Optimising carbon sequestration opportunities in Argyll and Bute (Work package 1 and 3)

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Acronyms & Abbreviations

A&B	Argyll and Bute
AECS	Agri-Environment Climate Scheme
BC	Blue Carbon
BGS	British Geological Survey
BLUE	Blue Maine Foundation
BRN	Business Reference Number
C	Carbon
CAR	Controlled Activities Regulations
CMPP	Clyde Marine Planning Partnership
DOC	Dissolved Organic Carbon
EU	European Union
EUNIS	European Nature Information System
eDNA	environmental DNA
EEZ	Exclusive Economic Zone
EPS	European Protected Species
ESG	Environmental, Social, and Governance
FCS	Forestry Commission Scotland's
FGS	Forestry Grant Scheme
FTE	Full Time Equivalent
FIS	Farmers Information Service
GHG	Greenhouse Gas
HIE	Highlands and Islands Enterprise
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
IC	Inorganic Carbon
IUCN	International Union for Conservation of Nature
LCA	Life-cycle assessments
LCC	Land Cover Classification
LULUCF	Land Use and Land Use Change and Forestry
MPA	Marine Protected Areas
MNCR	Marine Nature Conservation Review
MSP	Member of the Scottish Parliament
NbS	Nature-based Solutions
NERC	Natural Environment Research Council
NFE	National Forest Estate
NGO	Non-Governmental Organisation
NM	Nautical Miles
NORA	Native Oyster Restoration Association
NPP	Net Primary Productivity
OC	Organic Carbon
PA	Peatland ACTION
PC	Peatland CODE
PES	Payment for Ecosystem Services
POC	Particulate Organic Carbon
REDD+	Reducing Emissions form Deforestation and forest Degradation
RICS	Royal Institution of Chartered Surveyors
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation

SAMS	Scottish Association for Marine Science
SEPA	Scottish Environmental Protection Agency
SD	Standard Deviation
SMEEF	Scottish Marine Environmental Enhancement Funds
SPA	Special protection area
SRUC	Scotland's Rural College
UNEPFI SBE	UN Environment Programme's Sustainable Blue Economy Finance Initiative
USD	US Dollars
VER	Verified Emission Reductions
WCC	Woodland Carbon Code
WP	Work package
WWT	Wildfowl & Wetlands Tryst

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EXECUTIVE SUMMARY

The substantial terrestrial and marine resources of Argyll and Bute (A&B) represent significant carbon stores, offer considerable carbon sequestration potential, and accordingly, represent important opportunities for green financial investment through carbon markets.

Terrestrial environment

The carbon market in A&B is limited to the trading of terrestrial carbon credits through the Peatland CODE and the Woodland Carbon Code. A review of the state of the current carbon market in A&B for the terrestrial environment showed that there are currently **656.37 ha of Peatland CODE projects** (all under development) and **3027.63 ha of Woodland Code projects** either under development (2598.82 ha) or validated (428.81 ha), together amounting to a **total claimable emission reduction of 926,830 tCO_2e over the lifetime of those projects**.

Currently, the number of projects using those carbon accounting schemes for peatland restoration and woodland expansion is smaller than the number of projects publicly funded though Peatland ACTION, Agri-Environment and Climate Schemes and Forestry Grant Schemes. At the time of completing the report, 22 Peatland ACTION projects were included in the public repository for A&B and 74 Forestry Grant Scheme projects supporting a total of 5,535 hectares of woodland creation.

It is estimated that around **3,784 ha of actively eroding and 45,706 ha of drained modified peatlands fall under eligible categories for Peatland Code projects** and have the potential to bring emission reduction through avoided losses, **with a maximum annual potential supply opportunity of approximately 164 $ktCO_2e\ yr^{-1}$**. The current A&B strategy, 223,227 ha have been identified as having potential for forestry expansion, with 76,553 identified as the preferred areas for expansion. It is likely that some of these areas will be eligible for Woodland Carbon Code, providing further supply opportunities for the A&B carbon market.

Terrestrial ecosystems in A&B hold between 160-270 MtC (587-990 MtCO2e), of which 139-245 MtC (510-898 MtCO2e) comes from soils stocks to 1 m depth. In contrast, a much smaller stock of approximately of 20.9-24.3 MtC (76.7-89.2 MtCO2e) is held within the aboveground vegetation, half of which is held within the woodlands and forests. Thus, these belowground stocks account for over 85% of terrestrial carbon and hold more than ten times Scotland's annual greenhouse gas emissions.

Belowground C stocks are not evenly distributed, with 80% held within approximately 30% of the land area and associated with peat and peaty soils. While all terrestrial stocks face additional risks associated with climate change, these denser belowground stocks should be a priority for ameliorative restoration and protection actions. Failure to deliver on these will put the entire carbon stock at risk through the release of CO_2. **A priority should be targeting the estimated 7.5 MtC (27.5 MtCO2e) most at risk, associated with actively eroding peatlands.**

It is expected that peatland restoration and woodland expansion will increase in the short-term. In terms of supply opportunities for the carbon market through Peatland CODE and

Woodland Carbon Code, this is likely to be driven by demand for **offsetting (reduction in CO_2 emissions that compensates for external emission by an individual or companies) and insetting (reduction in CO_2 emission that compensates for emissions within an internal supply chain)**. In terms of non-marketable carbon opportunities, growth is going to be supported by public funding, such as the **£250M pledged by Scottish Government until 2030 to support peatland restoration**. Further opportunities for different types of activities for the farming sector are likely to arise in A&B, based on the Scottish Budget 2022-23, where over £50 million have been allocated to support the farming sector in tackling the climate and nature emergencies and to produce food more sustainably, including £10 million for the National Test Programme to transform agriculture and £35.8 million for agri-environment schemes.

Some likely scenarios **include NGOs and private estates continuing to engage with Forestry grants and Peatland ACTION but scoping out Peatland CODE and Woodland Carbon Code to develop and roll out medium-to-large projects in a "blended" model; multi-stakeholder partnerships facilitating development of large-scale programmes blending income streams supported by large investments from the private sector, enabling multi-year planning and increased government support and financial incentives for the maintenance and management of stocks for which there is no need for intervention (e.g. peatlands in good conditions)**

To maximise cost-efficiency of current schemes, it is recommended that Peatland CODE applications are developed for areas of actively eroding peatlands, while Peatland ACTION and/or Peatland CODE projects target the restoration of extensive areas of drained peatlands. Peatland ACTION should be used for drained/modified peatlands, afforested peatlands outside of renewable energy development sites and/or other eligible activities complimentary to restoration management. AECS applications should be used to bring income for sustainable management on peatlands where restoration options are limited (e.g. hand cut peat, modified but not drained, near natural). Forestry Grant Scheme and Woodland Carbon Code should be used for woodland creation and marketable carbon, in particular in areas identified as having moderate to excellent flexibility for trees, while Forestry Grant Scheme can be used for management of existing woodland and Small Woodland Loan Scheme and Forestry Grant Scheme can be used for small woodland creation.

The growth in supply for the carbon market from the terrestrial side, and to support existing ambitious targets of peatland restoration and woodland creation is **currently constrained by a lack of skilled workforce (contractors and advisors), constraints associated with practical delivery (e.g. limited supply of trees from nursery for woodland expansion, access restriction around weather and breeding bird for peatland restoration, cost-effectiveness), real and perceived complexity (e.g. application process, carbon finance), and limited practical options for delivery and monitoring over landscape scales.**

While there are currently no codes in place for agriculture, **a Hedgerow Carbon Code is under development** by the Game and Wildlife Conservation Trust and the Sustainable Soils Alliance is working on a **UK Farm Soil Carbon Code**. These developments would provide frameworks to calculate the carbon capture potential of hedgerow habitat improvements and quantify, qualify and verify reduced GHG emissions and/or soil carbon capture through regenerative farming practices.

We recommend that given the rapid growth in demand facing the land use sector, the **Scottish Government should support education or knowledge exchange programmes enabling landowners, farmers, land managing organisations to make informed decisions about which, if any of these options they should engage with, considers a unified framework for applications where multiple projects under different codes could be possible and provides guiding principles around ethical carbon offsetting.** In addition, to facilitate the blending of public and private finance, we recommend that the government considers investing in advisory roles for the development of applications for marketable carbon where proportionally small investments in people on the ground working with landowners could unlock much larger investment from the private sector.

Given the importance of maintaining intact natural assets in the terrestrial environment in good condition - particularly peat soils, existing woodlands and forests - we recommend that the government uses the opportunity around development of new agri-environment schemes to consider mechanisms to support financial rewards for landowners and land managers who already manage their carbon rich land sustainably and ensures that policy incentive for intervention associated with targets do not undermine existing carbon stocks with perverse outcomes for climate.

Within A&B, two key opportunities were identified for the development of pilot projects in the near future: a Woodland Carbon Code opportunity, focussed around a combined land-use of sheep production and forestry (or agro-forestry), potentially increasing several farmers and a Peatland CODE opportunity around restoration of eroded peatlands on Islay. For both of these terrestrial pilot projects the implementation strategy requires:

1) **Understanding of the process of application and engagement with existing support mechanisms where they exist;**
2) **Identifying project lead(s) (individuals/organisations);**
3) **Understanding/addressing needs/issues of insetting vs offsetting to derive best investment models;**
4) **Facilitating capacity building and knowledge exchange across stakeholders to identify and tackle barriers to uptake; and**
5) **Mapping of a pathway to delivering community benefits**

Marine environment

The marine sediments of A&B hold an estimated **6.2 Mt (22.7 MtCO2e) organic carbon and 39.2 Mt (144 MtCO2e) inorganic carbon in the top 10 cm of sediments.** These stocks represent a significant proportion of national carbon inventories**, with hotspots within the region accounting for 24% of the UK seabed that has an organic carbon content greater than 0.5 kg/m^2, despite the region making up only 2% of the UK EEZ**. These hotspots include much of the Clyde region and sea lochs in the area (Loch Etive, Loch Linnhe, Loch Fyne, and the Firth of Lorn). **Phytoplankton are the overwhelmingly important primary source of organic carbon exported to these marine sediments, with a contribution over**

twenty times that of coastal vegetated blue carbon habitats (kelp, saltmarshes and seagrass beds). However, it is the latter that are most directly associated with human activity and thus potentially most amenable to active management.

The nascent marine blue carbon (BC) market reflects the complexity and uncertainties associated with of the interaction between aquaculture - encompassing mature shellfish and emerging seaweed industries in A&B and carbon cycling in the natural environment. Currently the science better supports the inclusion of seaweed aquaculture within any BC framework. **Accredited frameworks for a BC market based on seaweed farming are still under development, as they need to address the challenge of attributing stored carbon to the place of production rather than its final long-term sink that will typically be away from the farm site, all within the context of Crown ownership of the seabed that lacks a mechanism for the long-term leasing or transfer of ownership.**

Projected climate change will also put marine carbon stocks at risk by altering the productivity, distribution, resilience, and community structure of marine coastal vegetated habitats and plankton within the water column. In addition to increasing the prevalence of invasive species and diseases, temperature change affects water chemistry (through ocean acidification) that will directly impact the stability of marine carbon stocks. Further considerations are coastal squeeze and trawling, both of which can lead to conflict between communities and the preservation or enhancement of carbon stocks. **Increasing sea levels and competition for space from planned coastal developments in A&B will reduce the extent to which coastal vegetated blue carbon habitats can be maintained, while trawling will continually erode marine carbon stocks in sediment stores. The monetary value of such lost carbon by trawling sediment carbon stores in the UK has been estimated in the region of US$ 12.5 billion within a 25-year timeframe.**

Drawing parallels from the more mature terrestrial markets can help to understand likely trajectories for the development of marine BC markets. Within the terrestrial environment Nature-based Solutions have been successfully integrated into the carbon markets, potentially accounting for two thirds of the voluntary carbon market by 2030. This approach could also be applied to the development of BC markets, partitioned along similar lines into marine protected areas that prevent BC habitat loss through dredge fishing, seaweed harvesting and seagrass bed degradation, restoration of BC habitats such as seagrass beds or native oyster beds, and fully engineered ecosystems such as Seaweed aquaculture. **The move away from a project-based approach to a "jurisdictional approach" in terrestrial systems could also be applied to marine systems to address the problems with the quantification and verification of BC relating to the export of carbon outside the project area.** Using the Nature-based Solutions framework to allow a jurisdictional approach may be particularly appropriate for A&B.

The inclusion of seaweed and shellfish aquaculture within a Blue Carbon trading scheme is currently limited, suggesting there may be merit in taking a less market orientated approach by valuing these operations within the context of other frameworks based on ecosystem services. In terms of Blue Carbon, regulating and supporting services are the principal categories of ecosystem services, specifically climate regulation (regulating services) and nutrient cycling (supporting services). Payment for Ecosystem Services allows for the financial reward for the delivery of public good through the enhancement of ecosystem services. **To address problems of quantification and verification associated with this, BC habitats could be coupled with marine protected areas that do deliver quantifiable and verifiable ecosystems benefits, such as flood protection or fisheries enhancement. Tackling multiple societal challenges while contributing to human wellbeing in this way is reflected in the Nature-based Solutions approach, which in 2020 attracted investments of $ USD 113B - mostly by domestic governments with private capital at 17% - and it has been estimated that this investment will need to treble by 2030. Aquaculture such as seaweed and shellfish production can be designed to align with this approach and hence tap into these investments.**

In addition to the Nature-based Solutions there are other emerging frameworks specific to the marine environment that can be applied to blue carbon projects based on seaweed and shellfish, whilst others are more generic sustainability frameworks. **These include the UN Environment Programme's Sustainable Blue Economy Finance Initiative for which ecosystem services could be included within future version of the programme guidelines. Similarly, the European Union Taxonomy for Sustainable Activities represents another possibility**. This currently covers the fisheries sector but there is an expectation it will be expanded to include aquaculture in the future.

Further, there are key questions that need to be addressed before any marine carbon market implementation strategy to incentive growth is established, namely, **defining the motivation for the BC scheme, whether it is to meet net zero targets, to generate value for local communities or to fund wider biodiversity conservation activities. And defining which carbon market is being targeted. Although the various types, strands and schemes have significant overlap, the steps need for development of A&Bs BC market is dependent on the criteria for entry into that market**

We recommend using a pre-existing framework for guidance, such as the Oxford Principles for Net Zero Aligned Carbon Offsetting, to define the mechanisms for offsetting and provide guidance as to which mechanisms will deliver desired outcomes. BC projects could be developed to fit within a number of different classifications, and these could be piloted as the first steps in an A&B BC scheme. We also suggest that BC projects within A&B take a regional or jurisdictional approach to developing BC markets. Although the concept is still in development, such approaches are characterised by **bringing together all relevant stakeholders from a landscape defined by political boundaries that are usually at the local government level; co-development of objectives aimed at promoting sustainable practices in this landscape and exhibit strong subnational government leadership.**

The development of marine blue carbon markets lags far behind the terrestrial equivalent. For the marine sector to move forward this requires:

1) **The production of equivalents to the Woodland and Peatland Codes. This process has begun with the development of the "UK Saltmarsh Code". Engagement with this research group may expedite the local application and benefits of the resulting code.**
2) **Incorporation of blue carbon within marine spatial planning frameworks, informing national, regional, and local scale management measures to protect existing carbon stocks. The potential application of spatial/temporal management measures must be explored to distinguish the implications on carbon stocks within designated areas weighed against necessary trade-offs (e.g. exclusion of towed fishing and/or offshore development) to incorporate these measures into the establishment of new marine protected areas.**
3) **Pursue the implementation of carbon offsetting schemes, potentially linked to community-driven habitat restoration projects (such as the Seawilding effort to restore seagrass meadows).**
4) **Applied research is required to understand the potential benefits of seaweed aquaculture on various scales, investigating the rate and fate of carbon export and sequestration as well as the overall environmental sustainability when incorporating various end-uses and markets.**

TAKE HOME MESSAGE

<u>Fundamental action is required to develop carbon markets in A&B, with an emphasis on capacity building for the terrestrial market while the nascent marine market requires scoping exercises.</u>

0 REPORT SUMMARY

The substantial terrestrial and marine resources of Argyll and Bute (A&B) represent significant carbon stores, offer considerable carbon sequestration potential, and accordingly, represent important opportunities for green financial investment through carbon markets.

WP1 of this report establishes the current carbon market, sequestration supply opportunities, stocks serving as natural assets and risks to these under climate change with a synthesis of primary drivers and trends in demand for carbon trading. The overriding theme here is one of maturity of the terrestrial relative to marine carbon markets that is reflected in supply opportunities, despite significant carbon stocks occurring within both the terrestrial and marine environments of A&B and the similar risk trajectory of these stocks under a climate change business as usual scenario.

0.1 Current market in A&B

The current carbon market in A&B is limited to the trading of terrestrial carbon credits as the marine carbon market is still nascent. These terrestrial credits involve the Peatland Code and Woodland Carbon Code. Publicly available data for projects listed under the UK Land Carbon Registry reveal that within A&B **there are presently 656.37 ha of Peatland Code and 3027.63 ha of Woodland Carbon Code projects amounting to a total claimable emission reduction of 916,830 tonnes of CO_2 equivalent.** Current interest in carbon market opportunities from peatland management in A&B should be considered as tentative due to the complex application process and relative immaturity of the Peatland Code, however, it is likely there will be growth in uptake for marketable carbon from peatland restoration as this is already being observed in other parts of the UK. By contrast, there is already widespread engagement with Woodland Carbon Code and Forestry Grant schemes suggesting an appetite for activities supporting the development and increase of Woodland cover in A&B (Figure A). This is partly motivated **by financial rewards available through existing schemes** and may be a consequence of the more mature process and generally favourable public perceptions of woodlands. The nascent marine blue carbon (BC) market reflects the complexity and uncertainties associated with of the interaction between aquaculture - encompassing mature shellfish and emerging seaweed industries in A&B - and carbon cycling within the natural environment. Currently the science better supports the inclusion of seaweed aquaculture within any BC framework. **Accredited frameworks for a BC market based on seaweed farming are still under development, as they need to address the challenge of attributing stored carbon to the place of production rather than its final long-term sink that will typically be away from the farm site**, all within the context of Crown ownership of the seabed that lacks a mechanism for the long-term leasing or transfer of ownership.

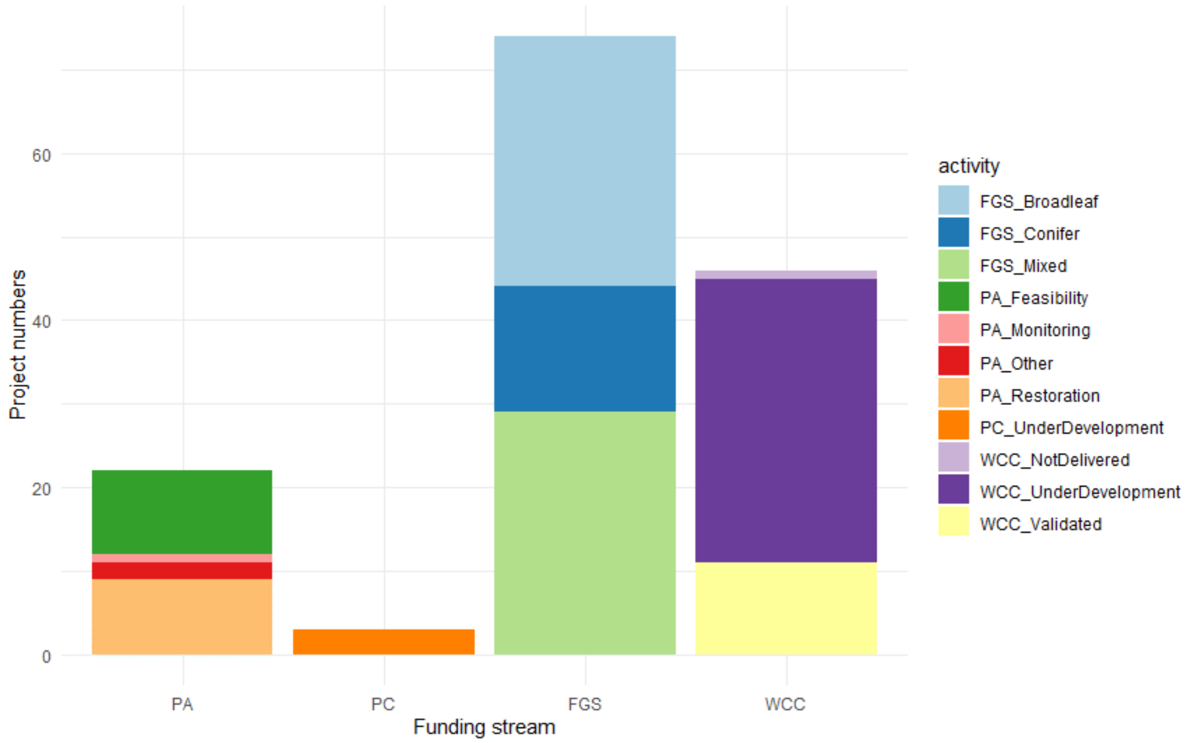

Figure A: Total number of projects funded through Peatland ACTION (PA), Peatland CODE (PC), Forestry Grant Schemes (FGS) and Woodland Carbon Code (WCC) in Argyll and Bute across a range of activities/statuses.

Priority carbon sequestration supply opportunities in A&B concern the areas where carbon emission reduction activities will have greatest impact, and at present, these areas are terrestrial rather than marine. There are significant opportunities for an increase in supply of projects delivering carbon emission reductions in A&B's terrestrial environment. **Large areas of actively eroding and drained modified peatlands fall under eligible categories for Peatland Code projects and have the potential to bring emission reduction through avoided losses (Table A).** There is likely an even bigger opportunity for an increase in supply through the Woodland Carbon Code although the scale of this opportunity is harder to ascertain due to the wide range of carbon sequestration available. These opportunities are recognised across government and agencies as offering benefit to rural communities, particularly through the creation of skilled jobs**. Over the next three to five years it is envisaged that 200 FTE jobs will be created from public investment in peatlands** along with associated part time roles. An increase in private funded work as well as an increase in forestry cover should also see an associated increase in roles. Realising similar opportunities within a marine context is hampered by the lack of equivalent management and ownership models to those of the terrestrial environment. **The need for such models cannot be over-emphasised given the importance of coastal vegetated habitats as highly productive and important stores of carbon, and seabed sediments as the largest store of marine organic carbon in the region,** both of which could offer potential opportunities for emission reduction through changes in area use activity.

Table A: Carbon supply opportunities through peatland restoration activities eligible under the Peatland CODE

Pre-restoration condition category (emission, $tCO_2e\ ha^{-1}\ yr^{-1}$)	Post-restoration category condition(emission, $tCO_2e\ ha^{-1}\ yr^{-1}$)	Emission reduction $tCO_2e\ ha^{-1}\ yr^{-1}$	Area in A&B	Maximum Annual Potential Supply opportunity $ktCO_2e\ yr^{-1}$
Actively Eroding, drained (23.84)	Drained, revegetated (4.54)	19.3	3,784	73.03
Drained modified grass/heather dominated or undrained actively eroding (4.54)	Modified (2.54)	2.00	45,706	91.41

Currently available data sources reveal that the largest and most significant carbon stocks that may serve as natural assets are the soil and sediment substrates that underly the terrestrial and marine environments of A&B. Due to differences in the manner in which these stocks were originally derived, a direct comparison between terrestrial and marine carbon within A&B was not possible, and accordingly these environments have been summarised separately (Table B-D). **Terrestrial ecosystems in A&B hold between 160-270 MtC, of which 139-245 MtC comes from soils stocks to 1 m depth. Thus, these belowground stocks account for over 85% of terrestrial carbon and hold more than ten times Scotland's annual greenhouse gas emissions. They are not evenly distributed, with 80% held within approximately 30% of the land area and associated with peat and peaty soils, among which actively eroding peatlands are considered at risk and should be prioritised for targeted field validation and management intervention (Table A). Approximately half of the 20.9-24.3 MtC aboveground carbon stock is held within woodlands and forests. It is noteworthy that other land cover classes of aboveground biomass are not negligible but require further data to accurately quantify.**

Table B*:* Estimation of soil carbon stocks for Argyll and Bute

	Soil Category	Data source	Area ha	Soil C content (tC ha)				Stock to 1m (MtC)			
				BioSoil	NSS	NSS low	NSS high	BioSoil	NSS	NSS low	NSS high
PEAT	Deep peat	Deep peat layer Hutton	34656	539	547	273	823	18.7	19.0	9.5	28.5
	Deep peat	E layer from Peat ESRI	25186	539	547	273	823	13.6	13.8	6.9	20.7
	Other peat	Peatwind with deep peat removed	161555	539	547	273	823	87.1	88.4	44.1	133.0
	Other peat	D and C2, Peat ESRI	182695	539	547	273	823	98.5	99.9	49.9	150.4
	Total stocks	*Hutton + Peatwind*	*196211*	*539*	*547*	*273*	*823*	*105.8*	*107.3*	*53.6*	*161.5*
	Total stocks	*Peat ESRI*	*207882*	*539*	*547*	*273*	*823*	*112.0*	*113.7*	*56.8*	*171.1*

	Soil Category	Data source	Area ha	Soil C content (tC ha)				Stock to 1m (MtC)			
				BioSoil	NSS	NSS low	NSS high	BioSoil	NSS	NSS low	NSS high
OTHER SOILS	Peaty Gleys	dystrophic basin peat, dystrophic blanket peat, peaty gleys, undifferentiated other peat	111757	242	121	402	362	27.0	13.5	44.9	40.5
	Peaty Podzols	peaty podzols, peaty gleyed podzols	46513	214	128	353	362	10.0	6.0	16.4	16.8
	Brown Soils	Brown calcareous soils, Brown earth, Lithosoils	44640	115	61	204	152	5.1	2.7	9.1	6.8
	Mineral Podzols	Apline podzols, Humus-Iron podzols, Iron podzols, subalpine podzols	39161	124	52	263	154	4.9	2.0	10.3	6.0
	Mineral gleys and other soils	Non calcareous gleys, alluvial soils, scree, undifferentiated rankers	24183	131	49	271	173	3.2	1.2	6.6	4.2
	Total stock other soils MtC							*50.2*	*25.4*	*87.3*	*74.3*
	Total stock soils A&B MtC							*162.2*	*139.1*	*144.1*	*245.4*
	Total stock soils A&B MtCO2e							*594.8*	*510.1*	*528.2*	*899.7*

Table C: Above ground C stocks estimates for Argyll and Bute

Land Cover (Method)	Area (ha)	% A&B area	tC ha^{-1}	MtC	MtCO2e
Wetland (JHI LC88)	158277.00	23.13%	43	6.8	25.0
Arable (JHI LC88)	58.00	0.01	2	0.0001	0.0004
Temperate Grassland (JHI LC88)	320412.00	46.83	7	2.2	8.2
Forestry (JHI LC88)	187209.43	27.36%	74	13.9	50.8
Forestry (A&B strategy map 2017)	160462.57	23.45%	74	11.9	43.5
Forestry (SpaceIntelligence Land Cover map)	206481.00	30.18%	74	15.3	56.0
Total	*656528.65*	*96-100*		*20.9-24.3*	*76.7-89.2*

Table D: Overall Marine C Summary for Argyll and Bute

Argyll and Bute Carbon 2022			*Organic carbon*								*Inorganic carbon*					
Habitat		Extent (km²)	Stock (Mt C) [0.1m depth]	Stock (g C/m2)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Stock (Mt C) [0.1m depth]	Stock (g C/m²) [0.1m depth]	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)
Phytoplankton	Argyll and Bute	12045			203	2439	244									
	Clyde Sea	4278			203	866	87									
All sediment	Argyll and Bute	11639	4.1	356				93	8.0	93.3	35.1	3074	9.11	104		
	Clyde Sea	4112	2.1	501				89	21.5	88.5	4.1	1037	1.67	7		
Biogenic habitats		439	0.2	12556	1539	145	14	1	129.0	1.5						
	Total / Average	16324	6.4													

The marine sediments of A&B hold an estimated 6.2 Mt organic carbon and 39.2 Mt inorganic carbon in the top 10 cm of sediments. These stocks represent a significant proportion of national carbon inventories, with hotspots within the region accounting for 24% of the UK seabed that has an organic carbon content greater than 0.5 kg/m^2, despite the region making up only 2% of the UK EEZ. These hotspots include much of the Clyde region and sea lochs in the area (Loch Etive, Loch Linnhe, Loch Fyne, and the Firth of Lorn) (Figure B). **Phytoplankton are of overwhelming importance as the primary source of organic carbon exported to these marine sediments with a contribution over twenty times that of coastal vegetated blue carbon habitats such kelp, saltmarshes and seagrass beds.** However, it is the latter that are most directly associated with human activity and thus potentially those most amenable to active management.

