough information to map all wetlands according to 2013 IPPC guidelines	H	M	We will conduct a systematic search to find country-level information that is likely to support the analysis. In this case, conducting the assessment at the level of each member State minimizes this risk, which may lead to some member States having more detailed maps than others (depending on data availability). This risk is higher for inland wetlands.
	Difficulties in identifying knowledge gaps for blue carbon monitoring	M	L	Our team for Task 2 is comprised by blue carbon experts with international experience on the topic, including a local researcher Dr Oscar Serrano.
Task 3 – Enhancing blue carbon sequestration	Lack of sufficient studies reporting specific costs of interventions for enhancing blue carbon sequestration in the EU region	M	H	We will, on projects that do not report these costs, contact the relevant correspondents seeking information that can be made available with regards to project costs, operational costs, planning costs and use these to arrive at estimates where specific intervention costs are not available. For the purpose of this our Stakeholder Engagement Strategy (See Section 4.1.2) will serve as the overarching guiding framework.

Project tasks	Risk	Severity	Probability	Contingency
	Lack of information on success of interventions	M	H	As assessing success may require before-after type of studies that are likely to be scarce in the EU context, especially on blue carbon interventions, we have proposed the approach of assessing success rates based on the logic of lower impediments could equal better success potential. Furthermore, we propose consulting academic experts such as Dr. Oscar Serrano who will be acting in advisory capacity in this project on potential success of specific interventions aiming to engage scientific knowledge on the aspect.
Task 4 – Presentation to stakeholders	Invited stakeholders are not available to participate in person	L	M	We will adopt a three-pronged approach to resolving this potential issue. Firstly, the workshop in hybrid format will allow even confirmed attendees to switch to attending online under exceptional circumstances that occurred preventing them from attending in person. This is not ideal, so to contain this from happening we will draw up a list of potential invitees longer than the specified 25 including a requirement to RSVP on the choice to attend in-person or online attendance. Thirdly, to minimize costs, carbon emissions, and risk of travel related cancellations we will prioritize selecting in-person attendees within the EU region and an accessible geographic circumference while aiming to maintain representativeness across stakeholder categories.
Task 5 – Preparation of article describing the results	Manuscript preparation delay	L	M	We have incorporated the process of manuscript into our methodology with a detailed breakdown of the writing process and framework. Further, given our Project Teams substantial record on peer-reviewed publishing and scientific and technical writing, we anticipate minimal risk on this aspect.
	Publication delay	L	M	While publishing the article remains outside of the scope of the project, we will endeavor, provisional to approval of the Contracting Authority, to proceed with submission of the article for final publication. Our team members having substantial experience with scientific publishing are well-equipped for this process. We have proposed an approach of selecting journals with quicker publication speeds in tandem with good impact for minimizing this risk.
Task 6 – Management of the study and overall	Delays in scheduling the Kick-off Meeting with the Commission, which will have negative impact on the entire timeline of the project	H	L	The project team will, immediately upon the signature of the contract, discuss with the client the available dates to schedule the Kick-off Meeting. We propose to schedule the meeting online, which allows for more flexibility when searching for available timeslots.

Project tasks	Risk	Severity	Probability	Contingency
project implementation	Risk that the project may not be completed on time – deadlines not respected	M	L	We have drafted a workplan which is feasible considering the number of staff allocated to the implementation of the project. Some alternative staff members are proposed in case of unexpected absence of a key project staff member (see the section on project continuity) and procedures have been set to ensure outputs are delivered on time (see the section on timely deliveries). We will also agree on clear working arrangements during the kick-off meeting to ensure deadlines are respected (e.g., time to give and process feedback).
	Methods proposed differ from current approach of the DG Environment	M	M	While drafting the proposal we have identified points that may require discussion at the Kick-off meeting. Furthermore, if successful, we will review feedback received from the tender evaluation to ensure we fully understand any discrepancies or gaps that may require resolving. All changes will be documented in the inception report.
	Unexpected staff unavailability	H	L	We have confirmed the availability of the nominated staff before submitting this proposal. In case a team member needs to be replaced, we already planned appropriate substitution with (at least) equivalent experience and expertise (see section on project continuity). In case of absence of the Project Leader, Work Package Leader, or QAM, our team has been set up in such a way that another key team member could immediately take over the responsibilities of the absent team member.
	Insufficient resources available within the project limit	H	L	We developed our proposal under consideration of the given resource limitations. As such we aligned the methods for each sub-task to work the most efficient and derive results that are useful for the whole project. We also dedicated experts to each task that are knowledgeable about the topic and thus can make the best use of the available resources. Further we suggest having most meetings online which ensures cost-efficiency as well.
	Deliverables do not fully meet requirements	H	L	We will keep a close relation and connection with the client throughout the project to ensure that expectations are understood and reasonable. KPIs and milestones will be agreed upon in the Kick-off Meeting. Regular progress meeting are planned to update
	The project lead is not capable of managing large scale projects under time schedule	H	L	Our project management team is composed of highly experienced and competent staff. The governance of the project has been on purpose designed in a way that distributes responsibilities and ownership across management partners – precisely to counter any issues of excessive stress. In addition, each of the management team members are experienced managers, know how to priorities and are capable of adjusting.

Project tasks	Risk	Severity	Probability	Contingency
	Difficulties in gaining stakeholder participation input	H	L	Our consortium members are highly experienced in stakeholder consultation. Our methodologies will be applied to the context and tailored to the targeted stakeholder groups to make the consultation as easy and pleasant for the stakeholder as possible while still generating useful outputs. Furthermore, due to previous projects and personal connections, our team members can make use of a broad and highly knowledgeable pool of potential stakeholders, spread all over the world.
	Conflict within the project team hinders the implementation process	H	L	The management team is highly experienced. Our team is in full agreement about the work programme and the approach to it. Trinomics have effective and efficient project management systems.
	Data privacy concerns regarding stakeholder consultation by non-EU partners in the project.	M	H	Two of the 3 partners implementing the project are non-EU based, from the UK and Australia. However, the EU and UK have signed a reciprocity agreement, whereby UK adheres to the EU privacy policies. The same is not true for Australia yet, so in case of the Blue Carbon Lab needing to engage with stakeholder(s), specific safeguards have been agreed with the Client and put in place, as follows: 1) Trinomics team member, in most cases project manager, in correspondence with stakeholders, 2) any data that is collected / provided by these stakeholders is stored on Trinomics' SharePoint, and is not linked to the authors, 3) no personal data (name, affiliation, contacts) of these stakeholder are stored.

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