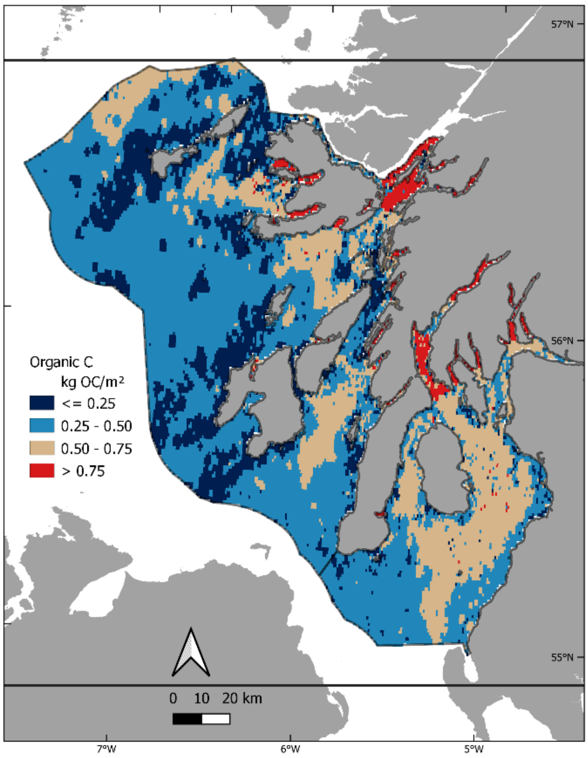

Figure B: Organic carbon (OC) in Argyll and Bute from data in Smeaton et al., (2021) as the mass of carbon per area of seabed to a depth of 0.1m (kg C m^{-2}). For organic carbon red areas show hotspot areas in sealochs where OC density is greater than 0.75 kg/m^2.

0.2 Risks to carbon stocks

Risks to carbon stocks under a climate change projections within A&B are uncertain, but on average over the region, a business-as-usual scenario will increase the risk of a reduction in both terrestrial and marine carbon stocks. Within terrestrial areas a higher incidence of drought stress, increased erosion associated with changing precipitation regimes, and increased risks of wildfires will stress and alter the composition of aboveground carbon stocks, leading to an increased susceptibility to pests and diseases. This can translate into direct economic impact on rural communities. While all terrestrial carbon stocks face an increased risk, **the denser carbon deposits found in peat and peaty soils should be a priority for ameliorative restoration and protection actions. Failure to deliver on these will put the entire carbon stock at risk through the release of CO_2** at a rate far exceeding that at which the carbon accumulated in the first place.

Projected climate change will also put marine carbon stocks at risk by altering the productivity, distribution, resilience, and community structure of marine coastal vegetated habitats and plankton within the water column. In addition to increasing the prevalence of invasive species and diseases, temperature change alters water chemistry (i.e., ocean acidification) that will directly impact the stability of marine carbon stocks. Further considerations are coastal squeeze and trawling, both of which can lead to conflict between communities and the preservation or enhancement of carbon stocks. **Increasing sea levels and competition for space from planned coastal developments in A&B will reduce the extent to which**

coastal vegetated blue carbon habitats can be maintained, while the continued disturbance caused by trawling on marine carbon stocks will continually erode sediment stores - the monetary value of anthropogenic and changing-climate pressures on sediment carbon stores in the UK has been estimated in the region of US$ 12.5 billion within a 25-year timeframe.

It is worth noting that within both the terrestrial and marine contexts, there is still lack of a good understanding of the interactions between the full range of management interventions and biogeochemical processes, and the impact of these on carbon stocks over different timescales.

0.3 Drivers

Primary drivers and trends in the demand for carbon trading have been synthesised through Strengths, Weaknesses, Opportunities and Threats analysis. The public sector recognises the need to restore and protect existing terrestrial carbon stores, and government targets give the private sector confidence and steer towards similar targets. **There is growing pressure to decarbonise business activity and it is likely that NGOs could become a key supplier of landscape scale restoration utilising marketable carbon, although they may not engage with businesses that don't demonstrate willingness to reduce their emissions through other means than engaging with offsetting schemes. Some of the likely future plausible trade scenario include:**

1. **NGOs and private estates continuing to engage with Forestry grants and Peatland ACTION but scoping out Peatland CODE and Woodland Carbon Code to develop and roll out medium-to-large projects in a "blended" model**
2. **Multi-stakeholder partnerships facilitating development of large-scale programmes blending income streams supported by large investments from the private sector, enabling multi-year planning**
3. **Increased government support and financial incentives for the maintenance and management of stocks for which there is no need for intervention (e.g. peatlands in good conditions)**

Figure C: Terrestrial Scotland Carbon Market SWOT Analysis

Strengths	Weaknesses
• Supportive net-zero policy environment • Existing schemes for peatland and woodland • Scale of landholdings • Support of public landowners (FIS) • Possibility to combine schemes (e.g. Peatland CODE + Peatland ACTION or Peatland ACTION + AECS) • Shared carbon registry has been set up in 2020 for the Woodland Carbon and Peatland Codes	• Mixed public perception • Complicated process through multiple agencies • Limited applicability of Peatland CODE to large-scale programme due to field-based validation methods vs small profit margin for small projects • Need for upfront capital for some schemes
Opportunities	**Threats**
• Net-zero targets • Increasing global market for carbon offsets • Charismatic Carbon (i.e. carbon associated with biodiversity and water benefits) • New technologies available to support landscape-scale delivery • Development of a range of skilled jobs associated with expansion of land-based interventions	• Weak global carbon price • Competition from international sellers • Climate change (i.e. compromising delivery of outcome, increasing intervention costs, reducing profit margins) • Mismatch between supply and demand

Drawing parallels from the more mature terrestrial markets can help to understand likely trajectories for the development of marine BC markets**. Within the terrestrial environment Nature-based Solutions have been successfully integrated into the carbon markets, potentially accounting for two thirds of the voluntary carbon market by 2030. This approach could also be applied to the development of BC markets, partitioned along similar lines into marine protected areas that prevent BC habitat loss through dredge fishing, seaweed harvesting and seagrass bed degradation, restoration of BC habitats such as seagrass beds or native oyster beds, and fully engineered ecosystems such as Seaweed aquaculture**. The move away from a project-based approach to a "jurisdictional approach" in terrestrial systems could also be applied to marine systems to address the problems with the quantification and verification of BC relating to the export of carbon outside the project area. Using the Nature-based Solutions framework to allow a jurisdictional approach may be particularly appropriate for A&B.

Figure D: Marine Scotland Carbon Market SWOT Analysis

Strengths	Weaknesses
• Huge demand for ESG investment in the marine environment • Huge potential to scale (largest habitat globally) • Alignment with other conservation/sustainability goals • Highly productive ecosystems • Market already developing	• Complex ownership of marine space • Existing traditional and new uses for marine environment • Hydrodynamic movement of carbon makes attribution difficult • Lack of maturity of market • Lack of robust quantification methods
Opportunities	**Threats**
• Growing demand for sustainable investment in Marine Environment • Clear political drive for net zero • Seaweed aquaculture is rapidly growing globally • There is political movement for the development of schemes that allow payment for ecosystem services • Community ownership of projects linking to greater devolution of natural asset management	• Climate change increasing storminess and sea surface temperature • Reputational damage from poorly developed schemes connected to an immature market • Complexity of the science, and possible poor communication to investors and policy makers • Singular focus on carbon dioxide

0.4 Opportunities

WP3 of this report establishes technically viable opportunities for carbon sequestration in the region within the context of the existing Woodland Carbon Code and Peatland Code and identifies approaches under consideration for the development of soil and marine codes. Differences in the maturity of options available reflect the significant differences that exist between land and sea in terms of ownership, governance, and management, such that there are currently far fewer options for generating economic value from carbon sequestration in coastal seas than terrestrial areas within A&B.

The most likely win-win options in terms of priority carbon trade opportunities within the existing peatland and code trade system concern:

- **Peatland CODE applications developed for areas of actively eroding peatlands**
- **Peatland ACTION and/or Peatland CODE for restoration of extensive areas of drained peatlands**
- **Peatland ACTION for small areas of drained/modified peatlands, afforested peatlands outside of renewable energy development sites and/or other eligible activities complimentary to restoration management**

- **AECS applications for sustainable management on peatlands where restoration options are limited (e.g. hand cut peat, modified but not drained, near natural)**

Within the existing woodland code trade system, priority options for carbon trade opportunities are:

- **Forestry Grant Scheme and Woodland Carbon Code for woodland creation and marketable carbon, in particular in areas identified as having moderate to excellent flexibility for trees**
- **Forestry Grant Scheme for management of woodland**
- **Small Woodland Loan Scheme and Forestry Grant Scheme for small woodland creation**
- **The Future Woodlands Trust for low-risk marketable carbon**

While the current uptake of the Peatland Code and Woodland Code within A&B suggests an appetite for these carbon trading opportunities, there are still barriers constraining this uptake (Table E). Further, there is a need to be mindful of calls for caution in the face of owners and managers enthusiasm to fund and capitalise on restoration prematurely without fully understanding the future implications of this.

Table E: Barriers and issues with codes/schemes

Barrier or Issue	Consequence	Applies to	Potential solution
Lack of skilled contractors to deliver peatland restoration on the ground	Failure to meet restoration targets	All peatland schemes	Development of dedicated training
Lack of skilled land agents and advisors to support applications	Failure to meet restoration targets	All peatland schemes	Development of dedicated training
Limited supply of trees from nurseries	Failure to meet woodland expansion targets	All Forestry schemes	
Constraints of timing of restoration delivery (e.g. snow, bird breeding season)	Periods without income for contractors	All peatland schemes	Combine multiple projects/areas, combine peatland and forestry work
Varying complexity of application process, not streamlined for combined applications across schemes	Need for advisors to support landowner	All schemes	Build up skilled workforce, improve application process
Lack of understanding around carbon finance and carbon markets for land-owners and land managers	Hesitancy, potential to become involved in poor deals	Peatland CODE & Woodland Carbon Code	Education
Need for upfront capital (to prepare applications, pay for AECS capital work, etc)	Potential to exclude key grounds inc. crofters	AECS, Peatland CODE, Woodland Carbon Code	Potential to combine with Peatland ACTION in flexible way
Not as cost-effective over small areas	Potential to put off smaller landowners/managers	All schemes	Prepare joint- or multi-owner applications

Barrier or Issue	Consequence	Applies to	Potential solution
Mismatch in growth between C market supply/demand, e.g. high demand low supply	Potential to miss out on opportunities from big private investors	Peatland CODE	Manage investors' expectation, continue to develop codes to adapt the supply
Potential issues about legal ownership of the C for applicants who are not landowners	Perverse outcome of C sale that takes away benefits from e.g. crofters and/or local community	Peatland CODE	Develop understanding of legal issues
Ground-based validation approaches limit landscape scale applicability	Potential to miss out on large investments	Peatland CODE	Identify remote-sensing solutions that can become accredited for verification and certification

Beyond the use of existing schemes for peatlands and tree covered areas, there is a clear need for additional trading codes in intact and transformed ecosystems, including terrestrial, marine, freshwater, estuarine and agricultural systems. No such codes are currently in place for agriculture, but **a Hedgerow Carbon Code is under development** by the Game and Wildlife Conservation Trust and the Sustainable Soils Alliance is working on a **UK Farm Soil Carbon Code**. These developments would provide frameworks to calculate the carbon capture potential of hedgerow habitat improvements and quantify, qualify and verify reduced GHG emissions and/or soil carbon capture through regenerative farming practices. In light of this potential multiplication of codes and a potentially rapid growth in demand we recommend that the government:

- **Supports education or knowledge exchange programmes enabling landowners, farmers, land managing organisations to make informed decisions about which, if any of these options they should engage with**
- **Considers a unified framework for applications where multiple projects under different codes could be possible**
- **Provides guiding principles around ethical carbon offsetting**

Given that the account holders of projects involving marketable carbon and attracting private sector investment in A&B are predominantly from the private sector, **it is in the interest of the government to facilitate the blending of public and private finances and attract private investment in Nature-Base solutions. To achieve this, and increase the uptake of the Peatland and Woodland Carbon Code, we recommend that the government considers investing in advisory roles for the development of applications for marketable carbon mirroring e.g. the Peatland ACTION project officer roles, as proportionally small investments in people on the ground working with landowners could unlock much larger investment from the private sector.**

For intact natural assets in the terrestrial environment - particularly peat soils, existing woodlands and forests - we recommend that the government:

- **Uses the opportunity around development of new agri-environment schemes to consider mechanisms to support financial rewards for landowners and land managers who already manage their carbon rich land sustainably**
- **Ensures that policy incentive for intervention associated with targets do not undermine existing carbon stocks with perverse outcomes for climate**

The inclusion of seaweed and shellfish aquaculture within a Blue Carbon trading scheme is currently limited, suggesting there may be merit in taking a less market orientated approach by valuing these operations within the context of other frameworks based on ecosystem services. In terms of Blue Carbon, regulating and supporting services are the principal categories of ecosystem services, specifically climate regulation (regulating services) and nutrient cycling (supporting services). Payment for Ecosystem Services allows for the financial reward for the delivery of public good through the enhancement of ecosystem services. **To address problems of quantification and verification associated with this, BC habitats could be coupled with marine protected areas that do deliver quantifiable and verifiable ecosystems benefits, such as flood protection or fisheries enhancement. Tackling multiple societal challenges while contributing to human wellbeing in this way is reflected in the Nature-based Solutions approach, which in 2020 attracted investments of $ USD 113B - mostly by domestic governments with private capital at 17% - and it has been estimated that this investment will need to treble by 2030. Aquaculture such as seaweed and shellfish production can be designed to align with this approach and hence tap into these investments.**

In addition to the Nature-based Solutions there are other emerging frameworks specific to the marine environment that can be applied to blue carbon projects based on seaweed and shellfish, whilst others are more generic sustainability frameworks. **These include the UN Environment Programme's Sustainable Blue Economy Finance Initiative for which ecosystem services could be included within future version of the programme guidelines. Similarly, the European Union Taxonomy for Sustainable Activities represents another possibility**. This currently covers the fisheries sector but there is an expectation it will be expanded to include aquaculture in the future.

0.5 Proposed Actions

Fundamental action is required to develop carbon markets in A&B, with an emphasis on capacity building for the terrestrial market while the nascent marine market requires scoping exercises. With increased focus on community ownership, wealth building, blended ownership and in light of the availability of voluntary community wealth funds, key recommendations for government in facilitation and incentivising terrestrial carbon market growth are:

1) **Short-term**
    a. Advocacy to the Scottish Government about the need to support capacity building and to streamline application processes where multiple income streams could be combined

   b. Engage with other landscape partnerships where similar work is being undertaken (e.g. Flow Country Partnership, Cairngorm Connect, Forth Era) and identify lessons that can be applicable to Argyll and Bute
   c. Develop Pilot Projects around key opportunities (see Implementation Strategy)
   d. Educate landowners about opportunities and identify barriers to uptake

2) **Medium term**
   a. Consider investing in advisory services complementary to existing roles (e.g. Peatland ACTION officer) to unlock supply
   b. Engage with existing CODE to support implementation and improvements relevant to A&B and to address barriers identified by landowners
   c. Consult with stakeholder to develop long-term landscape vision for A&B, including models to translate investments into community benefits
   d. Scope out potential long-term investment strategy
   e. Continue to develop pilot projects

3) **Long term**
   a. Implement long term vision supported by increased capacity and improved delivery of actions of the ground
   b. Monitor how investments and pilot projects are delivering on community benefits and carbon emission reductions

Further, there are key questions that need to be addressed before any marine carbon market implementation strategy to incentive growth is established, namely:

1) Defining the motivation for the BC scheme, whether it is to meet net zero targets, to generate value for local communities or to fund wider biodiversity conservation activities
2) Defining which carbon market is being targeted. Although the various types, strands and schemes have significant overlap, the steps need for development of A&Bs BC market is dependent on the criteria for entry into that market

We recommend using a pre-existing framework for guidance, e.g. the Oxford Principles for Net Zero Aligned Carbon Offsetting, to define the mechanisms for offsetting and provide guidance as to which mechanisms will deliver desired outcomes. BC projects could be developed to fit within a number of different classifications (Table F), and these could be piloted as the first steps in an A&B BC scheme. We also suggest that BC projects within A&B take a regional or jurisdictional approach to developing BC markets. Although the concept is still in development, such approaches are characterised by:

- **Bringing together all relevant stakeholders from a landscape defined by political boundaries that are usually at the local government level**
- **Co-development of objectives aimed at promoting sustainable practices in this landscape**
- **Exhibit strong subnational government leadership**

Table F: Within the Oxford typology examples of how BC projects could be included within a carbon offsetting scheme

Oxford classification	Description	Project type
1) Avoided emissions, or emission reduction without storage	N_2O abatement	Seaweed farming reducing nutrient loading, benthic habitats such as oyster beds reducing nitrification
2) Emissions reduction with short-lived storage	Avoided damage to ecosystems	MPAs to prevent dredging, coastal creep into salt marshes, protection of seagrass and kelp beds
3) Carbon removal with short-lived storage	Ecosystem restoration, carbon storage in sediments	Oyster, seagrass and kelp habitat restoration

This report concludes with carbon sequestration implementation strategies for A&B involving two suggested pilot projects for the mature terrestrial carbon market and a series of short-term recommendations for the emerging marine blue carbon market.

Two key opportunities were identified for the development of pilot projects in the near future around the two existing Woodland and Peatland codes relating to terrestrial carbon markets. The Woodland Carbon Code opportunity focuses on a combined land-use of sheep production and forestry or agro-forestry, which could involve a significant percentage of A&B farmers. Increasing the tree cover in agricultural landscape could generate carbon credits which could be traded for offsetting or used for insetting. **A key recommendation would be to identify existing groups or associations within the agriculture sector to take on the leadership responsibilities. HIE could play a key role facilitating, providing support around the development of business plans, community frameworks and social enterprise around a Woodland Carbon Code project(s) in agro-forestry and potentially supporting capacity building.** The Peatland Code opportunity concerns the peatland restoration in Islay. Many of the supporting functions identified in the Woodland Carbon Code scenario are applicable here**. In terms of implementation, targeting areas on Islay with active erosion would provide the most viable option for projects to generate a profit (i.e. get a bigger return than the project development and maintenance activities might cost). It may be possible to develop Peatland Code applications with applicants who already have capital (e.g. private estates) or with distilleries that own land, and also engage with crofters and farmers and combine Peatland Action and Peatland Code applications where there is a lack of capital for project development.**

For both of these terrestrial pilot projects the implementation strategy requires:

1) **Understanding of the process of application and engagement with existing support mechanisms where they exist**
2) **Identification of project lead(s) (individuals/organisations)**
3) **Understanding/addressing needs/issues of insetting vs offsetting to derive best investment models**
4) **Facilitating capacity building and knowledge exchange across stakeholders to identify and tackle barriers to uptake**

5) Mapping of a pathway to delivering community benefits

The development of marine blue carbon markets lags far behind the terrestrial equivalent and the recommended implementation strategy reflects this. Within A&B it is important to recognise that the majority of the blue carbon stock is held within marine sediments, particularly within sea lochs, and the value of this comes from its protection and/or management. The comparatively smaller vegetated blue carbon stock (macroalgae, seagrass, saltmarsh) has value not only in protection but also in enhancement or restoration**. For the marine sector to move forward we encourage:**

1) **The production of equivalents to the Woodland and Peatland Codes. This process has begun with the development of the "UK Saltmarsh Code". Engagement with this research group may expedite the local application and benefits of the resulting code.**
2) **Incorporation of blue carbon within marine spatial planning frameworks, informing national, regional, and local scale management measures to protect existing carbon stocks. The potential application of spatial/temporal management measures must be explored to distinguish the implications on carbon stocks within designated areas weighed against necessary trade-offs (e.g. exclusion of towed fishing and/or offshore development) to incorporate these measures into the establishment of new marine protected areas.**
3) **Pursue the implementation of carbon offsetting schemes, potentially linked to community-driven habitat restoration projects (such as the Seawilding effort to restore seagrass meadows).**
4) **Applied research is required to understand the potential benefits of seaweed aquaculture on various scales, investigating the rate and fate of carbon export and sequestration as well as the overall environmental sustainability when incorporating various end-uses and markets.**

1 INTRODUCTION

1.1 Project Background

The climate emergency and the just transition to 'net zero' targets mean that carbon markets are already developing. This project will inform and guide both investors and, communities and businesses to ensure that opportunities are realised in a sustainable manner. The substantial land and marine resources of Argyll and Bute offers significant carbon sequestration potential. This project seeks to articulate the scale of the opportunity for the area to attract green financial investment and the scale of the return that this could deliver for the benefit of private and community organisations with land or marine assets, to deal with investors seeking to use sequestered carbon as a means to offset commercial activity.

The project is trying to quantify the carbon sequestration potential of Argyll and Bute's natural resources and works towards providing a vision and methodology for carbon sequestration investment to underpin the local economy, its replicability to the wider region and to support green recovery plus articulate the potential of the area to attract green financial investment and to understand its scale of impact.

The overall project is divided into seven work packages. This report covers:

1. **WP1- An analysis of the current carbon sequestration market in Argyll and Bute**

Establishing the current state of the natural capital within the environment of the region is essential to determine the baseline of both stocks and fluxes against which opportunities for emission reduction or net sequestration can be mapped. This can be achieved by combining GIS-based mapping with desk-based Tier-2 modelling. The next step is to analyse the carbon sequestration supply opportunities as well as analysing the opportunities to secure the "at risk" carbon stored natural assets in the terrestrial and marine environment for the region. A review of the current state of the carbon market, including recent suggestions for investment in carbon assets through aquaculture and terrestrial nature-based solutions is also part of this work package.

2. **WP3- An expert review to establish the viable opportunities for future carbon sequestration in the region, from land and marine based resources**

Significant differences exist between land and sea in terms of ownership, governance, and management, which means that far fewer options currently exist for generating economic value from carbon sequestration in coastal seas than terrestrial areas in Argyll and Bute. The relative effort outlined within WP3 reflects that imbalance with more emphasis on land, but future opportunities for marine carbon sequestration schemes will be reviewed.

This expert review seeks to establish the technically viable opportunities for carbon sequestration in the Argyll and Bute in the context of the existing Woodland Carbon Code and Peatland Code, and to identify any approaches under consideration for the development of soil and marine codes. This consists of assessing credibility, recognising any constraints and recommending which ones could be applied in WP5/6 and results fed back to the developers of the codes. The review also identifies opportunities for aligning the existing codes with community wealth building principles that could potentially add value in Argyll and Bute.

1.2 Document Purpose

This report summarises the methodology employed and findings of the outlining opportunities for carbon sequestration (terrestrial and marine) in Argyll and Bute for work package 1 & 3.

2 ANALYSIS OF CURRENT MARKET ACTIVITIES IN ARGYLL AND BUTE

2.1 A description of the state of the current carbon market in A&B for the environment

2.1.1 Terrestrial environment

There are two main options currently available for trading carbon credits generated from land-use change in the UK. The Peatland Code is a voluntary certification standard for UK peatland projects wishing to market the climate benefits of peatland restoration and provides assurances to voluntary carbon market buyers that the climate benefits being sold are real, quantifiable, additional, and permanent (IUCN Peatland Programme). The Woodland Carbon Code (WCC) is the quality assurance standard for woodland creation projects in the UK and generates independently verified carbon units.

To better understand the current interest and uptake for those schemes, and therefore one aspect of the current carbon market in A&B for the environment, we looked at the UK Land Carbon Registry and searched for projects at any stages of development for both codes. As a reminder, the searchable public database is not a complete listing of all Registered Projects, but only those that the account holder has requested be publicly available – it is therefore possible that further projects exist or are being developed but are not publicly accessible.

2.1.1.1 Peatland code projects

Based on the information available on the public registry there are currently four validated projects in Scotland, none of which are in Argyll and Bute, and a further 35 projects under development, three of which are within Argyll and Bute (Figure 1). The details of the restoration approaches to be used are not provided in the summary but will likely involve techniques such as the creation of peat dams, bunding, hagg and gully reprofiling.

The three projects found within Argyll and Bute are:

- **Dunlossit D1&D2, Bowmore**

This project is the first in a phased restoration plan on the Dunlossit Estate. The project will cover the first two phases, targeting a 272.4 ha area made up of drained blanket bog (255.6 ha), drained blanket bog with haggs and gullies (15.6) and a small area of actively eroding blanket bog with haggs and gullies (1.1 ha). This project is set for duration of 100 years, during which the total predicted emission reduction is 50,774 tCO_2e, with the predicted claimable emission reduction over the project lifetime being 43,158 tCO_2e, with a predicted contribution to buffer over the project lifetime of 7,616 tCO_2e.

- **Duich moss, Laggan estate**

This project is targeting an area of 296.4 ha with a mixture of actively eroding haggs and gullies (2.3 ha), drained with haggs and gullies (42.1 ha) and drained (252 ha). This project is set for duration of 100 years, during which the total predicted emission reduction is 56,933

tCO_2e, with the predicted claimable emission reduction over the project lifetime being 48,393 tCO_2e, with a predicted contribution to buffer over the project lifetime of 8,540 tCO_2e.

- **Carrick Peatland, Carrick Castle estate**

This project is targeting an area of 114.62 ha with a mixture of actively eroding haggs and gully (0.47 ha), actively eroding flat bare peat (0.15 ha), drained with haggs and gully (14 ha) and drained (100 ha). This project is set for duration of 100 years, during which the total predicted emission reduction is 21,597 tCO_2e, with the predicted claimable emission reduction over the project lifetime being 18,357 tCO_2e, with a predicted contribution to buffer over the project lifetime of 3,240 tCO_2e.

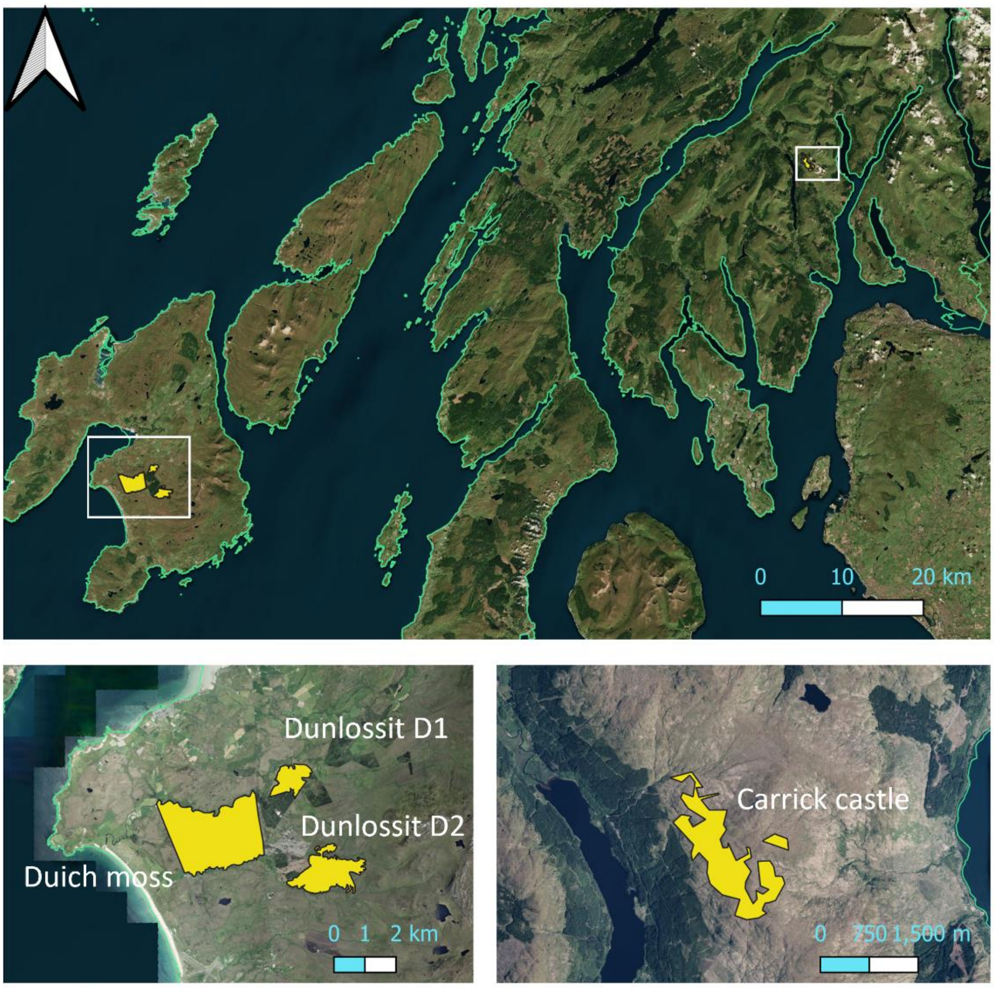

Figure 1: Map of current Peatland CODE projects in Argyll and Bute

2.1.1.2 Woodland Carbon Code projects

While the Woodland Carbon Code supports the human induced conversion to woodland of land that has not been under tree cover for at least 25 years and is not on organic soils (peat depth >50 cm), the carbon credits generated for any given projects also depend on a wide range of management activities, from the choice of the species planted (individual species, mixed species, broadleaf, conifers), the site preparation (vegetation removal, fencing, spacing of trees, mounding), the thinning or clearfelling regimes, etc. All of these and their associated C emissions are detailed in the guidance document on the Woodland Carbon Code website. Based on the information from the registry, there are currently 662 Woodland Carbon Code projects in Scotland, 45 of which are within Argyll and Bute. One of these projects appears as "Not delivered", while 11 are validated (Table 1), and a further 34 projects are under development (Table 2). Within the validated projects, two appear under the project category *"Mixed mainly continuous cover system"*, one under *"Mixed, mainly thinning"* and the remaining eight are under "*No thinning or clearfell"*. Overall, the validated projects have a total predicted carbon sequestration of 185,612 tCO2e, of which 148,490 tCO2e would be claimable over a total area of 428.81 ha.

The projects under development are split between the categories *"Mixed mainly clearfell"* (12), "*No thinning or clearfell"* (12), "*Mixed mainly thin and clearfell*" (4), "*Mixed mainly thinning*" (2), *"Mixed mainly no thin or clearfell"* (1), "*Thin and clearfell*" (1), "*Thin only*" (1), and "*Continuous cover system*" (1). Overall, the projects under development have a total predicted carbon sequestration of 823,040 tCO2e, of which 658,432 tCO2e would be claimable over a total area of 2,598.82 ha.

Table 1: Details of validated Woodland Carbon Code projects within Argyll and Bute

Name (category)	Total Area (ha)	Conifer (>80%) (ha)	Mixed Predominantly Conifer (50-80%)	Broadleaved (>80%)	Mixed Predominantly Broadleaved (50-80%)	Project Duration (years)	Total Predicted C Sequestration (tCO2e)	Predicted Claimable C Sequestration (tCO2e)	Predicted Contribution to Buffer (tCO2e)
8 Dalnabreac (No thinning)	16.2	0	0	16.2	0	65	4,229	3,383	846
Accurrach (No thinning)	32.31	0	0	32.31	0	100	12,956	10,365	2,591
Ballygowan (Mixed, mainly thinning)	83.58	0	0	83.58	0	100	36,796	29,437	7,359
Dunlossit Planting Phase 1 (No thinning)	114.93	0	0	114.93	0	100	33,766	27,013	6,753
Forest Carbon Group Scheme 10 - Millhouse (Mixed, mainly continuous cover system)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Forest Carbon Group Scheme 10 - Stronafian House (Mixed, mainly continuous cover system)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Glenorchy Farm Native Woodland (No thinning)	27.33	0	0	27.33	0	100	15,326	12,261	3,065
Lochgair(No thinning)	20.66	0	0	20.66	0	100	12,925	10,340	2,585
Luing Woodland Creation (No thinning)	90.2	0	0	90.2	0	100	54,466	43,573	10,893
Ruantallain Estate - Rozga's Wood NWC (No thinning)	43.6	0	0	43.6	0	65	15,148	12,118	3,030
Total	***428.81***	***0***	***0***	***428.81***	***0***	***730***	***185,612***	***148,490***	***37,122***

Table 2. Details of Woodland Carbon Code projects under Development within Argyll and Bute

Name	Total Area (ha)	Conifer (>80%) (ha)	Mixed Predominantly Conifer (50-80%)	Broadleaved (>80%)	Mixed Predominantly Broadleaved (50-80%)	Project Duration (years)	Total Predicted Carbon Sequestration (tCO2e)	Predicted Claimable Carbon Sequestration (tCO2e)	Predicted Contribution to Buffer (tCO2e)
Ardachuple (Mixed mainly clearfell)	69.25	29.71	0	39.54	0	100	25,719	20,575	5,144
Arden Estate Woodland Creation 2020 (Mixed no thin or clearfell)	23.39	0	0	0	23.39	95	14,377	11,502	2,875
Ardtornish Phase 2 Loch Tearnait and Achranich Blocks B, C and F (No thinning or clearfell)	83.36	0	0	83.36	0	100	38,986	31,189	7,797
Ardtornish woodland creation phase 1 Block D (No thinning or clearfell)	11.6	0	0	11.6	0	100	5,473	4,378	1,095
Ashens Forest (Mixed mainly clearfell)	69.2	50.97	0	18.23	0	55	16,635	13,308	3,327
Cameron Farm (No thinning or clearfell)	24.75	0	0	24.75	0	100	8,151	6,521	1,630
Carr Seasg (No thinning or clearfell)	24.93	0	0	24.93	0	50	6,355	5,084	1,271
Castle Lachlan (Mixed, mainly thin and clearfell)	152.46	0	152.46	0	0	100	36,484	29,187	7,297
Coire Aodainn (Mixed mainly clearfell)	73.53	39.71	0	33.82	0	65	15,195	12,156	3,039
Coire Ealt (No thinning or clearfell)	32.97	0	32.97	0	0	50	7,456	5,965	1,491

Name	Total Area (ha)	Conifer (>80%) (ha)	Mixed Predominantly Conifer (50-80%)	Broadleaved (>80%)	Mixed Predominantly Broadleaved (50-80%)	Project Duration (years)	Total Predicted Carbon Sequestration (tCO2e)	Predicted Claimable Carbon Sequestration (tCO2e)	Predicted Contribution to Buffer (tCO2e)
Corrachaive Farm (Mixed mainly thinning)	9.45	0	0	9.45	0	100	5,933	4,746	1,187
Dalness (No thinning or clearfell)	62.94	0	0	62.94	0	100	36,836	29,469	7,367
Glenkerran (Mixed mainly clearfell)	67.17	67.17	0	0	0	45	13,534	10,827	2,707
High Park (No thinning or clearfell)	28.55	0	0	28.55	0	55	10,796	8,637	2,159
Homeston (Mixed mainly clearfell)	34.82	26.25	0	8.57	0	45	11,893	9,514	2,379
Inverchaolain (Mixed mainly clearfell)	290.74	151.79	0	138.95	0	100	67,360	53,888	13,4272
Inveryne Woodland Restoration (No thinning or clearfell)	15.76	0	0	15.76	0	100	5,906	4,725	1,181
JDM - Group 1 – Allt Beithe (Mixed mainly clearfell)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
JDM - Group 1 – Cruach Moine (Mixed mainly clearfell)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Kate's Cottage Wood (Continuous cover system)	6.92	0	0	6.92	0	100	2,549	20,39	510
Kilchoan-Melfort Hill (No thinning or clearfell)	75.62	0	0	75.62	0	95	40,690	32,552	8,138
Kildavie New Woodland Creation (Mixed mainly clearfell)	48.77	43.71	0	5.06	0	45	12,115	9,692	2,423

Name	Total Area (ha)	Conifer (>80%) (ha)	Mixed Predominantly Conifer (50-80%)	Broadleaved (>80%)	Mixed Predominantly Broadleaved (50-80%)	Project Duration (years)	Total Predicted Carbon Sequestration (tCO2e)	Predicted Claimable Carbon Sequestration (tCO2e)	Predicted Contribution to Buffer (tCO2e)
Killiechonich (Mixed, mainly thin and clearfell)	12.23	12.23	0	0	0	35	2322	1,858	464
Letrault & Stuckenduff Woodland Creation	181.54	181.54	0	0	0	55	32,006	25,605	6,401
Loch Riddon Wood (Mixed, mainly thin and clearfell)	69.61	41.6	0	28.01	0	100	17,126	13,701	3,425
Otter Hill (Mixed mainly clearfell)	158.11	121.41	0	36.7	0	65	45,917	36,734	9,183
Otter Woodland Creation (Mixed mainly thinning)	130.74	101.98	0	28.76	0	65	57,024	45,619	11,405
Rest and Be Thankful Phase 1 (Thin only)	50	0	0	0	50	100	22,493	17,994	4,499
Rosehall West Plantation Phase 1 (Mixed mainly thin and clearfell)	25.44	25.44	0	0	0	45	6,691	5,353	1,338
Talatoll New Woodland Creation (Mixed mainly clearfell)	363.87	317.03	0	46.84	0	45	112,700	90,160	22,540
Three Bridges (Mixed mainly clearfell)	15	10	0	5	0	45	5,324	4,259	1,065
Torosay Hill Estate - Na Badain (No thinning or clearfell)	136.8	0	0	136.8	0	100	49,275	39,420	9,855
Torosay Hill Estate – Scallastle (No thinning or clearfell)	109.8	0	0	109.8	0	100	39,575	31,660	7,915

Name	Total Area (ha)	Conifer (>80%) (ha)	Mixed Predominantly Conifer (50-80%)	Broadleaved (>80%)	Mixed Predominantly Broadleaved (50-80%)	Project Duration (years)	Total Predicted Carbon Sequestration (tCO2e)	Predicted Claimable Carbon Sequestration (tCO2e)	Predicted Contribution to Buffer (tCO2e)
Torosay Hill Estate - Strath Bearnach (No thinning or clearfell)	139.5	0	0	139.5	0	100	50,144	40,115	10,029
Total	***2598.82***	***1220.54***	***185.43***	***119.46***	***73.39***	***2455***	***823,040***	***658,432***	***285,408***

2.1.1.3 Peatland ACTION projects in Argyll and Bute

As well as the Peatland CODE[1], Peatland ACTION[2] is another route to access funding for peatland management but it doesn't generate verified carbon credits. Peatland ACTION is the Scottish Government's programme of peatland restoration, supporting capital investments in restoration management, project development and monitoring and feasibility studies. Peatland ACTION includes a need for sites to be maintained in suitable conditions post-restoration, the cost of which is not covered by the project. However, projects undertaken through Peatland ACTION can be combined with Peatland CODE and Agri-Environment and Climate Scheme (see below). On their own, Peatland ACTION do not generate any income for landowners or land manager: instead, it is a programme aimed to offset the large upfront capital costs of large-scale intervention and a key incentive to landowners is the free service of project development and delivery, covering all the steps from initial project mapping to procurement of contractors, site verification, and project sign off.

Since its inception in 2012, Peatland ACTION has supported the restoration of 25,000 ha of peatlands across Scotland. In February 2020, the Scottish Government announced a substantial, multi-annual investment in peatland restoration of more than £250 million over the next 10 years, linked with an increased target of 20,000 ha of peatland put on the road to recovery annually.

There are currently several Peatland ACTION projects completed or underway in Argyll and Bute. While the public repository of project includes geographical coordinates, it doesn't include project area for any given project, or detailed project maps. A total of 10 feasibility studies are included in the public repository, two in 2015-16, six in 2017-18 and two in 2018-19. Nine projects involve restoration, one in 2012-13, two in 2013-14, one in 2014-15, two in 2018-19 and three in 2019-2020. By contrast, only one project involved monitoring (carbon flux) in 2014-15 and two projects included other eligible activity, namely *Rhododendron ponticum* control (2015-16) and volunteer engagement through the "Bog Squad" with Butterfly Conservation (2017-18 and 2018-19).

2.1.1.3.1 Agri-Environment and Climate Schemes

Payments for Ecosystem Services (PES) that promote non-marketable carbon sequestration are also available to promote land use change within Argyll and Bute. PES are used to describe financial incentives for land managers which maintain or improve ecosystems beyond what is required for regulatory compliance (Kuhfuss et al., 2018).

The Agri-Environment Climate Scheme (AECS) promotes land management practices which protect and enhance Scotland's natural heritage, improve water quality, manage flood risk and mitigate and adapt to climate change (Scottish Government, 2022). There is no available public register of AECS payments available for the Argyll and Bute area, and therefore it was not possible to document uptake of those schemes within the region. However, from the Scottish Budget 2022-23, over £50 million have been allocated to support the farming sector

[1] Introduction to the Peatland Code | IUCN UK Peatland Programme (iucn-uk-peatlandprogramme.org)
[2] Peatland ACTION Project | NatureScot

in tackling the climate and nature emergencies and to produce food more sustainably, including £10 million for the National Test Programme[3] to transform agriculture and £35.8 million for agri-environment schemes. This figure is of similar magnitude to the £34.2 million in the 2021-22 budget.

Further details are provided in WP3 regarding the currently available options that could support sustainable management of peatlands and woodlands and provide income to landowners and managers.

2.1.1.3.2 Forestry grant schemes in Argyll and Bute

The Forestry Grant Scheme (FGS) offers financial support for the creation of new woodland and the sustainable management of existing woodland. Within the scheme, there are a range of support options covering planting, woodland protection, harvesting and other costs associated with woodland in Scotland (Scottish Forestry, 2022a). Scottish Forestry (2022b) provide a public register which contains details of FGS and approved applications for Argyll and Bute can be found in (Table 3).

Based on the information from the registry, there are 74 approved FGS projects in Argyll and Bute. Of these projects broadleaf (30), conifer (15), and mixed developments (29) were characterised. FGS has supported 2,262 hectares of broadleaf creation, 3,273 hectares of conifer creation, and a total of 5,535 hectares of woodland creation. There are no carbon sequestration figures given on the FGS register.

In 2020 it is estimated that 1,462 hectares of new woodland creation was supported by FGS in Argyll and Bute (Scottish Forestry, 2022c).

Table 3: Details of Forestry Grant Scheme projects under Development within Argyll and Bute

Property Name	Total Area (Ha)	Broadleaf Area (Ha)	Conifer Area (Ha)
Inveryne Native Woodland	16.26	16.26	0
Kildavie New Woodland Creation 2022	54.88	1.5	53.38
Cruach Moine	48.28	12.62	35.66
Auchgoyle Farm Woodland Creation	10.12	10.12	0
Homeston NWC	37	4.79	32.21
Arden Woodland Creation 2020	26.4	18.74	7.66
Coire Aodainn Invernoaden	87.21	49.33	37.88
Castle Lachlan NWC 2020	168.74	18.11	150.63
Allt Beithe	50	0	50
Barachander Farm Woodland Creation	383.48	101.47	282.01
Luing Woodland Creation	104.79	104.79	0
Ardlamont House Woodland Creation 2020	11.15	0	11.15
Otter Hill Woodland Creation	165.56	22.24	143.32
Tormisdale Woodland Creation	3	3	0
Over Innens New Woodland Creation 2019	53.25	53.25	0

[3] Ambitious future for rural Scotland - gov.scot (www.gov.scot)

Property Name	Total Area (Ha)	Broadleaf Area (Ha)	Conifer Area (Ha)
Killiechonich	13.8	0	13.8
Coire Ealt Invernoaden	38.66	38.66	0
Millhouse	29.44	23.38	6.06
Otter Estate NWC 2019	144.58	17.17	127.41
Achnacarron Cottage Woodland Creation	2.75	2.75	0
High Park NWC 2019	5.12	5.12	0
CAMERON FARM WOODLAND CREATION	28.59	28.59	0
Glenkerran	73.87	3.01	70.86
Torosay Woodland Restoration	423.07	423.07	0
Ashens NWC	78.45	11.45	67
Three Bridges NWC	16.65	4.35	12.3
Glenorchy Farm Native Woodland	31.63	31.63	0
Kilchoan Melfort NWC 2018	87.87	87.87	0
Talatoll New Woodland Creation	397.19	24.29	372.9
Ardachuple	76.86	32.13	44.73
Loch Riddon Wood	76.91	25.91	51
Achalic woodland creation	3.91	3.91	0
Lochgair Woodland Creation	20.59	20.59	0
Stronafian house	19.34	13.06	6.28
Ruantallain New Woodland Creation 2019	51.25	51.25	0
Carr Seasg Woodland Creation	28.8	28.8	0
Arinafad Beg New Woodland Creation	7.56	0	7.56
Creagan Loisgte	27.7	18.6	9.1
Dunlossit FGS Woodland Creation	144.08	144.08	0
Cove Park New Native Woodland	3.62	3.62	0
Drumardoch Dell Low Density Native Woodland	6.11	6.11	0
Asknish New Woodland Creation	4.05	4.05	0
Ballimore Estate Woodland Creation	77.99	11.3	66.69
Accurrach Native Woodland Creation	38.01	29.17	8.84
Creag an Fhithich	20.4	12.4	8
Invergaunan Woodland Creation	326.79	76.12	250.67
Succothmore	495.66	13.42	482.24
Kilfinan Burn	45	0	45
Highfields New Woodland Creation	12	12	0
Brackley Farm Woodland Creation	34.95	34.95	0
Blairmore Creagan	13.8	13.8	0
Clachaig new planting	5.76	0	5.76
High Park New Woodland Creation 2017	89.09	37.17	51.92
Duncholgan Field	8.28	0	8.28
Achnaba Quarry Park	10.36	0	10.36

Property Name	Total Area (Ha)	Broadleaf Area (Ha)	Conifer Area (Ha)
Carskiey Woodland Creation 2017	54.97	54.97	0
Leckuary New Woodland Creation 2018	19.2	0.45	18.75
Ballygowan	93.96	93.96	0
Creag Bhreac	10.13	0	10.13
Kildavie Woodland Creation	38.04	0	38.04
Glenfinart Planting B	60.51	60.51	0
Carrick Estate Glenfinart and Carrick Low Density Planting	189.56	50	139.56
Achnacarron Woodland Creation	114.6	114.6	0
Balliemeanoch	46.21	46.21	0
Castleton Ben Mhor	5.15	5.15	0
WC Inverchaolain	259.16	80.5	178.66
Glen Fruin NWC	49.7	2.6	47.1
Stillaig Compartment 1	14.27	0	14.27
Scammadale Woodland Creation	143.97	27.94	116.03
Silver Craigs	9.52	0	9.52
Achnaba 3	7.93	0	7.93
Auchoish	25.16	0	25.16
Barmolloch 3	137.02	0	137.02
Stuckendroin 2016	15.45	15.45	0

2.1.1.3.3 Summary

Based on the publicly available data, the total claimable emission reductions over the projects' lifetime in Argyll and Bute would be 916,830 tCO2e, split between 109,908 tCO2e for a total of 656.37 ha of Peatland CODE projects, and 806,922 tCO2e for a total of 3,027,63 ha of Woodland Carbon Code projects. The financial details of these projects, including the price per ton of carbon agreed, are not available on the public registry, therefore it is not possible to speculate on the value of these projects.

While there is evidence of engagement with Peatland ACTION and Peatland CODE and therefore a likely interest in C market opportunities from peatland management in Argyll and Bute, this is somewhat tentative (Figure 2). With a pledge of £250M for peatland restoration through Peatland ACTION between 2021-2030, and the possibility to develop multi-year projects, it is likely that there will be growth in uptake. Some sectors appear to be more engaged with peatland restoration schemes, for example the NGOs (RSPB, Butterfly Conservation, Scottish Wildlife Trust), and some of the private estate (e.g. Laggan estate, Poltalloch Estate, Carrick Estate). It is likely that the complex application process and relative immaturity of the Peatland CODE explains the small uptake, but interest and growth of the appetite for marketable carbon from peatland restoration is anticipated and is already being observed in other parts of the UK. Barriers, issues and potential avenues forward are discussed in more details in WP3.

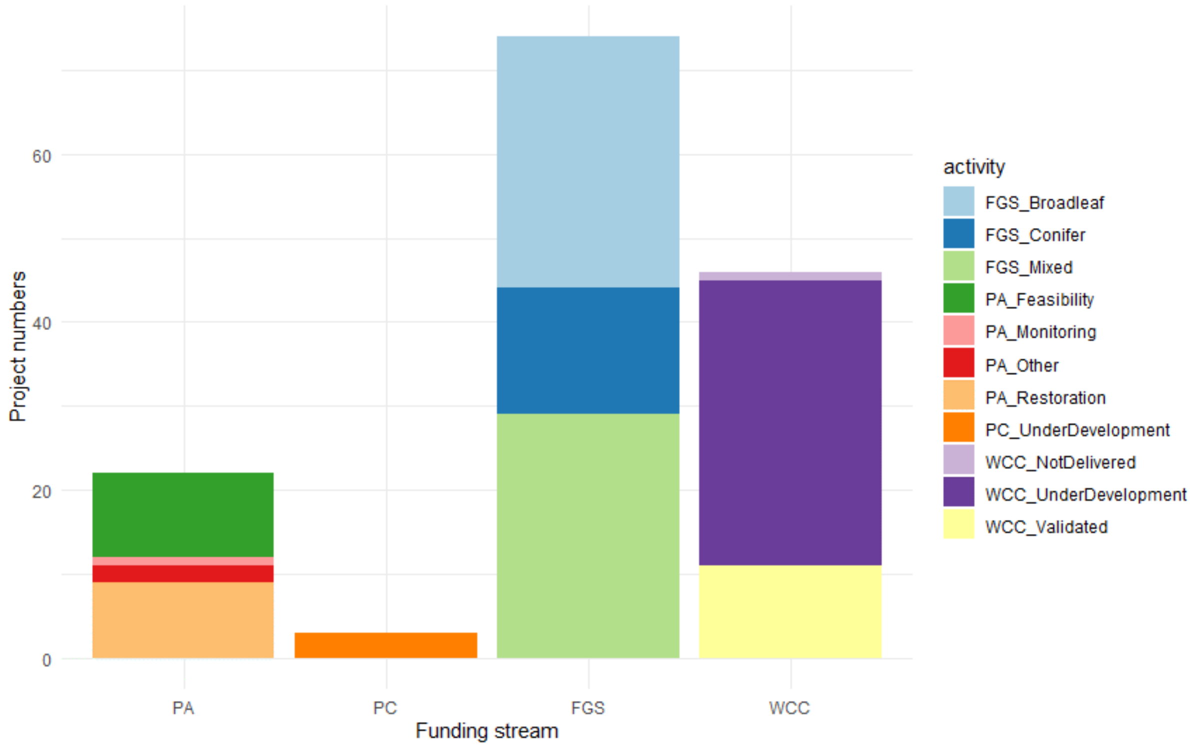

Figure 2: Total number of projects funded through Peatland ACTION (PA), Peatland CODE (PC), Forestry Grant Schemes (FGS) and Woodland Carbon Code (WCC) in Argyll and Bute across a range of activities/statuses.

On the other hand, it is clear from more widespread engagement with Woodland Carbon Code and Forestry Grant schemes (Figure 2) that there is an appetite for activities supporting the development and increase of Woodland cover in Argyll and Bute, and that this is partly motivated by financial rewards available through existing schemes. This may be a consequence of the more mature process and generally favourable public perceptions of woodlands (Nijnik and Mather, 2008).

2.1.2 Marine environment

2.1.2.1 Current Blue Carbon Market

The concept of carbon offsetting, receiving credits for reducing carbon emissions or through funding additional carbon sequestering projects to combat climate change, is relatively new. These initiatives are now well established in terrestrial environments that deal in Green Carbon, with significant focus on dry land forestry projects where trees are planted due their carbon sequestration abilities (Van Kooten et al., 2004). While progress has been made in recent years to expand these carbon credit systems to the Blue Carbon (BC) held in marine environments, the BC market remains largely underdeveloped when compared to Green Carbon markets. To date, research into developing a BC market has been focused on the preservation and restoration of ecosystems such as saltmarshes, sea grass and mangroves, which have vast capabilities when it comes to carbon sequestration (Himes-Cornell et al., 2018). There are many organisations focused on this area of work which are benefiting from the recent increase in interest into the potential impact BC habitats could have on reducing carbon levels. REDD+ (Reducing Emissions from Deforestation and forest Degradation) Mangrove Project Development is one such platform, which allows individuals, corporations and investors to donate or fund projects aimed at conservation, restoration and reforestation activities (BlueCarbonProjects, 2022).

Companies have begun to utilise carbon credit systems put in place to offset their own emissions and invest money back into conserving the ecosystems that they are impacting. Stripe, a technology company based in San Francisco is one example of this having recently committed 8 million USD in funding to various carbon offsetting initiatives (Stripe, 2021). Several of the companies receiving money through this funding are focusing on BC initiatives, Running Tide being an example. Their projects are currently aimed at removing or reducing carbon in the ocean. One method being investigated is the growing and then sinking of kelp in the deep ocean in the expectation that the carbon is stored on geological timescales. However, there is a lack of scientific evidence to validate this approach. They are also focused on ecosystem restoration and development of sustainable shellfish production (RunningTide, 2022).

Verra is one of the most widely used registries when it comes to the verification and policing of carbon credits; the organisation is based in Washington and runs the Verified Carbon Standard offset program. Verra has certified more than 855 million carbon credits, this has been achieved through almost exclusively terrestrial projects focusing on deforestation and reduced emissions from manufacturing. In 2021 Verra expanded their credit system to include blue carbon credits, from projects that focus on the conservation, restoration and expansion of mangroves, salt marshes, and seagrasses (VERRA, 2021), but has a current working group developing a macroalgae standard.

Opportunities have now become available for individuals to offset their carbon emissions using companies such as 'Gold Standard', which allows people to calculate their personal impact and purchase carbon credits to help reduce their carbon footprint (GoldStandard, 2022). There is increasingly more information becoming available on the value of a carbon credit which will make the market a more accessible concept for individuals and companies to invest in. Seastainable is another company offering people the opportunity to offset their carbon footprint though their 'Blue Carbon Package'. This company gives very specific details on what is being funded through the purchasing of these packages. Every purchased package is to plant 3 Mangrove Seedlings, 1 Seaweed seedling, and funding research for sustainable seagrass bed planting in Dompak Island, Bintan (SeastainableCo., 2022).

An area which has not yet been developed into an established market within the BC space, but has exciting potential, is Aquaculture. There has been considerable progress made in this area, with the first successful trade in carbon credits from the aquaculture sector made in China in 2021. Through a pilot project they have realised the blue carbon market potential for macroalgae, and shellfish cultivation given the large consumer market for both products in China (Committee, 2022).

2.1.2.2 Seaweed and Shellfish Aquaculture as it Relates to A&B

Seaweed cultivation is an emerging form of aquaculture in Scotland which has experienced a rapid growth of interest in recent years. Small scale trials on seaweed cultivation were carried out in 2004, however there still remain a number of issues preventing seaweed farming from reaching its full potential in Scotland. Work has been carried out in this area to determine the feasibility of seaweed cultivation and provide guidance for potential investors or business wishing to expand into this market (Stanley et al., 2019).

The initial trials carried out into seaweed production in Scotland focused on the growth of *Palmaria palmata* and *Saccharina latissima* and their use as a form of bioremediation at the Calbha salmon farm sites operated by Loch Duart on the Northwest Coast. While there was an increase in biomass yields of up to 63% when placed in close proximity to the fish farms, there were still questions regarding the use of the seaweed post-harvest. Seaweed farming in Scotland has taken place from Loch Fyne in the south to Lewis and Shetland in the north. In 2012 The Scottish Association for Marine Science (SAMS) developed a trial site based on a mussel cultivation system in the Sound of Kerrera and a grid system based at Port a Bhuiltin in 2014 (Sanderson et al., 2012). There has been a shift in focus from the use of seaweed in bioremediation and biofuels, to food and higher value products (e.g., cosmetics). The development of the SAMS Seaweed Academy aimed at cultivating the necessary skills to effectively manage a seaweed farm will further enable growth in this sector and elevate Scotland's position in the global seaweed market. Based on the current knowledge of requirements for seaweed species in inshore habitats, the suitability of A&B was analysed as a potential area for growth in seaweed farming. It was determined that based on several environmental factors (wave fetch, depth and the freshwater inputs on salinity), a number of areas in the A&B region would be suitable locations for seaweed farms (Sanderson et al., 2012).

Shellfish aquaculture is already a significant and established industry in Scotland, located primarily on the west coast where, due to the geography, there are a many ideal sites for shellfish production. Shellfish production is largely focused on mussels followed by pacific oysters, with lower levels of native oysters and scallops also being produced. Based on the Scottish Shellfish Farm Production Survey 2020 there are currently 313 active farm sites in Scotland, with the total valuation of production in 2020 reaching approximately £6.1 million. Of these sites, 69 are located in the Highlands, the region that includes A&B. There are currently 300 people employed on either a full-time or part-time basis by the shellfish farming industry in Scotland, the majority of these positions would be located in rural areas where employment opportunities are often low (Munro, 2020).

Different methods are used to farm seaweed depending on the existing infrastructure, and the requirements of the farm in terms of production biomass. For example, the double-headed rope system is most commonly used when repurposing an existing mussel site for seaweed production but otherwise would not be economically viable due to the biomass constraints (Figure 3).

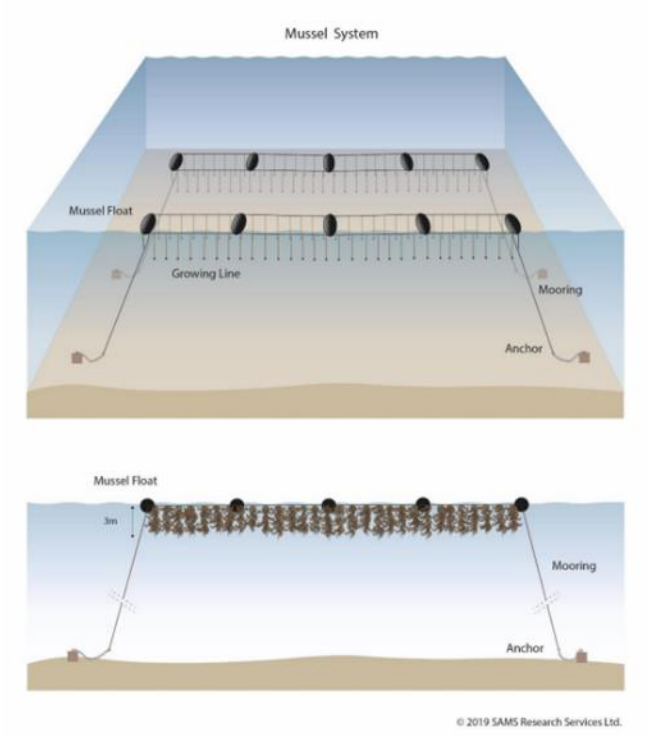

Figure 3: Diagrammatic view of a pair of double-headed rope mussel systems used for seaweed cultivation. © SAMS Enterprise Copyright, All rights reserved

Longline systems are simple, cheap construction, generally with moorings every 100 m. The moorings can be made using various materials depending on availability including concrete blocks or eco-anchors containing local stone. They are easy to handle due to the growing line being loose, this allows for regular inspection. Space is left between parallel lines to avoid interaction during storm events. This system is not economical at a large scale due to the need for many anchors.

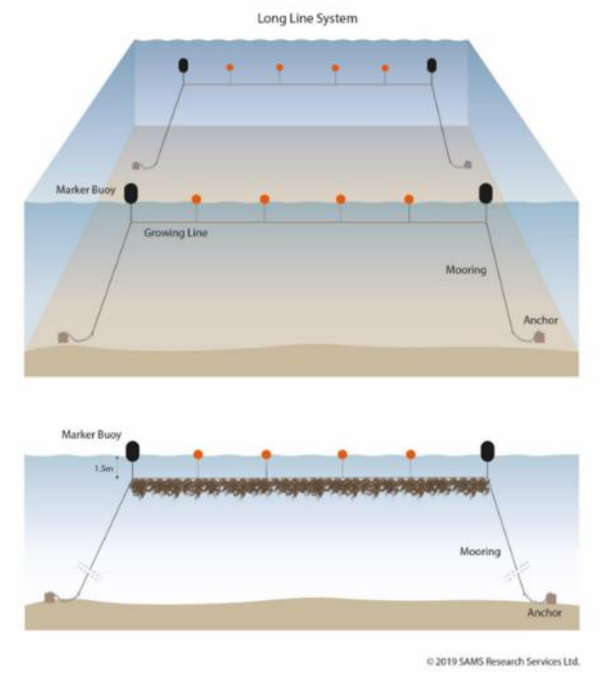

Figure 4: Diagrammatic view of a grid-based system used for seaweed cultivation. © SAMS Enterprise Copyright, All rights reserved

Grid systems are suitable if space constraints are an issue with the farm location (Figure 4 & 5). Once the grid is assembled it requires less anchorage than longline systems, but due to the grid being tensioned below the water, it can be difficult to gain access to the growing lines from the surface without a mechanical winch.

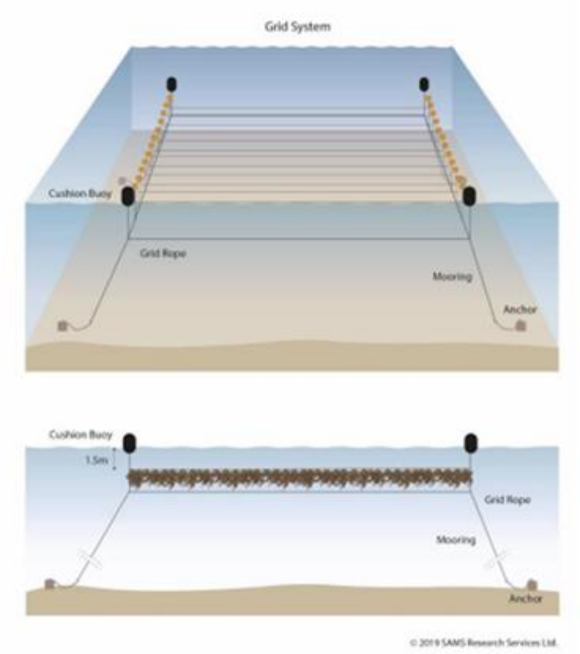

Figure 5: Diagrammatic view of a grid-based system used for seaweed cultivation. © SAMS Enterprise Copyright, All rights reserved

Mussel cultivation in Scotland is carried out by growing the mussels on vertical ropes or fabric, which are then suspended in the water from heavy horizontal ropes and flotation buoys arranged in long lines normally parallel to the shoreline. The most common practice uses the double-headed rope system, as pictured above. Scallops can be grown using a similar method, hanging from lines or they can also be grown in small, suspended net enclosures known as lanterns. Oysters are most commonly grown in bags which are made from heavy plastic mesh, these are then set up on platforms known as trestles or in baskets suspended from frames (Scotland's Aquaculture, 2022).

It is important to consider the carbon cost associated with production of the infrastructure used during seaweed and shellfish related aquaculture practices when determining if they act as a net source or sink of carbon. If determined as the latter, the incorporation of these associated carbon costs would add integrity to increase assurance in aquaculture-related carbon stocks.

2.1.2.3 Blue Carbon Potential in Aquaculture

Aquaculture is the fastest growing animal-based food industry of the last few decades, due in part to an improvement in productivity and an expansion of the global market. While seaweed cultivation has largely been focused on in Asian countries, where over 95% of production occurs, its importance is now being recognised in terms of the global food market (Chung et al., 2017). With seaweed aquaculture in such a period of growth, significant opportunities to develop methods which contribute to climate change mitigation are achievable. There is even potential to contribute significantly to the offset of CO_2 emissions from agriculture on a regional level, according to a study carried out into the potential for blue growth in the mitigation of climate change (Froehlich et al., 2019). They found that while offsetting global emissions is unlikely, in certain areas at the right scale seaweed farming could create a carbon-neutral agriculture sector.

The total level of carbon sequestered in cultivated seaweed is small in comparison to wild stocks and is only estimated to reach an upper limit of 6% by 2050, this is largely down to the vast difference in area covered. Its current carbon capture potential is estimated to be around 1500 tonnes CO_2 km^2 /year (Duarte et al., 2017). Based on a recent report stating production of farmed seaweed could be 24,000 tonnes (Scottish Government, 2022a) by 2040, this would equate to approximately 3600 tonnes CO_2. It is thought that if seaweed is harvested later in the season, it could increase the carbon export by 30-50%. This carbon must then be permanently buried for it to be considered fixed and inaccessible to the biosphere. This can be done by sinking seaweed in the deep ocean, however the impact this could have on these ecosystems is unknown and needs to be further studied (Fieler et al., 2021). In countries like China where the seaweed industry is well established due to the high market demand, the environmental impacts of seaweed aquaculture have been more closely examined. They found that alongside the removal of phosphate and nitrogen there was significant sequestration of carbon (Zheng et al., 2019).

Green wave is a company already utilising the research carried out into the potential carbon sequestration properties of seaweed aquaculture to directly pay farmers for the environmental impact of their work, through the pilot Kelp Climate Fund project. The farms participating in this project provide up to date measurements of their crop's growth, these along with additional sampling carried out monthly are used to calculate the carbon and nitrogen removal and reef restoration (GreenWave, 2022).

Shellfish cultivation has long been considered a low emission form of aquaculture when compared with its land-based equivalent (Jones et al., 2022). However, when compared with seaweed, there have been far fewer studies carried out investigating the potential for shellfish aquaculture's role in carbon sequestration. While work is ongoing in this area there are a significant number of mitigating factors to consider when determining the potential for cultivated shellfish as a carbon sink. A study carried out in the Sacca di Goro lagoon, located in the southernmost part of the Po River Delta, in the north-western Adriatic Sea determined that the farming of the manila clam (*Ruditapes philippinarum*) is not only a fully sustainable aquaculture practice but also has potential to act a carbon sink. The study found that the amount of CO_2 sequestered by the manila clam results in the farming operations acting as a net sink for carbon. This was quantified in the study as 1 ton of clams at the end of their growing cycle sequestering 54.5 kg of C, which corresponds yearly to a total of 723.8 tonnes of C in the whole lagoon (Turolla et al., 2020).

While Oyster cultivation on its own has not yet been determined to have long term carbon sequestration capabilities, it is possible that cultivating it alongside other species such as eelgrass could result in a net carbon sink. A study carried out into the feasibility of this method of oyster cultivation was carried out in the French Mediterranean Sea and the Seto Inland Sea of Japan, found that spat growth and survival rate after the settlement were significantly higher in eelgrass beds. They concluded that it may be possible to use the proximity of the eelgrass beds to mitigate any carbon production from the oyster farming (Hori et al., 2021). Despite the significant amount of research carried out around shellfish in blue carbon, there is still limited evidence available to quantify the potential for cultivated shellfish to sequester carbon (Scottish Government, 2022a). Currently production of seaweed in Argyll and Bute is less than 1000 tonnes and represents an insignificant amount of CO_2 being fixed.

2.1.2.4 The potential for Seaweed and Shellfish Aquaculture to be included in Blue Carbon trading Schemes

For seaweed and shellfish aquaculture to be included in blue carbon trading schemes it can be expected that any project could be aligned with current blue carbon trading schemes, using similar frameworks, definitions and exclusions. Currently (as of February 2022) the number of operational blue carbon verification methodologies is limited and those methodologies that are currently used have been questioned scientifically (Johannessen et al. 2016). However, within the technical limitations of current scientific understanding, the methodology and framework developed by the registry Verra (VM0033, 2021) is coherent and rigorous, and could be used to explore how similar frameworks would be applied to seaweed and shellfish farming (Oreska et al., 2018).

Within the Verra methodology for tidal wetland and seagrass restoration, there are essentially four mechanisms through which a project can generate GHG emission reductions or removals:

- Increased biomass (above or below ground)
- Increased autochthonous soil organic carbon

- Reduced methane and/or nitrous oxide emissions due to increased salinity or changing land use
- Reduced carbon dioxide emissions due to avoided soil carbon loss

An important consideration of this approach is that there are defined temporal and spatial boundaries around these projects and for the mechanisms for GHG emissions or reductions. In terms of spatial boundaries, the geographical boundaries of one or more discrete area must be defined.

Using these four criteria as a benchmark it is possible to examine the carbon pools and fluxes, along with the fluxes of other GHG that are associated with seaweed and shellfish aquaculture to inform a discussion on their suitability to be included within a BC trading scheme.

2.1.2.5 Seaweed Aquaculture

The ecological role of kelp forests is well studied and the contribution that these habitats make to coastal carbon fluxes is relatively well understood and quantified (see figure 6) (Krause-Jensen & Duarte 2016).

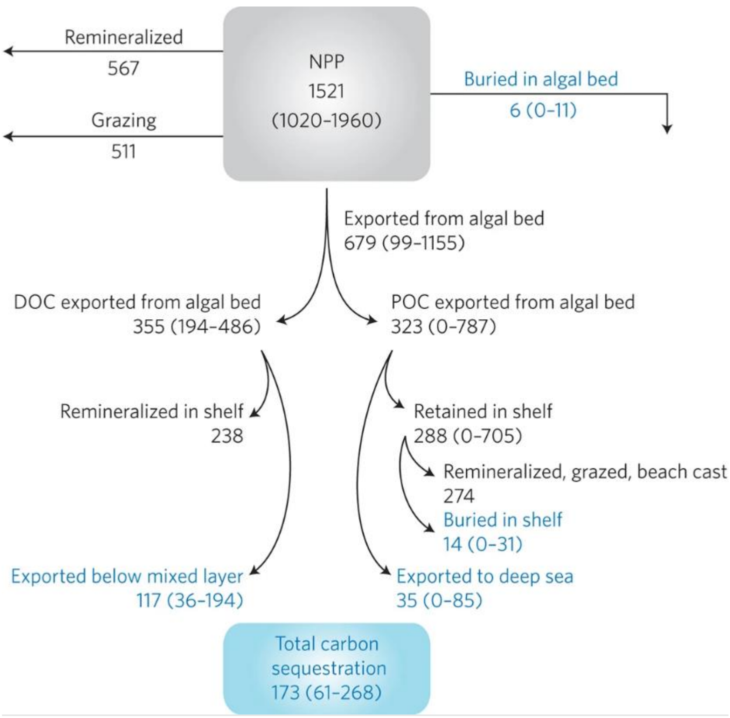

Figure 6: Ecological role of kelp forests

It is clear that kelp ecosystems play a significant role in coastal blue carbon systems (see 2.2.2.1.3). However, there are a number of areas where seaweed ecosystems and seaweed aquaculture differ in terms of their carbon pools and flows. Using the mechanisms described above, the implications of the difference between kelp forests and seaweed aquaculture systems can be examined.

2.1.2.5.1 Increased biomass (above or below 'ground)[4]

Unlike many blue carbon rich habitats such as salt marshes or sea grass beds, the largest carbon pool in both seaweed aquaculture and kelp forests is not in the sediment, but in the above 'ground' biomass. For seaweed aquaculture where the biomass is grown on artificial structures (often ropes) suspended within the photic zones and above the substrate, the entirety of the biomass can be classified as above ground. For seaweed aquaculture likely to take place in A&B (see section 2.1.2.2) there is an annual production cycle, where biomass will effectively grow from zero (as the seeded line is placed out into the open sea) normally in early winter, and then the biomass rapidly increases until harvest, normally in early summer (See Figure 7) for a Norwegian example. (Broch et al., 2019).

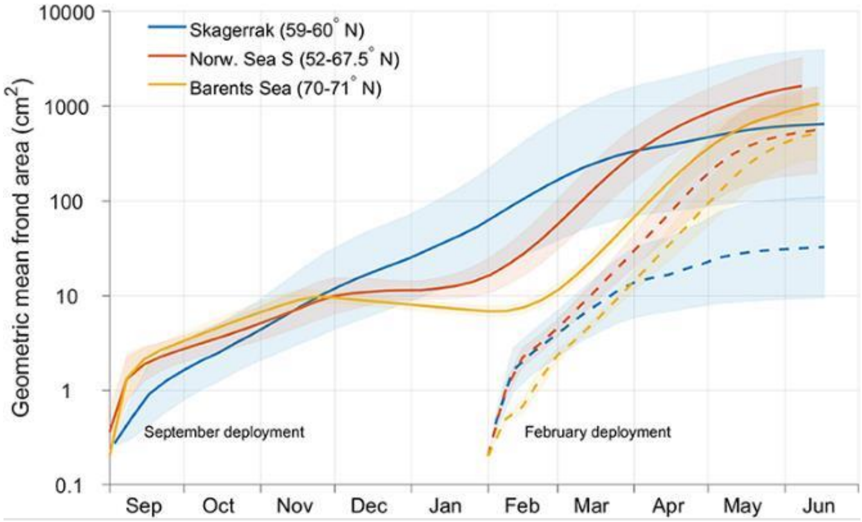

Figure 7: Time series of average (spatial geometric mean) simulated frond areas within Skagerrak (blue lines), Norwegian Sea S (red lines), Barents Sea (yellow lines) ecoregions. At 1.5m depth. The continuous lines represent deployments in September, while the dashed lines represent deployment in February. The shaded regions indicate the geometric standard deviation factors within each region. Note the logarithmic scale of the ordinate axis (Broch et al., 2019)

At this point the biomass is harvested and the biomass effectively returns to zero. This is clearly different to kelp forests where kelp standing stocks vary on interannual or decadal cycles and maintain a standing stock of biomass, and therefore a standing stock of carbon is maintained. As such it is unlikely that carbon contained in the biomass of seaweed aquaculture, where that biomass is harvested annually, can be used for blue carbon trading schemes associated with that location. However, the removed biomass may act as a carbon pool depending on the ultimate fate of that biomass and the carbon it contains, but it is likely that this fate will be outside the discrete area defined by the project and as such may fall outside the scope of the blue carbon trading scheme.

[4] Marine sediments are the combination of inorganic and organic material that accumulates on the seafloor. They cover approximately 70% of the Earth's surface and can trap carbon as they form.

2.1.2.5.2 Increased autochthonous soil organic carbon

In the case of blue carbon, soil organic carbon can functionally be interchanged with sediment organic carbon. Within this framework autochthonous[5] sediment organic carbon, is the carbon generated within the defined area, that is then stored within sediments within the defined area. In natural kelp ecosystems which are normally located on hard substrates such as rocky reefs or rocky intertidal areas, the flux of carbon that is buried in situ is extremely small (approx. 0.4% of NPP) (Krause-Jensen & Duarte 2016). It is likely that the situation will be different in seaweed aquaculture especially in the A&B context where for regulatory reasons it is unlikely that seaweed farms will be placed in the water above priority and sensitive habitats such as submerged rock reefs or boulder fields. As such it is likely that seaweed farms will be placed above soft sediments which do offer opportunities for autochthonous sediment storage of carbon. The rate that these pools accrue at and their eventual size will be dependent on a number of factors. A primary concern is the pathway by which carbon from seaweed cultivation is incorporated into the sediment carbon pool. There are two predominant pathways by which carbon from seaweed aquaculture can arrive at the sediments.

Firstly, as seaweed grows there is abrasion and erosion of the frond that results in a loss of relatively small pieces of seaweed from the edges of the frond. There is a distinct seasonal pattern to this loss of material, with rates much higher in the summer prior to harvesting, and an increase in the rate of frond erosion maybe be a trigger to start the harvest. Although steps are taken (i.e., harvesting) to reduce this erosion in seaweed aquaculture, estimates of this loss over the growing season of up to 8-13% of the final produced biomass have been made (Fieler et al., 2021). The second mechanism is the loss of whole fronds from the farming structure as a result of storms, waves or currents. The impacts of these stochastic events are much more difficult to quantify but can be significant in terms of loses and are likely to become more frequent in the future with projected increases in storminess (Callaway et al., 2012). Notwithstanding this, annual estimates have been generated for Chinese production in a sheltered bay, and these are in the range of 10% of the harvested biomass (Zhang et al., 2012).

For both of these mechanisms any accumulation of carbon within the boundaries of the defined area will be a function of:

- the local hydrodynamic regime that will determine where and when any material lost from the farm will settle onto the sediments
- the nature and size of the material and how quickly it sinks and the chance of resuspension moving material out of defined boundaries
- how that material is processed once it reaches the sediment in terms of how quickly it is buried or consumed
- the size of the project area, with larger projects likely to retain more autochthonous biomass

Small scale experiments have not revealed any increase in sediment organic loading associated with kelp farming (Visch et al., 2020), neither has an increase been observed in larger scale kelp cultivation sites in Chile (Buschmann et al. 2014). However, isotopic studies of a major seaweed farming site in China showed significant contribution of seaweed detritus

[5] Autochthonous - Originating or formed in the place where found; indigenous.

to sediment organic material within the farm area (Xia et al., 2014) and may account for up to 37% of organic carbon in the sediment (Sui et al., 2019).

As previously discussed, (section 2.1.2.5) as seaweeds grow they release a significant proportion of their net primary productivity as dissolved organic carbon. In terms of aquaculture based blue carbon trading, this carbon will be rapidly moved away from the site by oceanic circulation and are thus unlikely to be able to be included in trading schemes unless the flow of carbon from farms to destination can be quantified and verified and those sediments be protected and linked to the farm.

2.1.2.5.3 Reduced methane and/or nitrous oxide emissions due to increased salinity or changing land use

Nitrous oxide is a potent greenhouse gas with a global warming potential of 298 times that of CO_2 and is often released during the conversion of organic to inorganic nitrogen. The oceans and soils are natural sources of nitrous oxide but human activity such as agriculture and fossil fuel use have significantly increased nitrous oxide emissions (Freing et al., 2012). The production of nitrous oxide in the marine environment is linked to the nitrogen loading of the surrounding water body (Seitzinger et al., 1998) and as such a reduction in the nitrogen loading of a water body could lead to a consequent reduction in nitrous oxide release. It is known that seaweed aquaculture can be an effective tool for bioremediation of coastal nutrient loading, removing inorganic nitrogen from the surrounding water as part of the growing process and incorporating it into the seaweed biomass. It has been estimated that one hectare of kelp can remove approximately 350 kg of nitrogen (Broch et al., 2013), but the impact of this on nitrous oxide production has not been quantified. However, seaweed farming has been suggested as a mechanism to remediate point and diffuse sources of nitrogen enrichment.

2.1.2.5.4 Reduced carbon dioxide emissions due to avoided soil carbon loss

This category is analogous to reducing carbon loss from sediments due to a change in use. The impacts of human perturbation of marine sediments are detailed in section 2.2.2.1.1. The presence of seaweed aquaculture at any one site would preclude a number of these activities (e.g. benthic trawling or dredging), that would in turn reduce CO_2 emissions. Aquaculture activities can act as de facto MPAs (Le Gouvello et al., 2017) and can be used as an active fisheries management tool (Clavelle et al., 2019). If significant areas of the marine environment were closed to bottom fishing due to the presence of seaweed farms it is likely that this would increase the carbon sequestration of the area.

2.1.2.6 Bivalve Aquaculture as a Potential Source of Blue Carbon

In terms of shellfish aquaculture when examined in the context of A&B and the four mechanisms used by Verra, there are some significant differences between seaweed and shellfish aquaculture.

2.1.2.6.1 Increased biomass (above or below 'ground)

Although shellfish aquaculture undoubtably creates a carbon rich biomass in terms of the calcium carbonate shell, there is currently a high degree of uncertainty as to whether bivalve aquaculture is a source or a sink of atmospheric CO_2 and as such whether the activity and its products can be included in any carbon trading scheme. The bivalve group is characterised by and gets its name from the two shells or valves that enclose the organism following metamorphosis of the free-swimming larvae into a settled adult. The valves can account for 50% or more of the final weight of the organism at harvest and are composed of biogenically created calcium carbonate within a protein matrix. As the carbon content of bivalve shells is approximately 12% the shells can represent a significant marine pool of carbon. The process of shell formation is known as calcification and involves an active physiological process that combines one molecule of calcium with a molecule of bicarbonate to give a molecule of calcium carbonate and the release of carbon dioxide and water.

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

In an open oceanic system, the released CO_2 will be transferred to the atmosphere (Frankignoulle et al., 1994). The kinetics of this reaction depends on both the physiology of the calcifying organism and the seawater chemistry. In addition, to calculate net contribution to atmospheric CO_2 it is necessary to also consider CO_2 release from the respiration of the organism. This balance has been calculated for a number of bivalve aquaculture systems that have shown that bivalve production is a net source of CO_2 to the atmosphere (Munari et al., 2013). For example, for the Mediterranean mussels, 136.6 mol (CO_2) m^{-2} $year^{-1}$ was sequestered in the shell but 273 mol (CO_2) m^{-2} $year^{-1}$ was released through respiration and calcification, denoting a net source to the environment. Similar findings were reported for Manila clam farming in Italy which concluded clam aquaculture to be a significant additional source of CO_2 to the atmosphere (Mistri & Munari 2012), and from large scale bivalve farming in China (Li et al., 2021). However, this precept is challenged by some researchers who maintain that bivalve farming is a sink for atmospheric CO_2. It has been argued that local variation in seawater chemistry and temperature result in approx. 55kg of carbon being sequestered per tonne produced (Turolla et al., 2020). The categorisation of bivalve aquaculture as a net sink of CO_2 was further supported by the inclusion of other parameters such as the burial of organic matter in bio deposits, the cycling of inorganic nitrogen into the microplankton and subsequent production of dissolved organic carbon, and a consideration that primary ecosystem functions from aquaculture include protein production and additional carbon release should be considered as a by-product of this activity (Filgueira et al., 2015). These additional factors may or may not change the overall carbon balance for bivalve aquaculture, but the scientific uncertainty about their contribution is significant. This scientific uncertainty will preclude the inclusion of bivalves from current carbon trading frameworks.

2.1.2.6.2 Increased autochthonous soil organic carbon

Shellfish are filter feeders, filtering organic material from the water column and ingesting that material. However only a portion of the ingested material is used by the animal, the rest is either deposited after digestion (faeces) or rejected prior to digestion and ejected as pseudofaeces. In either case the material is packaged by the animal in a mucus bound pellet which falls rapidly out of the water column onto the sediment below the farm to enrich that sediment in carbon (McKindsey et al., 2011). However, this effect is only found at some sites and is dependent on sediment type and hydrodynamics.

2.1.2.6.3 Reduced methane and/or nitrous oxide emissions due to increased salinity or changing land use

Mussel aquaculture has also been cited as a possible mechanism to reduce nutrient loading in coastal waters by the reduction of total system nitrogen during the harvesting of the mussels and by extension has the possibility to reduce nitrous oxide emissions from these water bodies (Holdt & Edwards 2014). However, the depositional environment underneath the farm also has potential to increase the methane and nitrous oxide release into the surrounding environment. Shellfish aquaculture can increase rates of sediment denitrification and so reduce sediment nutrient loading (Kaspar et al., 1985). However, in doing so it may increase the production of nitrous oxide. Furthermore, shellfish aquaculture has been associated with higher levels of methane emissions, possibly associated with anaerobic conditions within sinking and sediment bound faeces and pseudofaeces (Hou et al., 2016).

2.1.2.6.4 Reduced carbon dioxide emissions due to avoided soil carbon loss

The arguments for this are similar to those for seaweed aquaculture.

2.1.2.7 Aquaculture and Habitat Restoration

Further to aquaculture for food production it is also possible to consider aquaculture as a mechanism to improve habitats independent of food production. Aquaculture is often not considered when developing projects for habitat conservation or restoration. Indeed, there has been significant research carried out into the negative impacts that poorly managed aquaculture can have on the environment, from destruction of habitats to the introduction of harmful pollutants into ecosystems (Froehlich et al., 2017). There has been a push for more environmentally friendly forms of aquaculture in recent years, with the improvements made in available technology a lot of these are now possible (Edwards, 2015).

An example often referred to when considering the impact aquaculture has had on habitat destruction is with shrimp farming and the devastating impact it has had on mangroves. Mangrove forests are an important habitat when it comes to blue carbon due their role as a carbon sink. While the growth of shrimp farming during the 1980's and 1990's resulted in improved socioeconomic conditions for workers it also led to the destruction of mangroves all over the world (Ahmed et al., 2017). To mitigate the damage caused by this form of aquaculture a new method of integrated mangrove-shrimp cultivation has been developed. Not only does this method of farming require that the area used not contain more than 50% deforested mangrove to obtain organic standards, but it also promotes mangrove reforestation. The terms reforestation and mangrove restoration are often interchangeably used, the requirements set out by naturland for this are as follows. During a period of 5 years, former mangrove area in parts of the shrimp farm must be reforested to at least 50% (Ahmed et al., 2018). Mangroves provide an excellent opportunity for the BC market due their high levels of carbon sequestration (174 gC m-2 year -1), accounting for 14% of carbon sequestered in coastal habitats (Alongi, 2012).

Conservation aquaculture (or regenerative aquaculture) is an area gaining more interest in recent years, which focuses on applying aquaculture methods to restoration projects. To determine the effectiveness of using aquaculture as a tool in the conservation of oysters, a trial using the olympia oysters (*Ostrea lurida*) in Elkhorn Slough, California was carried out. Using hatchery reared oysters fixed to stakes in a way that would mimic their natural habitat, they were deployed into the intertidal range. These oysters successfully grew to reach reproductive size within a few months, indicating that aquaculture techniques could be successful in other similar situations (Wasson et al., 2020).

Within Europe and the UK there is a push to reverse the European native oyster's current trajectory towards extinction. In order to restore oyster habitats two different methods are being used, active restoration of the marine habitats and species, and allowing natural recovery by reducing pressure on the systems (Preston et al., 2020).

There are several organisations involved in projects focused on the restoration of native oyster populations in the UK, many of these projects are a collaboration between oystermen, government, conservationists, and academia (see Figure 8). The goal of many of these organisations is to create self-sustaining populations of native oysters where they would have previously existed. The Native Oyster Restoration Association (NORA) is a resource available to a wide audience from groups interested in developing oyster restoration projects to educational and outreach information. NORA's goal is to support restoration using responsible sustainable practices, in compliance with biosecurity and sustainability (NORAEurope, 2022).

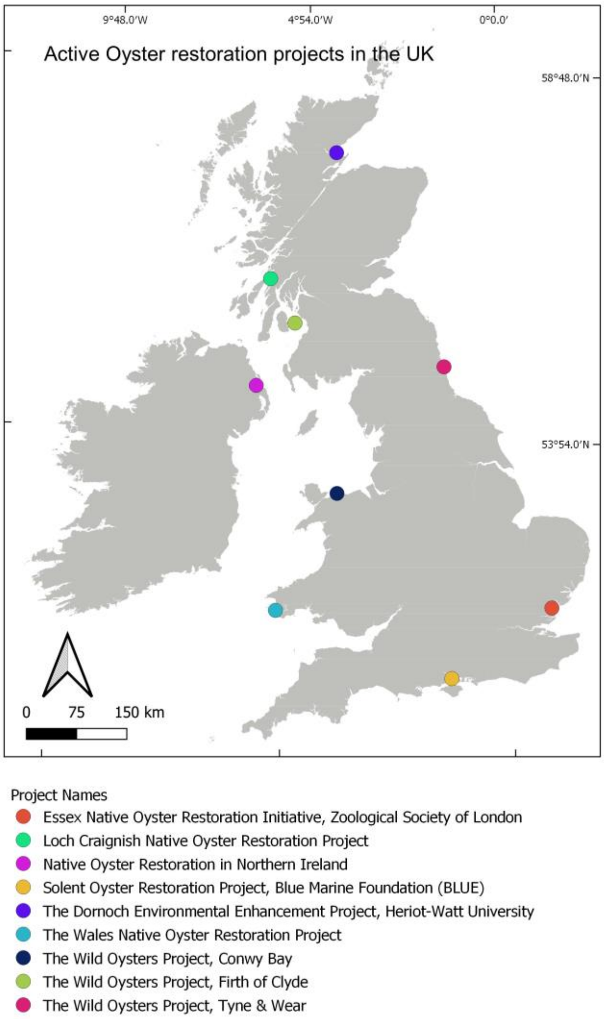

Figure 8: Map showing current native oyster restoration projects in the UK

Located between the Isle of Wight and mainland the Solent is a strait where oyster populations have declined due to over exploitation in recent years. The restoration efforts carried out by Blue Maine Foundation (BLUE) on the native oyster populations using various methods aim to achieve a sustainable population of oysters to support the development of a viable fishery. They are using a combination of wild and cultured oyster spat to re-seed the Solent's water, along with various management strategies to ensure their success. The reared native oysters would be supplied by a hatchery based in Whitstable, Kent and would be used to re-seed oyster beds and to provide juvenile oysters for on growing in pontoon cages and ranching systems. Using cultured juvenile oysters provides the opportunity to significantly increase the current oyster populations (Harding et al., 2016).

There are a number of factors to consider when determining if wild oyster beds are a net source or sink of carbon, one of which is the sediment type surrounding the bed. A study carried out to determine their carbon impact found that reefs on intertidal sandflats were net sources of carbon (7.1 ± 1.2 MgC ha−1 yr−1 (μ ± s.e.)) resulting from predominantly carbonate deposition, whereas shallow subtidal reefs (−1.0 ± 0.4 MgC ha−1 yr−1) and saltmarsh-fringing reefs (−1.3 ± 0.4 MgC ha−1 yr−1) were predominantly made up of sediments rich in organic carbon and functioned as net carbon sinks equal to that of vegetated coastal habitats (Fodrie et al., 2017). Taking this finding into account, oyster restoration carried out in areas of shallow subtidal reefs and saltmarsh-fringing reefs could also result in a carbon net sink and may therefore offer a BC market opportunity.

2.1.2.8 Current seabed ownership in Argyll and Bute

It has been assumed by the Scottish courts that the Crown owns the seabed under the territorial seas. However, there are 11 marine regions in Scotland which were established for the purposes of regional marine planning. These regions were defined by The Scottish Marine Regions Order (2015) and are sub areas of the 'Scottish marine area' and the 'Scottish inshore region', which are defined in the Marine Scotland Act (2010) and the Marine Coastal Access Act (2009) respectively (Marine (Scotland) Act 2010, 2010; The Scottish Marine Regions Order 2015, 2015; Marine and Coastal Access Act 2009, 2009). The region defined for Argyll and Bute is 12,048 km^2 and extends from the tip of the Mull of Kintyre out to a boundary of 12 nautical miles (NM) from the coast (where possible) around the islands of Coll, Tyree and Mull. The boundary ends in Loch Linnhe incorporating half of the loch including the Isle of Lismore and Shuna. While not strictly under the management of Argyll and Bute council, the Clyde region which incorporates Loch Fyne and the Firth of Clyde, is the marine region to the east of Argyll and Bute. Argyll and Bute Council is a member of the Clyde Marine Planning Partnership (CMPP) so, for the purpose of this report the two regions are joined and this incorporates an additional 4,279 km^2.

The foreshore is the area of the shore between the high and low water mark of ordinary spring tides. The shore must be regularly covered by tides. Approximately 50% of the foreshore and tidal riverbeds in Scotland are owned and managed by the Crown Estate. The Crown Estate also owns and manages the territorial seabed and there is a general predisposition against sales of the seabed. Any aquaculture development which requires an area of the seabed, or Crown Estate managed foreshore, therefore needs the necessary permissions from the Crown Estate usually in the form of a lease or license. In some cases, the foreshore is owned by the crown and in others by private landowners. Private landowners whose rights extend to the foreshore also have the right to control how others use it, including fishing and navigation.

In Argyll and Bute, there are a number of existing marine protected areas (MPA's), special areas of conservation (SAC) and special protection areas (SPA) (Figure 9). NatureScot is the competent authority and statutory advisor to the Council with respect to aquaculture, SPA and SAC management and European Protected Species (EPS). NatureScot directly advises Marine Scotland regarding licensing of EPS, and the Scottish Environmental Protection Agency (SEPA), with regard to Controlled Activities Regulations (CAR) and water quality. With regard to management and protection of existing carbon stores and habitats which can provide enhanced carbon drawdown, NatureScot is the competent authority which can advise on establishing new SPA or SAC where applicable. Argyll and Bute Council are responsible for policy and guidance on aquaculture and development within the allocated marine zone. But any occupation or use of the seafloor or Crown Estate foreshore will need permission or a lease from the Crown Estate (Scottish Crown Estate Act, 2019).

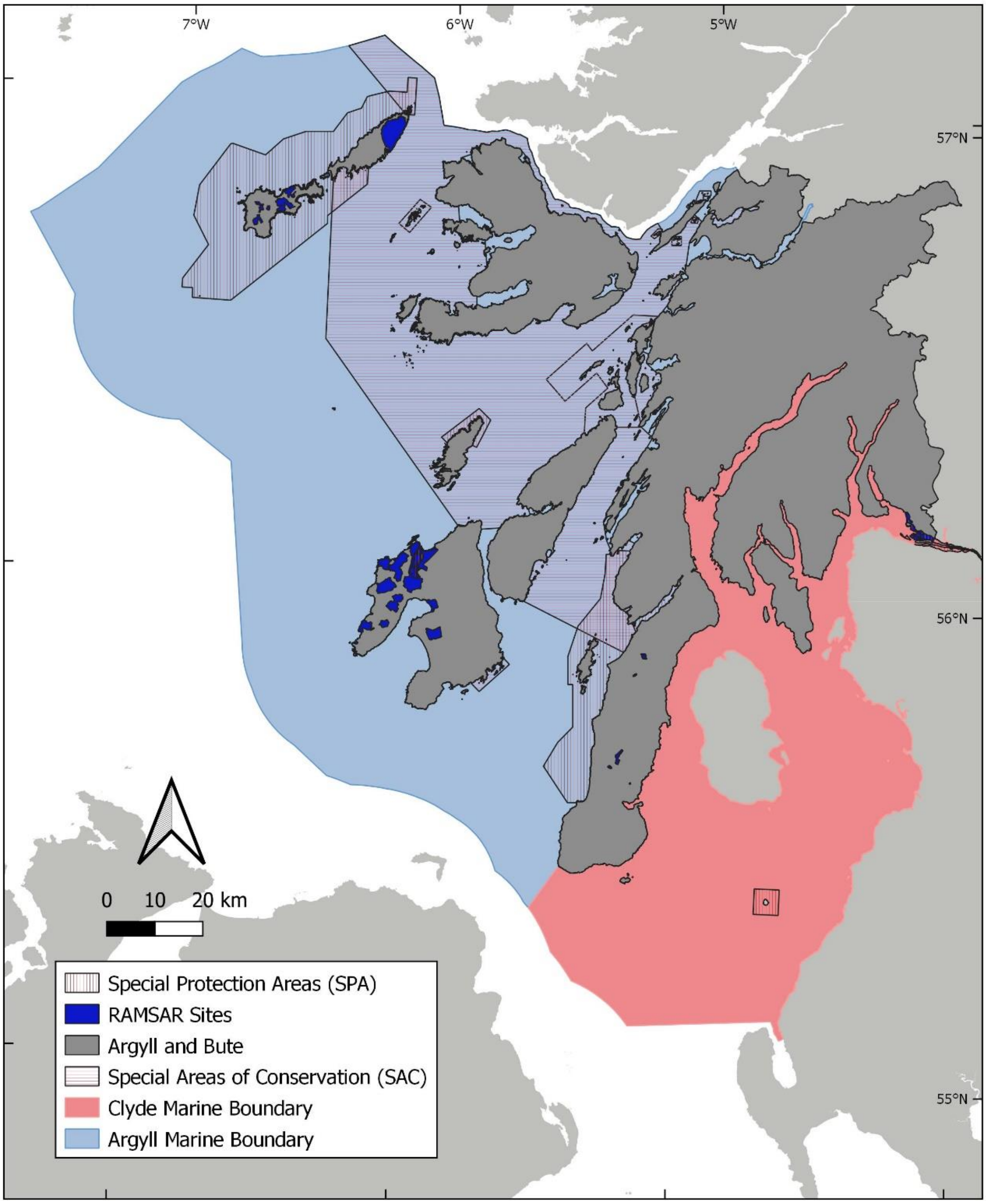

Figure 9: The Current protection status within Argyll and Bute (blue shaded region) and the Clyde (pink shaded region) marine management zones.

2.1.2.9 Summary

Argyll and Bute is home to a mature shellfish aquaculture sector and a nascent seaweed aquaculture industry. Both types of aquaculture have complex interactions with the carbon and nitrogen biogeochemical cycles. Currently the science better supports the inclusion of seaweed aquaculture within any BC framework, while significant questions remain as to whether shellfish cultivation is a source or sink of carbon dioxide to the atmosphere. The current development of a BC market based on seaweed farming is being limited by a lack of accredited frameworks for the quantification and certification of BC credits associated with seaweed farming. At the time of writing the carbon trading company Verra is developing guidelines for such a framework, but it is not understood if this framework will be applicable to the Argyll and Bute area. Any such framework will have to mitigate several compatibility issues for seaweed farming in regard to key criteria used in existing frameworks for BC, such as those that are applied to mangroves and seagrass beds. One major limitation of current schemes is their reliance of defined geographical boundaries (linked to the BC habitat) for the carbon sequestration to take place in. For Seaweed aquaculture this reliance on defined boundaries will be problematic for two main reasons

1) Water currents are likely to move released carbon from the farm site beyond the defined boundaries of the particular project, making quantification and verification of long-term storage problematic. This issue is further exacerbated by public (Crown) ownership of the seabed and a lack of mechanism for long term (100 years +) leasing or transfer of ownership.

2) The carbon contained in the final product will also be moved beyond the project boundary and the nature and longevity of any storage of this carbon will be entirely dependent on the final use. As such its inclusion in any carbon trading is likely linked to the final use and not the production. This will create problems of robustly attributing any stored carbon to the place of production rather than the location of use.

2.2 Identification of priority carbon sequestration supply opportunities for communities in A&B

2.2.1 Terrestrial environment

2.2.1.1 Baseline assessment of emissions from the terrestrial environment

In order to identify the priority carbon sequestration supply opportunities for communities in A&B, we conducted a baseline estimation of emissions from the land use sector. We identified the most relevant land use categories within Argyll and Bute and their associated emission factors from UK specific inventories (equivalent to Tier 2 IPCC methodology) wherever possible. The emission factors for each category, equivalent to the net annual flux of CO_2e towards the soil (sink, or negative fluxes) or the atmosphere (source, or positive fluxes) are estimated from annual budget of greenhouse gases (CO_2, CH_4 and N_2O) and dissolved organic carbon (DOC). For peatland land use categories, we use the emission factors provided by Evans et al. (2017) and used their approach to derive an equivalent emission factor for heather moorland (not on peat), based on best available published evidence (Table 4). For forestry land use categories, we based our estimates on Morison et al. (2012) (Table 5). For grassland and pasture, UK Tier 2 methodology is not available, so we used IPCC guidelines (IPCC, 2006) and an emission factor of 0.92 $tCO_2e\ ha^{-1}yr^{-1}$.

Table 4: Direct and indirect GHG emissions from peatlands under a range of land-use conditions. Modified from: Evans et al., 2017

LU condition category	Drainage status	Direct CO_2	CO_2 from DOC	CO_2 from POC	Direct CH_4	CH_4 from Ditches	Direct N_2O	Ind. N_2O	Total
Unit		tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1	tCO_2e ha-1 yr-1
Data source		*Evans et al 2017*	*IPCC 2013*	*Evans et al. 2016*	*Evans et al. 2017*	*IPCC 2013*	*Evans et al. 2017*	*IPCC 2006*	
Tier		*Tier 2*	*Tier 1*	*Tier 2*	*Tier 2*	*Tier 1*	*Tier 2*	*Tier 1*	
Forestry on bog (peat emissions only)	Drained	7.39	1.14	0.3	0.12	0.14	0.65	0.17	9.91
Heather/Grass Dominated Modified Bog	Drained	-0.14	1.14	0.3	1.36	0.66	0.05	0.03	3.4
Heather/Grass Dominated Modified Bog	Undrained	-0.14	0.69	0.1	1.36	0	0.05	0.02	2.08
Actively eroding	Drained	0.85	1.14	0.89	1.19	0.66	0.06	0.06	4.85
Actively eroding	Undrained	0.85	0.69	0.71	1.19	0	0.06	0.05	3.55
Rewetted Bog	Rewetted	-2.23	0.88	0.01	2.02	0	0.04	0	0.81
Extensive grassland	Drained	13.33	1.14	0.3	1.82	0.66	1.5	0.29	19.04
Intensive grassland	Drained	23.37	1.14	0.3	0.37	1.46	2.8	0.48	29.92
Extracted Industrial	Drained	6.44	1.14	5.00	0.20	0.68	0.14	0.24	13.84
Near Natural Bog	Undrained	-3.54	0.69	0	2.83	0	0.03	0	0.01
Data source		Quin et al. 2015	IPCC 2013	Evans et al., 2016	M. S. Carter et al. 2012	IPCC 2013	M. S. Carter et al. 2012	IPCC 2006	Total
Upland heathland heather	Undrained	-3.45	0.69	0.1	0.026	0	0.05	0	-2.58

Table 5: Range of GHG emissions from relevant forestry classes, source: Morison et al., 2012

Category	NEE CO2 highest	NEE CO2 lowest	NEE CO2 (median)	CH4 from soil (mean)	N2O from soil (mean)	Total
Unit	tCO2e ha-1 yr-1	tCO2e ha-1 yr-1	tCO2e ha-1 yr-1	tCO2e ha-1 yr-1	tCO2e ha-1 yr-1	
Data source	*Morison et al. 2012*	*Morison et al. 2012*	*Morison et al. 2012*	*Morison et al. 2012*	*Morison et al. 2012*	
Forest on organo-mineral	3.7	-32.6	-9.1	0.21	0.56	-8.33
Forest on mineral	3.7	-32.6	-9.1	-0.03	0.25	-8.88

The second element of the baseline estimation of emissions is the area covered by each of the relevant land use categories within the region of interest. There is currently no readily available remote sensing or mapped product well-aligned with IPCC reporting categories for the Land Use and Land Use Change and Forestry (LULUCF), making an exact calculation of areas under relevant LU categories, and therefore a precise balance of emissions, impossible. Instead, the area estimation for each of the relevant LU categories within Argyll and Bute was achieved through a combination of existing land cover, soil categories and soil organic content, making assumptions (Table 6). The baseline LU emissions for Argyll and Bute can subsequently be estimated by multiplying the area and emission factor for each land use category (Table 7).

Table 6: Land Cover categories used for estimation of GHG emission from terrestrial environment in Argyll and Bute and details of how area of each LCC was generated.

Categories (land cover)	Categories (soil types)	How it was calculated	Area (ha)	% Argyll & Bute area
Forestry on peatland (peat only)	Peat	[Sum of the intersections of the layers Deep peat (JHI) x Existing Woodland (A&B Forestry strategy) and Other peat x Existing Woodland]-forestry removal for restoration	12,913	1.9
Actively eroding drained	Peat	27.5% of polygons identified as highest rates of subsidence based on TerraMotion™ UK wide assessment + visual polygon assessment	3,784	0.6
Actively eroding undrained	Peat	72.5% of polygons identified as highest rates of subsidence based on TerraMotion™ UK wide assessment + visual polygon assessment	9,975	1.5

Categories (land cover)	Categories (soil types)	How it was calculated	Area (ha)	% Argyll & Bute area
Drained heather/grass dominated modified bog	Peat	27.5% of LC88 reclass C2, D, E with *Forestry on peatland, Rewetted bog, near natural bog, extraction* removed.	35,731	5.4
Undrained heather/grass dominated modified bog	Peat	72.5% of LC88 reclass C2, D, E with *Forestry on peatland, Rewetted bog, near natural bog,* removed.	94,201	14.2
Extensive Grassland	Peat	Peat ESRI LC88rec categories C2, D, E, + LC88 primary classification *smooth grass and low scrub, smooth grass* or *undiff smooth grass* + grassland/pasture under the soil types MSSG *Blanket peat, Drystrophic peat* and *undiff basin peat*	4,271	0.01
Intensive Grassland	Peat	Peat ESRI LC88rec categories C2, D, E, + LC88 primary classification *Arable or Improved grassland*	1,746	0.01
Rewetted bog	Peat	Peatland Code total + hand drawn polygons around Peatland ACTION PeatDepth layer	3,572	0.6
Near natural bog	Peat	Peat ESRI, LC88rec categories C2, D, E + LC88 primary classification *blanket bog vegetation, Dubh lochans*	55,602	8.1
Extraction Industrial	Peat	Peat ESRII, LC88 primary classification *Industrial Peat*	23	<0.01
Heather moorland/montane vegetation	Organic soils/organo-mineral soils	Peat ESRI LC88 removing C2, D, E + LC88 primary classification *undiff heather, montane, dry heath and wet heath*	99,102	14.5
Forest/Woodland (Broadleaves & conifers)	Organo-mineral soils	[LC88 primary classification forestry class – Forestry on peatland] – [Forestry on deep peat + Forestry on peat + Forest and Woodland on mineral soils]	146,013	21.3
Forest/Woodland (Broadleaves & conifers)	Mineral soils	[LC88 primary classification forestry class – Forestry on peatland] + MSSG names *Humus iron podzols, iron podzols, mineral alluvial soils, non-calcareous gleys, scree, subalpine podzols, undiff rankers*.	27620	4.0
Grassland/pastures	Organic soils/organo-mineral soils	[Peat ESRI, LC88rec categories 0, A1, A2 B, C1 + LC88 primary classification *Arable, Imp. Pasture, Improved pasture, link area (grass), maritime grassland, Smooth grass low scrub, Smooth grass bracken, undiff. Smooth grass, undiff low scrub, undiff nardis/Molinia, undiff*	173,950	25.4

Categories (land cover)	Categories (soil types)	How it was calculated	Area (ha)	% Argyll & Bute area
		bracken] + Soil Types MSSG *Blanket peat, Drystrophic peat* and *undiff basin peat removed*.		
Built up/out of scope areas	Variable	LC88 primary classification *Airfield, Built-up, cliffs, cemeteries, Caravan sites, Golf course, quarries*	7,966	1.2
Water	NA	LC88 primary classification *Water*	805	0.1
Total			*666,823*	*97.4*

Table 7: GHG emissions in CO2e from the land-use sector in Argyll and Bute

Categories of land use	Emission F actor ($tCO2e\ ha^{-1}\ yr^{-1}$)	Area (ha)	kt CO2e yr^{-1}
Forestry on peatland (peat only)	9.91	12,913	128.0
Actively eroding drained peatland	4.85	3,784	18.4
Actively eroding undrained peatland	3.55	9,975	35.4
Drained heather/grass dominated modified bog	3.4	36,906	121.5
Undrained heather/grass dominated modified bog	2.08	97,298	195.9
Intensive grassland	29.92	1746	52.2
Extensive grassland	19.04	4329	82.4
Rewetted bog	0.81	3,572	2.9
Near natural bog	0.01	55,602	0.6
Extraction	13.84	23	0.3
Heather moorland/montane vegetation	-2.58	99,102	-255.7
Forest/Woodland (Broadleaves & conifers) organo mineral soils	-8.33	146,013	-1216.3
Forest/Woodland (Broadleaves & conifers) mineral soils	-8.88	27620	-245.3
Grassland/pastures	0.92	170,646	156.4
Total		***666,823***	***-923.2***

Based on this approach, we estimate that Argyll & Bute is likely to be a net sink for GHG, or approximately 923 ktCO2e yr^{-1}.

This is largely due to the strong net sink behaviour estimated for the *Forest and Woodland* LU category (-14641kt CO_2 yr^{-1}). When looking at the categories that are contributing to the net emissions of CO_2, the biggest culprits are the drained and undrained heather and grass dominated modified bogs, contributing together nearly half of the total emissions (317.4 out of 794 ktCO2 yr^{-1}) despite covering only 20% of the land area. The other big emitters are the grassland and pastures, which contribute 20% of the emission over a similar proportion of land area.

There are of course caveats to this approach and areas of uncertainty or ambiguity that may affect the total emissions. It is highly possible that there is an underestimation of the extensive grassland category and an over estimation of the grassland/pasture categories and/or undrained heather/grass dominated modified bog simply because these categories are more likely to be assigned the same land cover class but have different land management histories. In particular, changing an area from the grassland/pastures category to the extensive or intensive grassland category would lead to a significant a reduction of the current sink strength with increased emissions, and vice versa. A similar conundrum applies to the heather moorland/montane vegetation: they are difficult in practice to differentiate from the undrained heather/grass dominated bog without field validation and have a similar magnitude of emissions but in the opposite direction.

A particular issue around forestry is the difficulty of quantifying forestry removal (other than for peatland restoration). It is clear from the earth imagery that some areas that were under conifer plantation forestry have been removed to make way for wind farm development or as part of the long-term management plan for these areas. Using the current emission factors, it would however take a reduction of forestry cover more than 50% to tip the balance towards a net source, which is highly unlikely.

For forestry on peat, it is important to mention that the fluxes are soil fluxes only and do not include tree uptake of CO_2 – the above-ground canopy fluxes of conifer plantations on peat are extremely poorly constrained (Evans et al., 2017; Sloan et al., 2018). Another source of uncertainty in the context of forestry is the wide range of emission factors report in Morison et al. (2012) that have not fully been unpacked here – instead using an average value. Ultimately, the emission factors themselves include some uncertainty and limitations – despite being the best available dataset, they are still relatively poorly constrained for some peatland categories and do not include for example fluxes data specifically from sites within Argyll and Bute.

2.2.1.2 Potential for land use change to supply opportunities for communities in Argyll and Bute

The two categories of peatland degradation currently eligible for Peatland CODE are the drained heather/grass dominated modified bog and the actively eroding drained peatlands. It is estimated that there is a large potential to supply opportunities for communities in Argyll and Bute through peatland restoration, based on the areal estimates generated above and the current guidance from the Peatland Code on emission reduction calculations (Table 8). However, for a given area identified as drained or eroded, only a proportion is eligible for Peatland CODE, which includes the feature targeted by intervention (drain, hagg, gully) and a 30m buffer around it. Further, a proportion of the carbon credit are used as a buffer, and therefore not all credits can be used for offsetting or for trading. Therefore, while we can here identify the maximum potential C supply opportunity, the realised C supply and associated revenue stream will be smaller and can only be fully appraised through ground-truthing and detailed mapping.

Table 8: Carbon supply opportunities through peatland restoration activities eligible under the Peatland CODE

Pre-restoration condition category (emission, $tCO2e\ ha^{-1}\ yr^{-1}$)	Post-restoration category condition (emission, $tCO2e\ ha^{-1}\ yr^{-1}$)	Emission reduction $tCO2e\ ha^{-1}\ yr^{-1}$	Area in A&B	Maximum Annual Potential Supply opportunity $ktCO2e\ yr^{-1}$
Actively Eroding, drained (23.84)	Drained, revegetated (4.54)	19.3	3,784	73.03
Drained modified grass/heather dominated or undrained actively eroding (4.54)	Modified (2.54)	2.00	45,706	91.41

There is already a forest and woodland strategy for Argyll and Bute with a clear mandate for expansion of existing woodland cover, with a potential forestry expansion area of 223,227 ha, of which 76,553 ha have been identified as preferred areas for expansion (Figure 10). The carbon potential of expansion of forestry over these areas will be dependent on a range of parameters, including the choice of tree species (broadleaf, conifers, mixed), the size of the projects (standard or small) and the different management options included as well as the baseline (carbon sequestration without future woodland), leakages (emissions caused by the project). Given the wide range of options and possible scenarios of woodland expansion and management eligible for WCC, it is not possible to constrain the maximum potential supply opportunity in a similar way than was done for the peatlands, where the options are much more limited.

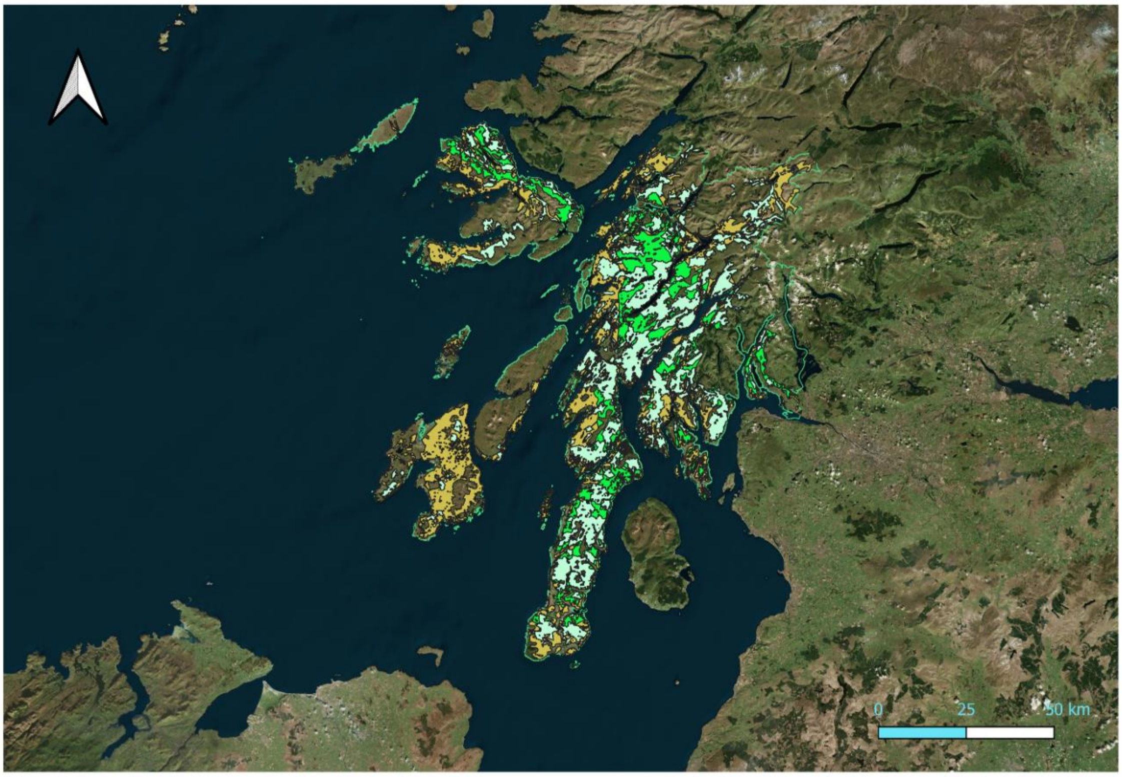

Figure 10: Existing woodlands (pale green), preferred areas of woodland expansion (bright green) and potential area of woodland expansion (mustard yellow) in Argyll and Bute. Source: Open_Data_-_Woodland_and_Forestry_Strategy — Open_Data_-_Woodland_and_Forestry_Strategy.shp

2.2.1.3 Socio-economic Opportunity for Argyll and Bute Communities

Land use change to mitigate and adapt to climate change has been identified as a potential driver for the social and economic development of rural Scotland. The Scottish Government (2020a) set out that they will work with the rural sector on the path to net-zero to ensure that farmers, crofters, and land managers, as well as the wider rural and island communities share the benefits that come from opportunities arising from land use change. The government sets out that land use change will provide green economic and employment opportunities, offer public health benefits, help to address rural depopulation, and provide social benefits to communities across Scotland.

This position has been endorsed by Scotland's Just Transition Commission (2021) who identified that large scale investment in restoring peatlands, tree planting and woodland management needs to ensure the benefits that can arise from this are felt widely by rural communities. The Commission further sees a just transition accounting for the current injustices associated with land use in Scotland, including unusually concentrated land ownership in an international context (Scottish Land Commission, 2021a), and the wider challenges faced by many rural communities. Opportunities arising for communities in Argyll and Bute are integral to delivering a just transition and this needs to be bold; communities need to see the experience of transition as fair; delivering climate mitigation without consideration of being socially just will stall, and achieving climate targets and a just transition cannot be separated (Just transition Commission, 2021).

Carbon markets and land use change in respect to net-zero targets are an emerging sector and as such research in the socio-economic benefit is less well established. Hirst and Lazarus (2020) however identify that nature-based jobs grew at more than five times the rate of all jobs in Scotland in the period 2015-19 and accounted for one third of all job growth in Scotland in this period. They also expect to see significant further growth in nature-based jobs through to 2030 in sectors such as blue carbon, woodland planting and restoration, and peatland restoration.

In respect to peatland restoration a comprehensive valuation of economic efficiency of restoring as climate-critical ecosystems have been lacking in the past. Glenk and Martin-Ortega (2018) set out non-market benefits peatland restoration offers in respect to opportunities for securing and enhancing critical ecosystem services provided by peatlands. These include carbon storage, water regulation and water quality, and support for biodiversity and wildlife.

At a community level peatland restoration offers local communities' opportunities for skilled jobs in remote and rural areas. NatureScot (Skills Development Scotland n.d) identify that a range of specialist and technical jobs will be needed including front line machinery operators, hydrologists, satellite data analysts, surveyors, ornithologists, ecologists and project managers. It is estimated that over 3-5 years starting in 2021-22, peatland restoration associated with existing commitment to invest around £25 million annually will build to supporting around 200 FTE contractor and delivery jobs across Scotland, on the basis that every £1 million of investment in peatland restoration is estimated to create around 10 contractor/delivery jobs. However, this would actually comprise a higher number of contractor posts on a part-time basis given the seasonal nature of groundwork (i.e. the need to work outside severe winter conditions and restrictions around work during the bird breeding season). This doesn't include any additional investment through private finance, but the same principle would apply in terms of job creation. The economic contribution of forestry has been covered in detail (Forestry Commission Scotland 2015c) with similar local economic benefits such as supporting jobs in remote and rural locations across multiple roles and business operations.

2.2.1.4 Summary

There are significant opportunities for an increase in supply of projects delivering carbon emission reduction in Argyll and Bute. Large areas of actively eroding and drained modified peatlands fall under eligible categories for Peatland CODE projects and have the potential to bring emission reduction through avoided losses. While the broad-brush mapping exercise identifies a maximum potential supply ~164 kT CO2e yr^{-1}, the likely supply will be smaller, as in reality only a fraction of the degraded area will be used in C accounting terms. On that basis, actively eroding areas where emission reductions are higher per area have a greater potential of being profitable. By contrast, only projects with very large projects may be profitable for drained modified areas where emission reductions per area are small.

There is likely an even bigger opportunity for an increase in supply through the Woodland Carbon Code, though the scale of this opportunity is harder to constrain, given the wide range of carbon sequestration achievable.

Land use change towards carbon sequestration is recognised across government and agencies as offering benefit to rural communities, particularly through job creation of skilled jobs. The sector is growing at five times the rate of all jobs in Scotland over a four-year period, accounting for one third of all national job growth. Ove the next three to five years it is envisaged that 200 FTE jobs may be created from public investment in peatlands along with associated part time roles. An increase in private funded work as well as an increase in forestry cover should also see an associated increase in jobs.

2.2.2 Marine environment

2.2.2.1 Review of habitats involved in carbon sequestration and storage in Argyll and Bute

The ocean plays a vital role in the removal of atmospheric CO_2. The following section discusses and estimates the current understanding of natural carbon sinks and habitats with high sequestration capacity within the Argyll and Bute marine planning region. Where possible, using data and existing models from peer reviewed literature, the dynamics of carbon accumulation by these habitats is estimated.

2.2.2.1.1 Sediments and seabed type

The oceans currently absorb approximately 30% of annual anthropogenic CO_2 emissions from the atmosphere (Friedlingstein et al., 2021). The fate of this carbon is to alter the chemical balance (i.e., acidification or alkalinity) of the seawater (Doney et al., 2009), be mixed into deep ocean circulation (Sabine, 2004) or become incorporated into organic (i.e., coastal macrophytes or phytoplankton via photosynthesis) and inorganic (i.e., carbonates through calcification) carbon compounds and enter the biological pump (refers to the gravitational settling of phytoplankton cells once blooms terminate and the carbon is 'pumped' into the sediments below) (Basu & Mackey, 2018; Boyd et al., 2019). It is currently understood that up to 99.5% of organic carbon is converted back to CO_2 through remineralization (Burdige, 2007). However, organic carbon that escapes remineralization or grazing will ultimately end up in marine sediments (Keil, 2017). Marine sediments are both places of carbon turnover and accumulation, and although less than 1% of organic ocean carbon makes its way to marine sediments, the amount is still significant (Diesing et al., 2021). Continental margins (i.e., the coastal shelf and regions within fjords) often contain large amounts of organic carbon in their sediments (Bianchi et al., 2018). Different types of sediment (i.e., soft, shelly, sandy) contain different amounts of organic carbon (originally classified by Wentworth, (1922)). Identifying the different types of sediment can indicate where hotspots of organic carbon are formed (Hunt et al., 2020). Recent reviews have found that stocks of organic carbon in surficial sediments within the Scottish EEZ are greater than those held in the biomass of coastal macrophytes such as kelp, seagrass and saltmarshes (Burrows et al., 2014, 2017; Smeaton et al., 2021). The extended Scottish Exclusive Economic Zone (EEZ) is currently thought to contain 221 ±

92 Mt OC within the top 10 cm of sediments (Smeaton et al., 2020). With an additional 252.4 ± 62 Mt OC in post-glacial sea loch sediments. In some lochs, the thickness of sediments has been recorded as up to 70 m (Baltzer et al., 2010; Smeaton et al., 2017) meaning the total OC content of sediments is usually under-reported.

Carbon in sediments is stored in both inorganic and organic forms (IC and OC respectively). Inorganic carbon consists of precipitated carbonates and organic carbon is usually formed from the decomposition of organic compounds. Some regions are rich in organic carbon and others contain more inorganic carbon (Burrows et al., 2021). The organic carbon content of sediments has been shown to be higher in fjords and sea lochs than on the rest of the continental shelf (Burrows et al., 2017; Cui et al., 2016; Smith et al., 2015). A range of OC content between 0.02 – 8.86% (of dry weight) has been reported (de Haas et al., 2002; Hunt et al., 2020; Legge et al., 2020; Loh et al., 2010; Overnell & Young, 1995; Queirós et al., 2019; Smeaton & Austin, 2019; Smith et al., 2015). Links exist between grain size, dry bulk density and OC content, and in general, finer sediments contain more OC and are less dense (Smeaton et al., 2017; Smeaton & Austin, 2019). Recent modelling analysis estimates that the Firth of Clyde region stores 3.42 Mt OC and 0.33 Mt Nitrogen in the top 10 cm of its sediments (Pace et al., 2021). The classification of the seabed in Argyll and Bute is well constrained thanks to data from the EUNIS Classification scheme (Figure 11).

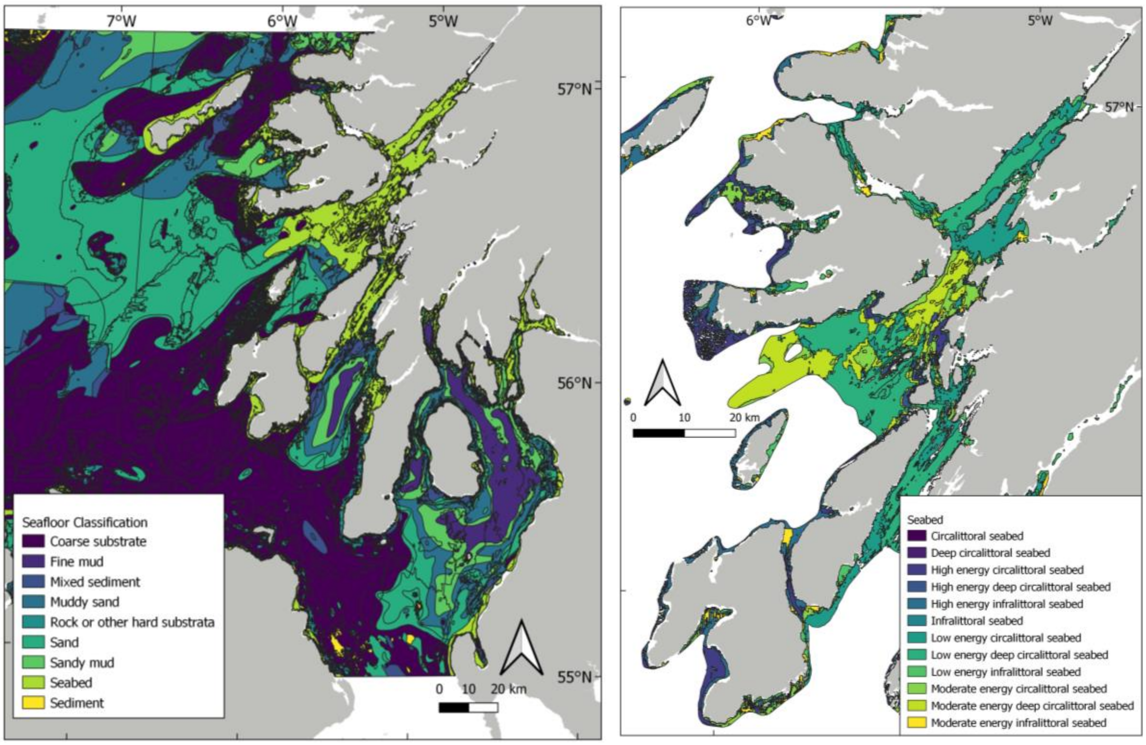

Figure 11: a) The EUNIS classification of seabed types applied to the Argyll and Bute and Clyde marine planning regions. Areas where organic carbon accumulates can be estimated from seafloor classification. For example, fine mud regions often have higher OC content. The EUNIS dataset classifies 'Seabed' under different littoral types (b) which are subject to varying levels of energy.

Average sedimentation rates have been studied in Argyll and Bute and found to be between 0.012 – 0.046 kg/m^2/day estimated in Loch Linnhe, of which 0.082 g C/m^2/day was found to be chlorophyll (and hence associated with photosynthetic organisms, often assumed to be phytoplankton) (Overnell & Young, 1995). A carbon budget of Loch Creran was also recently formed (Loh et al., 2010). Loh and colleagues estimated a budget of 10^6 kg OC/year (0.01 Mt OC) within Loch Creran, a total of 1.23^6 kg OC/year accumulates in the sediments annually. Previous studies using core samples and ^{210}Pb dating have estimated sedimentation rates annually are much lower over a long period of time, likely due to compression factors. Swan and colleagues (1982) found sedimentation rates of between 0.02-0.12 kg/m^2/year in sea lochs tested within the Clyde region (Swan et al., 1982), and between 0.02 – 0.06 kg/m^2/year inside sea loch sediments was found by Teasdale et al., (2011). Other regions of the UK have also been studied, the south coast of England for example was recently found to accumulate 0.06 kg C/m^2/year (Queirós et al., 2019) and areas of the North Sea (further from shore) much lower at 0.0002 kg C/m^2/year (de Haas et al., 1997).

There are uncertainties which remain regarding the dynamics of sediment carbon accumulation and deposition. For example, with respect to the processes which control areas where OC accumulates in large quantities or 'hotspots' of carbon accumulation and the factors which govern the length of time that carbon is retained in sediments. Current budgets for sediment carbon flows take into account; 1) air to coastal flux, 2) riverine input (terrestrial carbon), 3) air to water flux through the absorbance and releases of CO_2, 4) coastal productivity, burial (blue carbon), and the export of dissolved and particulate carbon (DOC and POC) from coastal macrophytes, 5) transport of carbon outside of the system or region of interest, 6) the eventual burial or net gain of organic carbon annually in sediments (Figure 12, see also Legge et al., 2020).

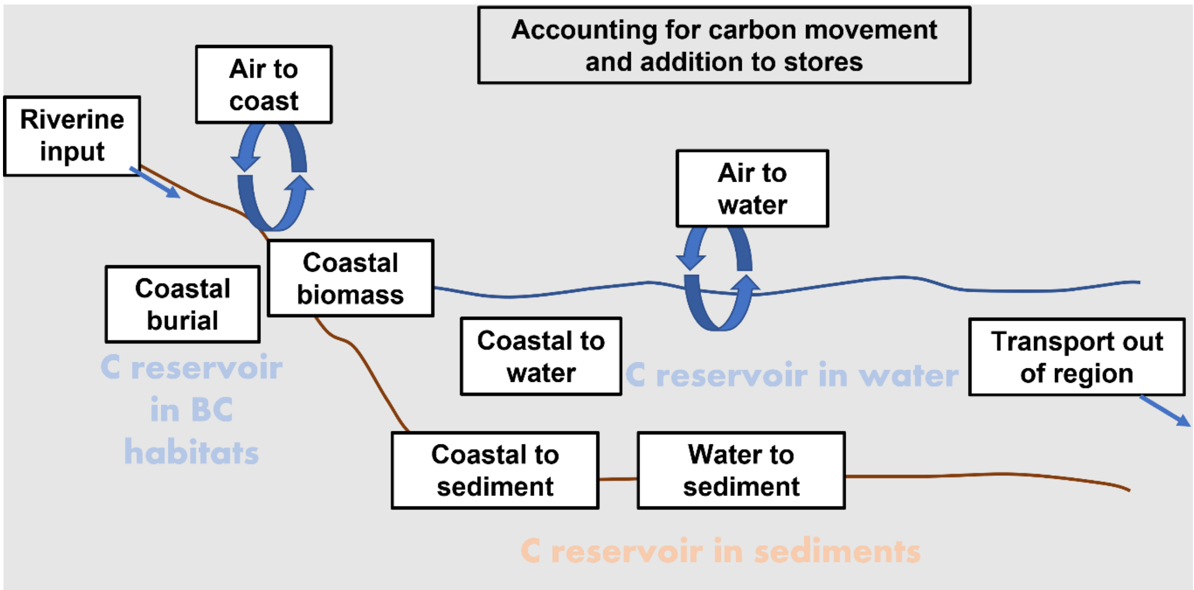

Figure 12: An overview of accounting methods for marine carbon budgets including addition to sediments based on recent work by Legge et al., (2020)

2.2.2.1.2 Blue carbon habitats in Argyll and Bute

Blue carbon (BC) describes the carbon fixed and sequestered by coastal vegetation including mangroves, seagrass, saltmarsh and macroalgal beds/forests (Nellemann et al., 2009). In

Scotland, the BC habitats of interest are seagrass meadows, saltmarsh/wetland systems and macroalgae which includes kelp (subtidal macroalgae of the order Laminariales) and fucoids (intertidal macroalgae of the Fucales order) (Burrows et al., 2014, 2021). There is considerable work taking place to try and understand the contribution to sediment carbon stores by other important species which calcify and/or form biogenic reefs. For example, Maerl (*Phymatolithon calcareum* and *Lithothamnion glaciale)* and oyster beds have been shown to protect carbon rich sediments beneath the habitats they form (Porter et al., 2020). There is still considerable discussion surrounding the role that calcifying organisms play in offsetting carbon (see 2.1.2.6.1) (Fodrie et al., 2017; Kalokora et al., 2020; Macreadie et al., 2017). The following section outlines existing knowledge of carbon draw-down, sequestration and function of BC habitats in Argyll and Bute. Existing data are plotted from the archive for marine species and habitats collection (open source, available at; https://www.dassh.ac.uk/data/search-data) which includes survey data from the Joint Nature Conservation Committee (JNCC), NatureScot and the Marine Nature Conservation Review (MNCR). These data are mostly observational, which for some species generates reasonable indications of extent. However, for some other species modelling provides a better indication of the true extent (i.e., macroalgae which are present on most rocky shorelines).

2.2.2.1.3 Macroalgae

Macroalgae refers to large seaweeds which includes red (mostly within Rhodophyta), green (including Chlorophyta and Charophyta/Streptophyta) and brown seaweeds (within the Phaeophyceae). Intertidal rocky regions in Argyll and Bute are likely to be dominated by fucoid seaweeds within the Fucales order, while shallow subtidal regions are likely to be dominated by stipitate kelps from the order Laminariales (Smale et al., 2016). Until recently the contribution to BC stores from macroalgae has been seen as largely uncertain. Recent effort has been made to clarify the pathways by which seaweeds contribute to carbon storage pathways and eventual incorporation into sediments (de Bettignies et al., 2020; Filbee-Dexter et al., 2018; Filbee-Dexter & Scheibling, 2016; Filbee-Dexter & Wernberg, 2020; Pessarrodona et al., 2018; Queirós et al., 2019; Trevathan-Tackett et al., 2015). Macroalgae are highly productive, but they do not grow on soft sediments or muds and therefore do not sequester carbon directly beneath their standing stock. The main route of long-term carbon storage by macroalgae therefore comes in the form of detritus (Krause-Jensen & Duarte, 2016). A large proportion of macroalgal production is donated to detrital pathways annually (up to 82%) (Krumhansl & Scheibling, 2012). This detritus contributes to sediment carbon adjacent to macroalgal beds and in distant sediments through interconnected pathways via dispersal and movement of detritus (Filbee-Dexter et al., 2018; Krause-Jensen et al., 2018; Queirós et al., 2019; Smale et al., 2018). Detritus from macroalgae contributes a significant amount of carbon to adjacent and distant food webs in the marine environment and thereby also contributes to productivity of higher trophic organisms know as secondary production (Duggins et al., 1989, 2016).

2.2.2.1.4 Intertidal fucoid species

Habitat suitability modelling and information based on surveys shows a good distribution of fucoid species along the rocky shorelines of Argyll and Bute (Yesson et al., 2015). Observational data indicate a strong presence of most of the larger forms of fucoids such as *Ascophyllum nodosum, Fucus serratus, Fucus vesiculosus, Fucus spiralis*, *Himanthalia elongata*, *Halidrys siliquosa, Pelvetia canaliculata* and the non-native *Sargassum muticum* (Figure 13).

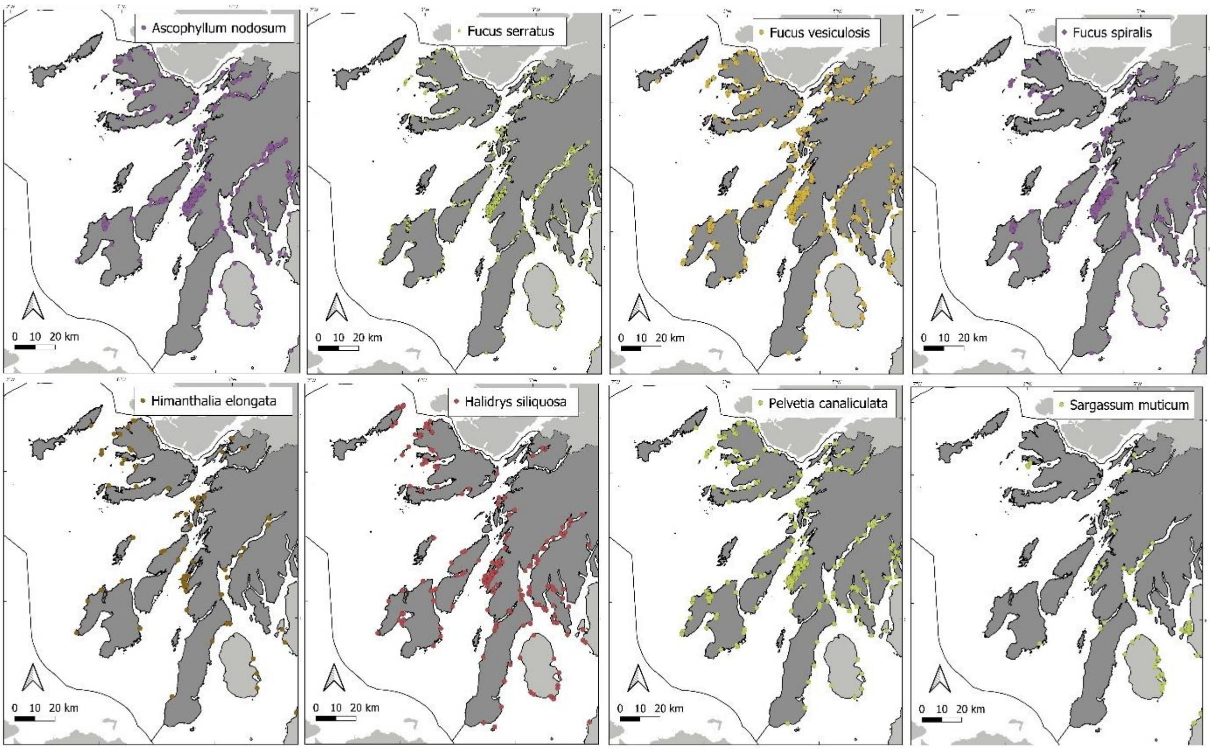

Figure 13: Observed data from surveys of fucoids present in Argyll and Bute and Clyde marine planning regions. Each data point represents a survey undertaken by either the JNCC, NatureScot, MNCR or other research organisation. Absence of an observation here does not mean species are not present, rather those areas are not surveyed.

It was previously thought that intertidal species were less productive than subtidal macroalgae for example, the kelps (Mann, 2000). However recent reviews of the literature have shown that the ranges of productivity are similar and that intertidal fucoids produce between 4-1800 g C/m^2/year (Burrows et al., 2021; Lewis, 2020). Productivity estimates from fucoid species in the UK remain limited, and few exist from elsewhere in the literature (Table 9). Much recent estimates have come from intertidal studies in Wales and the work of Lewis (2020) on the species, *A. nodosum, F. vesiculosus* and *F. serratus* which were studied across seven sites in mid and north Wales (Lewis, 2020). Productivity (Table 4.1), standing stock (Table 10) and detritus production was estimated, the figures can be compared to existing data on fucoid production.

The intertidal foreshore area of the Argyll and Bute and Clyde regions is 161km^2 (from OSOpenData vector sources, currently excluding some areas in upper sealochs), of which 65km^2 is rock (from the Defra Intertidal Foreshore substratum type dataset, https://data.gov.uk/dataset/6efcebae-874e-4691-bf46-53057bdebda1/intertidal-substrate-foreshore-england-and-scotland). Assuming 30% of this rocky shore area is covered by macroalgae, the above values for carbon density and production rates give estimates of 8,000t OC in living seaweeds in the region and 24,000t OC produced per year (see Burrows et al., 2021 for methods). Only a fraction of this annual carbon production would ultimately be exported to sediment stores, here generously assumed to be 10% but likely lower based on the ratio between production rates in macroalgae beds (c600 gC/m2/yr, Burrows et al., 2014) and rates of addition of macroalgae-derived carbon to coastal sediments (9 gC/m2/yr, Queirós et al., 2019).

Table 9: Literature values of fucoid species productivity (± standard error) (organic carbon fixation) from the UK and elsewhere

Species	Productivity mean g C/m^2/year	Range	Location	Reference
F. vesiculosis	430 (± 106)	166-946	Wales, UK	Lewis, 2020
F. vesiculosis	426	-	U.S.A.	Roman et al., 1989
F. serratus	611 (± 124)	222-958	Wales, UK	Lewis, 2020
A. nodosum	49 (± 10)	16-70	Wales, UK	Lewis, 2020
A. nodosum	-	90-935	Spain	Lamela-Silvarrey et al., 2012
A. nodosum	594	max 894	Canada	Vadas, 2004
A. nodosum	-	600-2820	Canada	Cousens, 1984
A. nodosum	1179	-	U.S.A.	Roman et al., 1989

Table 10: Standing stock estimates from three intertidal species of fucoids generated in Wales, UK

Species	Standing stock mean g C/m^2	Range	Location	Reference
F. vesiculosus	536 (± 29)	358-634	Wales, UK	Lewis, 2020
F. serratus	659 (± 127)	214-1213	Wales, UK	Lewis, 2020
A. nodosum	1033 (± 134)	696-1649	Wales, UK	Lewis, 2020

Detrital production from fucoid species occurs via three main mechanisms: erosion of blade material, whole plant dislodgement during storm/disturbance events and senescence of reproductive receptacles which occurs seasonally. Again, limited studies exist on the production of detritus by fucoids and much of the UK knowledge is from Lewis (2020). Export of carbon in the form of detrital production by *F. vesiculosus* was 377 g C/m^2/year, from *F. serratus* 368 g C/m^2/year and from *A. nodosum* 387 g C/m^2/year (Lewis, 2020). A recent study in Finland supports these findings showing that *F. serratus* in the area exported 300 g C/m^2/year in the form of detritus (Attard et al., 2019). Studies elsewhere (Canada) have found that *A. nodosum* loses approximately 54% of its biomass annually estimating that full turnover of biomass occurs every two years (Vadas et al., 2004). The addition to sediment carbon stores was estimated as 0.04 kg C/m^2/year as a combined contribution from the three species *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* per unit area of habitat (Lewis, 2020). It is highly likely that these three species contribute the most to intertidal macroalgal production and detritus export.

2.2.2.1.5 Kelps

Large stipitate macroalgae within the order Laminariales are referred to as kelps in the United Kingdom. Kelps are dominant in the shallow sub-littoral and form dense highly productive forests on rocky areas. Kelp forests are ubiquitous in Argyll and Bute, the Clyde region and throughout the west coast of Scotland (Burrows et al., 2014, 2018). In the shallowest, high-energy part of the sub-littoral zone the most common species is generally *Laminaria digitata,* beneath this zone *L. digitata* is outcompeted by *Laminaria hyperborea* which is the dominant canopy forming species in the area able to survive to depths of up to 24 m (Smith et al., 2021). The third common species found in Scotland is *Saccharina latissima*, visibly different to *L. digitata* and *L. hyperborea, S. latissima* thrives in areas of lower energy and while often present in lower numbers within *L. hyperborea* forests, is more frequent in sheltered sea lochs (Johnston et al., 1977). There are good observational survey data for all three common species of stipitate kelps in Argyll and Bute and Clyde regions (Figure 14).

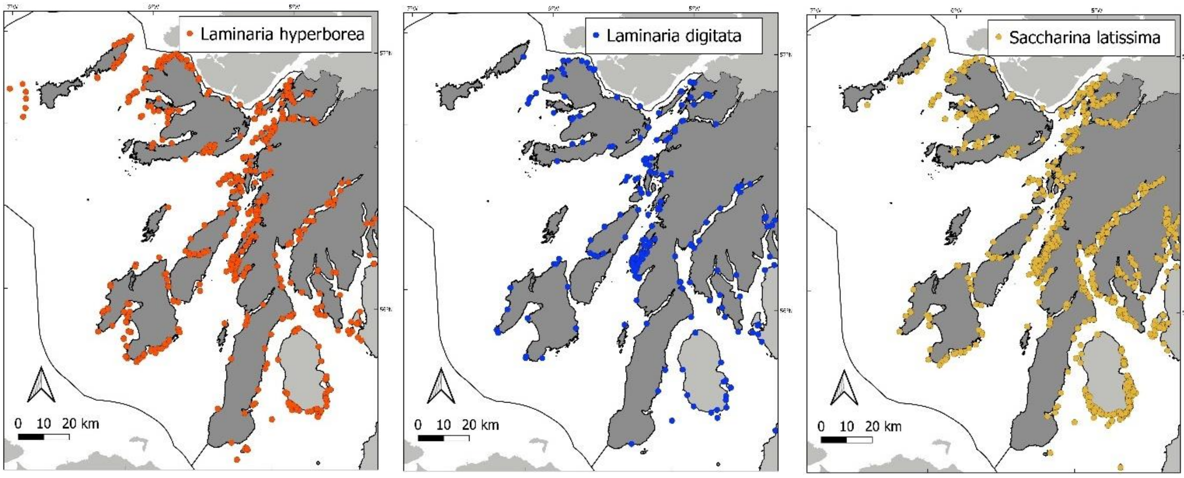

Figure 14: Observed locations of three stipitate kelps in the Argyll and Bute and Clyde regions. Each data point represents a survey undertaken by either the JNCC, NatureScot, MNCR or other research organisation. Absence of an observation here does not mean species are not present, rather those areas are not surveyed.

Other kelps present in Argyll and Bute are *Alaria esculenta* which is limited to areas of high energy and more exposed areas and *Saccorhiza polyschides* thought to be an annual species and more warm water tolerant. There are good observations of both *A. esculenta* and *S. polyschides* showing that both species are present on Argyll and Bute coastlines (Figure 15). The most prevalent species in the region is *Laminaria hyperborea* and as such it has been the focus of multiple recent studies with the aim of generating greater understanding of the factors limiting production (Smith et al., 2021), distribution (Smale et al., 2020), detrital production (Pedersen, 2019; Pessarrodona et al., 2018) and degradation (de Bettignies et al., 2020; Frontier et al., 2021). While data on production, standing stock and detrital production for the other stipitate kelps that persist in Argyll and Bute exists, it is often from outside of the region, but still useful (Table 11).

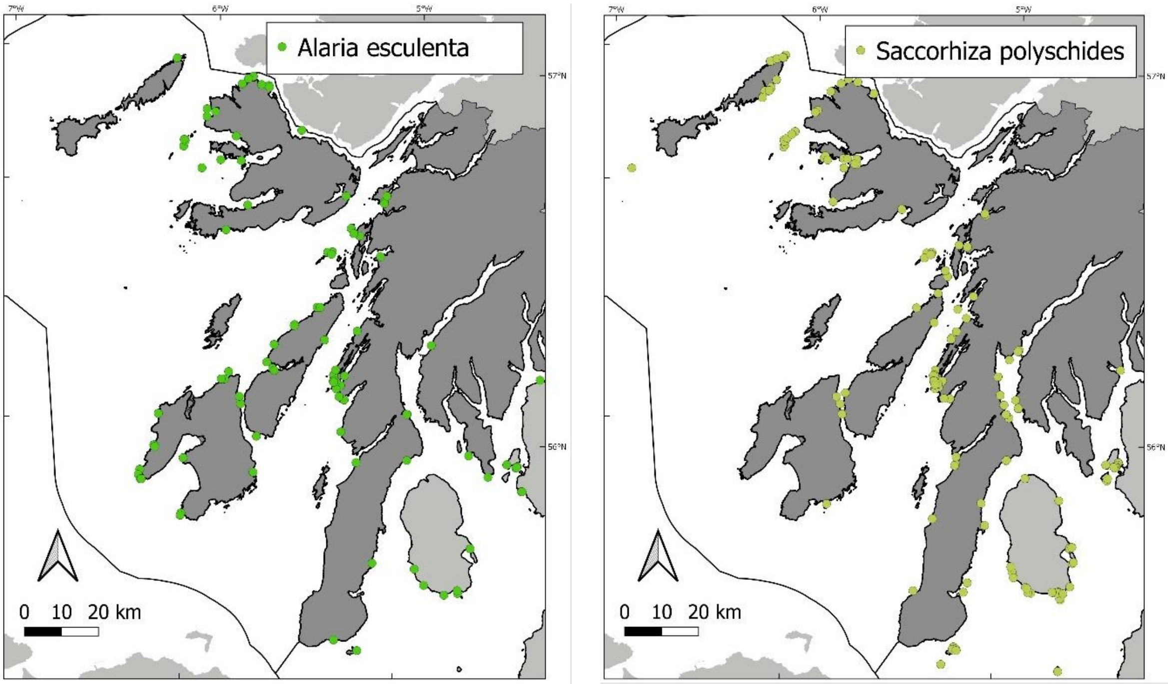

Figure 15: Observed locations of two less common kelps in the Argyll and Bute and Clyde regions Alaria esculenta and Saccorhiza polyschides. Each data point represents a survey undertaken by either the JNCC, NatureScot, MNCR or other research organisation. Absence of an observation here does not mean species are not present, rather those areas are not surveyed.

Table 11: Primary productivity estimates of the three large canopy-forming macroalgae species common to Scotland. Studies are from various locations and are specific to individual species. N refers to the number of datapoints used to calculate mean and errors (Table from O'Dell, in review).

Species	g C/m^2/year	SE	n	References
Laminaria digitata	480	120	20	Gunnarsson 1990; Krumhansl and Scheibling 2021; Smith 1988
Laminaria hyperborea	330	70	42	Kain 1977; Gunnarsson 1990; Jupp & Drew 1974; Luning 1969; Pessarrodona et al., 2018; Sjotun et al., 1995; Smale et al., 2016
Saccharina latissima	290	110	12	Borum et al., 2012; Brady-Campbell et al., 1984; Krumhansl & Scheibling 2012; Johnston et al., 1977

Productivity can be highly variable in kelp forests, ranges between 110 – 1780 g C/m^2/year have previously been found (Mann, 2000). Recent studies have found ranges of Net Primary Production (NPP) between 166-738 g C/m^2/year (Smale et al., 2020) and standing stock estimates between 208-1709 g C/m^2/year (Pessarrodona et al., 2018) in *L. hyperborea* forests. The studies were both conducted from southern 'warm' sites (in southwest Wales and England) to cooler northern sites (in west and north Scotland). Smale and colleagues found NPP to be 1.5 times higher in cool northern regions and Pessarrodona and colleagues found standing stock to be 2.5 times greater in cooler northern sites than in southern warm sites. A recent study of *L. digitata* again found northern cool sites to have higher primary production values and higher standing stock, but only during the high growth season (NPP 135-402 g C/m^2/year, standing stock 278 g C/m^2/year) (King et al., 2020). Limited data from *S. latissima* exists although it is an important species in upper sea lochs, with production shown to be in excess of 120 g C/m^2/year (Johnston et al., 1977). Given recent findings of higher primary productivity and standing stock in cooler northern sites, it is highly likely that kelp forests in Argyll and Bute are the most productive BC habitat in the region.

2.2.2.1.6 Carbon storage by macroalgae

The fate of detritus produced by kelp forests is key to the long-term storage of macroalgal carbon (Krause-Jensen & Duarte, 2016; Krumhansl & Scheibling, 2012). There are a number of processes that govern the transportation, deposition and eventual burial and incorporation of detritus into sediments (Filbee-Dexter et al., 2018; Filbee-Dexter & Scheibling, 2016). Only a small amount of detritus produced is likely to remain in-situ, the majority of detritus is transported away from kelp forests, evidence of macroalgal detritus exists in deep fjord regions (400 m), away from the continental slope (~5,000 km from shore) and in deep continental areas (1,800 m) (Filbee-Dexter et al., 2018; Krause-Jensen et al., 2018; Ortega et al., 2019). There is also evidence emerging from eDNA (environmental DNA) studies which show that macroalgal carbon is incorporated into distant sediments (Ortega et al., 2020) and in deep sediment cores (Anglès d'Auriac et al., 2021; Frigstad et al., 2021). There is still some uncertainty surrounding the total amount of carbon annually added to sediments stores, but strong evidence that macroalgae are key contributors.

2.2.2.1.7 Saltmarshes

Saltmarsh systems are important provisioners of various ecosystem services such as water filtration and regulation, carbon fixation and sequestration, habitat provision for birds and other wildlife, defence against floods, public amenities (visual and otherwise for visitors including walkers) and the support and habitat for numerous rare and protected species (Hughes, 2004; Lockwood & Drakeford, 2021). There is a large amount of plant diversity within saltmarshes and multiple species thrive in the zones, saltmarshes represent the transition zone between fresh and brackish water and as such, a number of specialist species thrive in these areas (Haynes, 2016). There are several RAMSAR protected wetlands within the Argyll and Bute region, and observational data of species such as *Spartina townsendii,* as well as multiple other species in the region (Figure 16). A comprehensive review of Scottish saltmarshes was conducted in 2021 (Austin, 2021) In the top 10 cm of Scottish saltmarsh soils there are 0.37 ± 0.1 Mt OC and the density of OC is approximately 6.0 ± 1.8 Kg/m^2 (Austin, 2021).

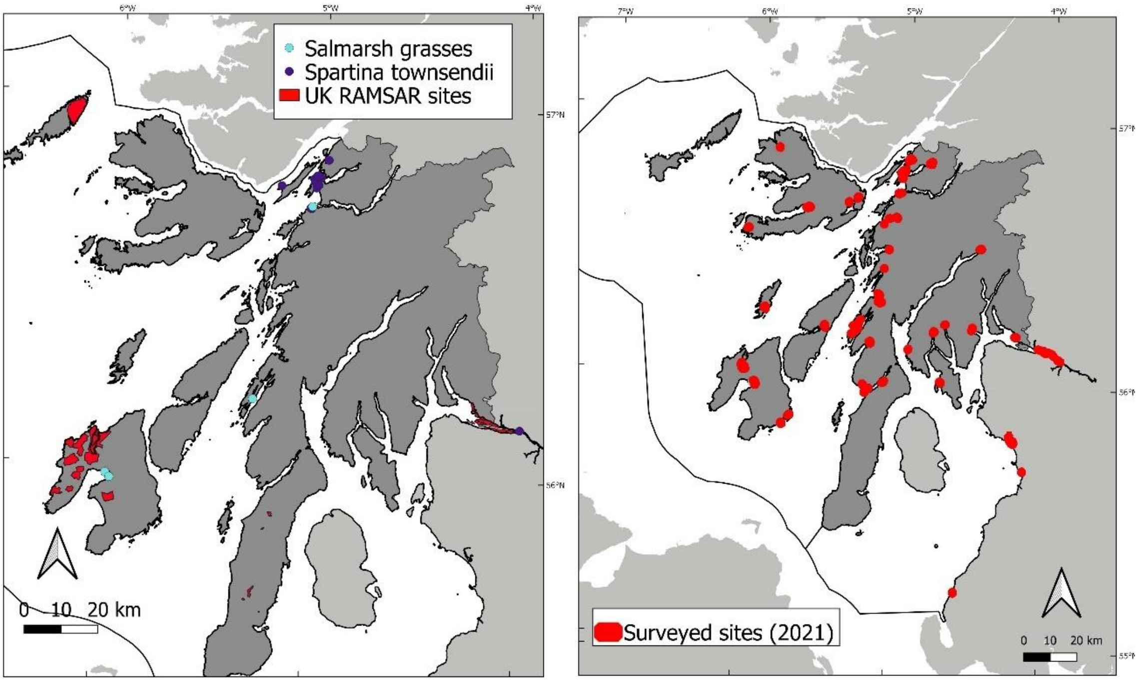

Figure 16: Saltmarsh and RAMSAR sites in Argyll and Bute, limited observational data were found on the archive for marine species and habitats portal, although multiple species of salt marsh grasses are present (left map). However, recent efforts to map Scotland's saltmarshes have produced highly accurate estimates of the extent of saltmarshes (right map) which are present in Argyll and Bute and the Clyde region (Austin et al., 2021).

2.2.2.1.8 Seagrass

Seagrass meadows provide a wide range of ecosystem services and are recognized as ecologically and economically important (Cullen-Unsworth et al., 2014; Mtwana Nordlund et al., 2016). Seagrass meadows remove atmospheric CO_2 and sequester the carbon within it into sediments for long periods of time, as such they are recognized as a blue carbon habitat (Nellemann et al., 2009). Current knowledge of the biomass and extent of seagrass meadows in the UK depends upon limited observational and modelling studies. Recently an effort has been made to map and quantify seagrass extent in the UK, finding there are 8,493 ha based on observations and modelling (Green et al., 2021). There are several observational datasets which verify the presence of seagrass meadows in Scotland and open-source data are available from the archive for marine species and habitats archive (https://www.dassh.ac.uk/data/search-data). Much recent effort from organisations such as Project Seagrass ® is underway to improve observations using citizen science with websites such as https://seagrassspotter.org/. Current observational information exists for *Zostera marina* only (Figure 17). Intertidal seagrass meadows in Scotland are formed by two key species: *Zostera noltii* or *Zostera marina.*

The carbon contents of sediments beneath *Z. marina* and *Z. noltii* has recently been shown in Scotland to be (mean ± SD) 54.79 ± 35.02 t C/ha (Potouroglou et al., 2021) with a range of between 22.7 t C/ha and 107.9 t C/ha (Potouroglou, 2017) (Figure 17). A Scotland wide estimate was placed in the region of 91,200 t C based on the figures above and storage of carbon in sediments beneath seagrass beds. An additional 0.07-0.5 t C/ha is held within the biomass of plants above sediments (Lima et al., 2020).

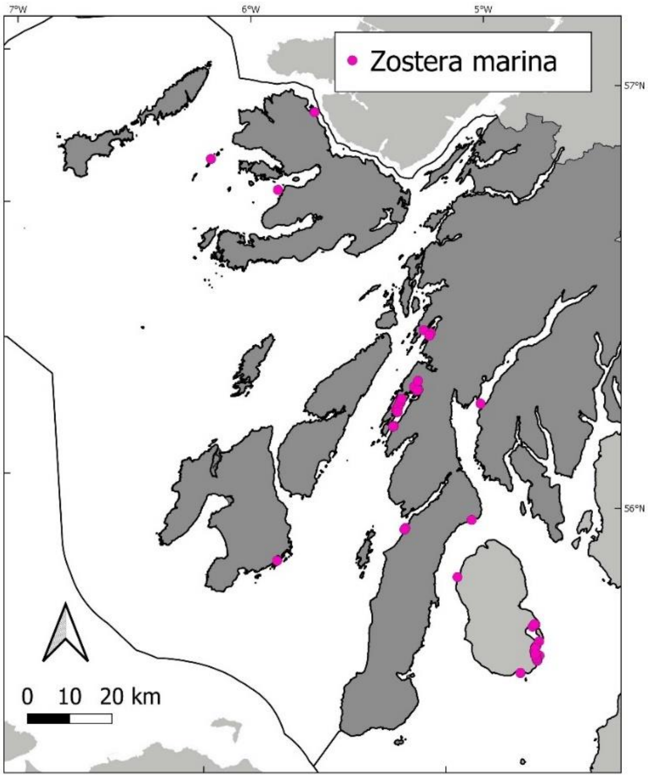

Figure 17: Observational data available for seagrass (*Zostera marina*) in Argyll and Bute observational data on *Zostera noltii* is lacking.

2.2.2.1.9 Calcifying species

While considerable debate remains surrounding the role calcifying organisms play in carbon sequestration, work has been done to estimate the carbon that these habitats contain in organic and inorganic forms. Limited studies exist, but globally coralline algae has been estimated to produce 330 g OC/m^2/year and 900 g $CaCO_3$/m^2/year (van der Heijden & Kamenos, 2015). It was recently estimated that 7.38 t OC/ha is stored in the top 25 cm of maerl beds and net inorganic carbon production is ~22 g/m^2/year in Scotland (Porter et al., 2020). There is again good knowledge of the existence of maerl in Scotland, and in Argyll and Bute (Figure 18). The two main species being *Phymatolithon calcareum* in areas of moderate to high water flow and *Lithothamnion glaciale* which is more abundant in the sea lochs of Scotland but also in areas of high water movement.

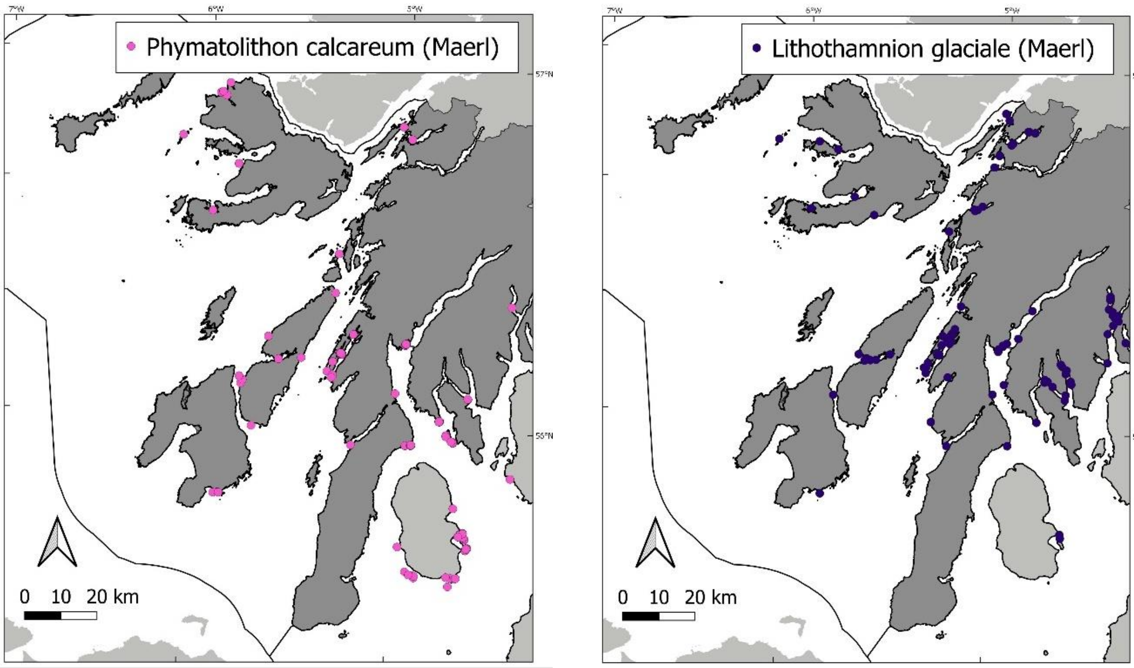

Figure 18: Observational data on the locations of two species of maerl in Argyll and Bute. *Phymatolithon calcareum* is more common on outer parts of sea lochs while *Lithothamnion glaciale* is often found in upper parts of sea lochs.

Two highly protected bivalve species are present in abundance in Argyll and Bute, the horse mussel *Modiolus* and the flame shell *Limaria hians.* Both of which are priority marine features and UK BAP habitats, and both are considered OSPAR declining and threatened habitats. Protected areas in Loch Creran, Loch Fyne (upper) and Loch Goil are in place to safeguard these features (Figure 19). Bivalves filter water, accumulate organic carbon in their tissues and inorganic carbon in their shells. There is a downward transfer of organic carbon through faecal matter formation and protection of sediment stores beneath the dense beds that they form (Dame 2012). The rates and quantity of organic carbon stored beneath bivalve systems in Scotland is poorly understood. But assimilation of dissolved and particulate organic carbon is thought to be significant in these organisms (Newell, 1990).

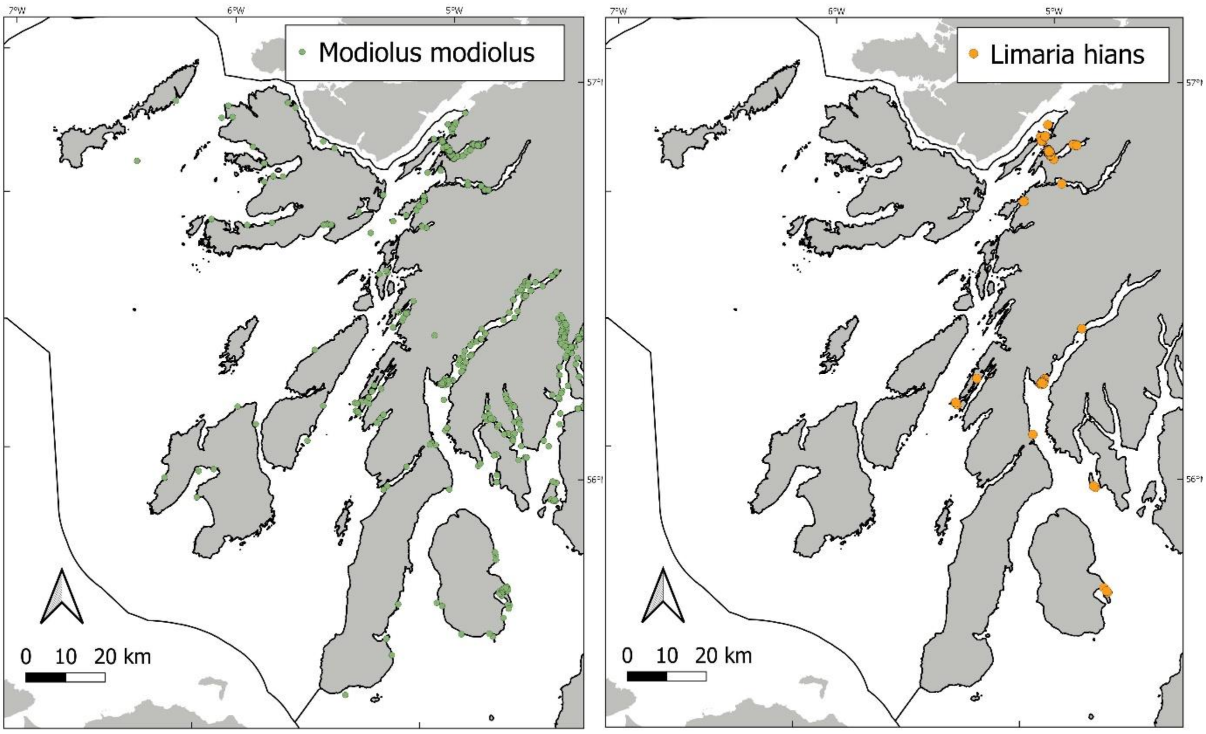

Figure 19: The known location of important bivalves in Argyll and Bute.

2.2.2.1.10 Phytoplankton

Particulate organic carbon (POC) in the water column is likely to be dominated by photosynthetic microalgae (phytoplankton) which form the autotrophic community of plankton. The phytoplankton assemblage in the Argyll and Bute region is dominated by dinoflagellates and diatoms, the zooplankton assemblage is dominated by copepods (Barne et al., 1997; Brito et al., 2015). Carbon fixation by phytoplankton is maximum during summer months and has been found to be between 488-4047 mg C/m^2 (sea surface)/day in the Firth of Lorn (between 178-1477 g C/m^2/year) (Rees et al., 1995). Temperate coastal production by phytoplankton has been estimated between 100 - 300 g C/m^2/year previously in temperate regions (Mann, 2000). Most carbon fixation occurs in the top 10 m of water because of light availability, estimates of productivity by phytoplankton at a specific station (LY1, Lynn of Lorn observatory) ranged between 150-225 g C/m^2/year (Tett, 2016). There are regular, seasonal phytoplankton blooms observed in the Clyde region (Hallegraeff et al., 2021; Napier, 1995). Seasonal blooms can be obvious depending on the species (for example, see https://www.eumetsat.int/big-bloom-firth-clyde). It is likely due to regular bloom formation that organic carbon in sediments in the region is high (Pace et al., 2021). Taking the average of the published values gives a value of 202.5 g C/m^2/year (Figure 20).

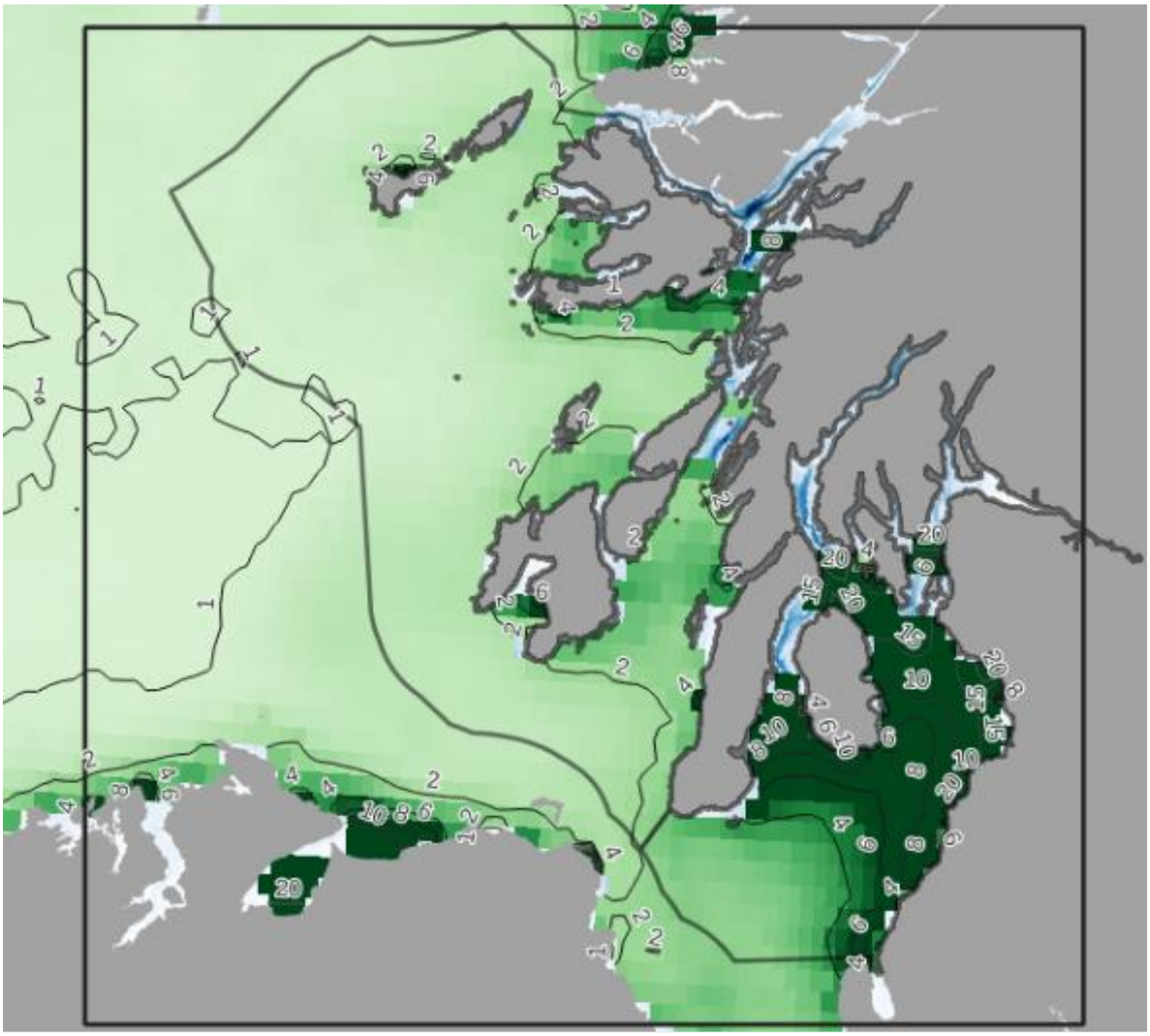

Figure 20: Phytoplankton concentrations across the Argyll and Bute and Clyde regions. Values are shown as chlorophyll a mg/m^3 at the sea surface, derived from the average of estimates from satellite data (MODIS-Aqua 2003-2018).

2.2.2.1.11 Summary

The capacity of natural marine habitats to sequester and store carbon in Argyll and Bute is largely without equivalent management and ownership models to those of the terrestrial environment; the lack of which is a major barrier to market development. Coastal vegetated habitats, saltmarshes, seagrasses and seaweed beds, are highly productive and important stores of carbon. Seabed sediments, particularly in sealochs, are the largest store of marine organic carbon in the region.

2.3 Identification of priority natural assets to secure carbon stock at risk

2.3.1 Terrestrial environment

2.3.1.1 Belowground stocks (soils)

Mapping of soil carbon stocks across the UK is necessary for to provide baseline data for monitoring the effects of climate change, developing carbon accounting, and informing land management decisions. Several different approaches have been used for national-scale soil C stock mapping including interpolation between sample points (Bradley et al., 2005), characterisation by map unit (Batjes, 2010); raster-based soil process modelling (e.g. Smith et al., 2007), estimation from point data (Chapman et al., 2013) and more recently, neural network model (Aitkenhead and Coull, 2016). Most of these approaches broadly agree that Scottish soils hold around 3000 Mt of C in the top meter of soil (Rees et al., 2018). The total stocks are far more difficult to estimate, because they require high resolution detailed profiles of soil depths, which is only realistically achievable on a small scale. Therefore, we have limited the soil stock assessment to the top 1m of soil for Argyll and Bute, using readily available values of soil carbon content (tC ha^{-1}) across a range of soil types relevant to the region and their respective area (Table 12).

Table 12*:* Estimation of soil carbon stocks for Argyll and Bute. Source: BioSoil Soil C content data: Morison et al., 2012; NSS (National Soil Survey) data: Rees et al., 2018. Soil Carbon and Land Use in Scotland. Final Report. ClimateXChange report. soil-carbon-and-land-use-in-scotland.pdf (climatexchange.org.uk)

	Soil Category	Data source	Area ha	Soil C content (tC ha)				Stock to 1m (MtC)			
				BioSoil	NSS	NSS low	NSS high	BioSoil	NSS	NSS low	NSS high
PEAT	Deep peat	Deep peat layer Hutton	34656	539	547	273	823	18.7	19.0	9.5	28.5
PEAT	Deep peat	E layer from Peat ESRI	25186	539	547	273	823	13.6	13.8	6.9	20.7
PEAT	Other peat	Peatwind with deep peat removed	161555	539	547	273	823	87.1	88.4	44.1	133.0
PEAT	Other peat	D and C2, Peat ESRI	182695	539	547	273	823	98.5	99.9	49.9	150.4
PEAT	*Total stocks*	*Hutton + Peatwind*	*196211*	*539*	*547*	*273*	*823*	*105.8*	*107.3*	*53.6*	*161.5*
PEAT	*Total stocks*	*Peat ESRI*	*207882*	*539*	*547*	*273*	*823*	*112.0*	*113.7*	*56.8*	*171.1*
OTHER SOILS	Peaty Gleys	dystrophic basin peat, dystrophic blanket peat, peaty gleys, undifferentiated other peat	111757	242	121	402	362	27.0	13.5	44.9	40.5
OTHER SOILS	Peaty Podzols	peaty podzols, peaty gleyed podzols	46513	214	128	353	362	10.0	6.0	16.4	16.8
OTHER SOILS	Brown Soils	Brown calcareous soils, Brown	44640	115	61	204	152	5.1	2.7	9.1	6.8

	Soil Category	Data source	Area ha	Soil C content (tC ha)				Stock to 1m (MtC)			
				BioSoil	NSS	NSS low	NSS high	BioSoil	NSS	NSS low	NSS high
		earth, Lithosoils									
	Mineral Podzols	Apline podzols, Humus-Iron podzols, Iron podzols, subalpine podzols	39161	124	52	263	154	4.9	2.0	10.3	6.0
	Mineral gleys and other soils	Non calcareous gleys, alluvial soils, scree, undifferentiated rankers	24183	131	49	271	173	3.2	1.2	6.6	4.2
	Total stock other soils MtC							*50.2*	*25.4*	*87.3*	*74.3*
	Total stock soils A&B MtC							*162.2*	*139.1*	*144.1*	*245.4*
	Total stock soils A&B MtCO2e							*594.8*	*510.1*	*528.2*	*899.7*

2.3.1.2 Forestry and above ground biomass

A similar approach to that used for belowground C can be used for above-ground C stocks, multiplying the area for relevant categories with their respective stock of C per hectare. To derive relevant area of land cover categories we used the same datasets and approaches as above:

- We combined the “near natural peatland”, “montane and heather moorland vegetation” and “rewetted peatland” to derive a land cover class equivalent to the IPCC “Wetland” category
- We took the area classed as “arable” under LC88 to derive a land cover class equivalent to IPCC “Cropland”
- We combined all the degraded peatland categories except “extracted” with the “Grassland/pasture” except “arable” to derive a land cover class equivalent to IPCC “Temperate grassland”
- We used the James Hutton LC88 map and filtered all polygons including primary classifications relating to forestry and woodland, including recent felling and open canopy) to derive an area estimate of 187,209.43 ha

The aboveground vegetation is likely to be dominated by the contribution from forestry. Given some of the issues around the LC88 dataset discussed about, we also derived the area under Forestry using two further alternative approaches:

- We used the openly accessible Argyll and Bute Forestry Strategy Map (2017) of “existing woodland” to derive an area estimate of 160,462.57 ha

- We used the regional statistics from recently completed and open access Land cover tool produced by SpaceIntelligence to derive an area estimate of 206,481.10 ha

The areas can then by multiplied by the stock of C per ha. In their review of carbon and greenhouse balance of forests in Britain (Morison et al., 2012), the authors break down the carbon stocks from forestry into tree carbon, litter carbon and soil carbon. Given that our estimation of soil carbon includes forestry soils, and to avoid double counting of soil stocks, our estimates of the forestry stocks did not include belowground stocks included in Morison et al. (2012) and focused on the tree and litter elements only. For simplicity, we multiplied the overall UK averages of 57 tC ha^{-1} (tree) and 17 tC ha^{-1} (litter and understorey) by the area covered by woodland and forestry in Argyll and Bute. We used IPCC 2006 values of average above ground biomass for the estimation of C stocks from other land cover categories.

Using this approach, we estimated that the aboveground C stock in Argyll and Bute is between 20.9-24.3 MtC or 76.7-89.2 MtCO2e, with 11.9-15.3 MTC or 43.5-56.0 MTCO2e or a little over half of this held within the forest and woodland biomass (Table 13).

Table 13: Above ground C stocks estimates for Argyll and Bute

Land Cover (Method)	Area (ha)	% A&B area	tC ha^{-1}	MtC	MtCO2e
Wetland (JHI LC88)	158,277	23.13%	43	6.8	25.0
Arable (JHI LC88)	58	0.01%	2	0.0001	0.0004
Temperate Grassland (JHI LC88)	320,412	46.83%	7	2.2	8.2
Forestry (JHI LC88)	187,209	27.36%	74	13.9	50.8
Forestry (A&B strategy map 2017)	160,463	23.45%	74	11.9	43.5
Forestry (SpaceIntelligence Land Cover map)	206,481	30.18%	74	15.3	56.0
Total	*656,528*	*96-100%*		*20.9-24.3*	*76.7-89.2*

While the three approaches used to derive forestry area (LC88, existing forestry and woodland layers and SpaceIntelligence Land Cover map) arrive to similar totals, they are unlikely to be accurate and might notably not include recent felling. In addition, as a result, this total is likely an overestimate of the sink strength from that land use sector.

2.3.1.3 Summary

In Argyll and Bute, we have estimated the total soils stocks to 1m to be between 139-245 MtC or 210-900 MtCO2e, and the aboveground C stock to be between 20.9-24.3 MtC or 76.7-89.2 MtCO2e. The combined above and belowground C stocks from the terrestrial ecosystems in Argyll and Bute is therefore estimated to be between 160-270 MtC or 587-989 MtCO2e. Importantly, the estimation of C stocks for Argyll and Bute's terrestrial environment reveals that:

a. The total soil C stocks are approximately one order of magnitude bigger than the total biomass stocks, and hold more than 10 x Scotland's annual GHG emissions (Scottish Government, 2021a)
b. >85% of the C stocks are held belowground
c. 80% of the soil's C stocks to 1m are held within ~30% of the land area associated with peat and peaty soils
d. 7.5MtC associated with actively eroding peatlands are particularly at risk and should be prioritised for targeted field validation and management intervention
e. While approximately half of the aboveground biomass is held within the woodlands and forests, above ground biomass from other land cover class is not negligible – but may need to be more accurately estimated.

2.3.2 Marine Environment

Marine habitats around Argyll and Bute have been mapped and carbon stocks estimated from existing data sources to identify those habitats and areas with the largest and most significant carbon stores that may serve as natural assets.

2.3.2.1 Sediments

Recognition and understanding of sediment carbon stocks in the North-East Atlantic are currently being improved (Diesing et al., 2021; Legge et al., 2020; Luisetti et al., 2019; Parker et al., 2020; Smeaton et al., 2020). To estimate the amount of organic carbon held within the top 10 cm of sediments in Argyll and Bute, open source data from Smeaton et al., (2021) were used. These data were generated using samples of surficial sediments (top 10 cm) taken by the British Geological Survey (BGS). Using data from the whole of the UK allows a comparison of the carbon held in Argyll and Bute sediments to the rest of the UK Exclusive Economic Zone (UK EEZ).

Argyll and Bute and Clyde marine planning regions hold an estimated 6.2 Mt organic carbon (OC), and 39.2 Mt inorganic carbon (IC) in the top 10 cm of sediments (Figure 21, Table 14). Much of the Clyde region has highly carbon-rich sediments (>0.5 OC kg/m^2). Sediments in the sea lochs in the area (Loch Etive, Loch Linnhe, Loch Fyne, and the Firth of Lorn) have a very high OC content (>1 kg/m^2), and as such are hotspots for organic carbon storage.

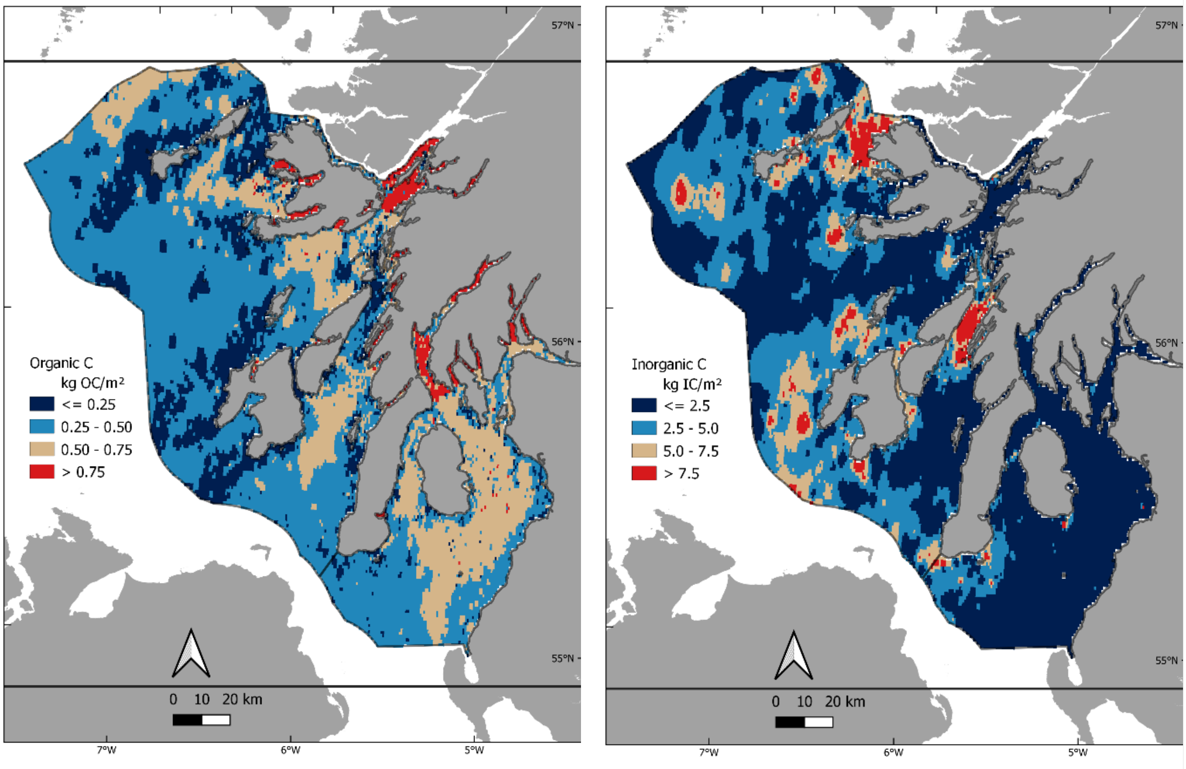

Figure 21: Organic carbon (OC, left) and inorganic carbon (IC, right) in Argyll and Bute from data in Smeaton et al., (2021) as the mass of carbon per area of seabed to a depth of 0.1m (kg C m^{-2}). For organic carbon (left), red areas show hotspot areas in sealochs where OC density is greater than 0.75 kg/m^2. Inorganic carbon (right) is distributed differently, with areas of high concentrations (red areas) mostly in deeper offshore areas to the west of the region.

Table 14: Marine sediment carbon stores in the Argyll and Bute and Clyde Marine Regions, with estimates of rates of carbon storage.

Argyll and Bute plus Clyde Region — <0.1m — *Organic carbon*

Region	Habitat C stock range (kg C/m²)		Extent (km²)	Component area (km²)	Stock (1000 t)	Stock (kg C/m²) avg	Sequestration rate (g C/m²/yr) min	max	avg	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Source
Argyll	<0.25	Rock and coarse sed	11639	2668	376	0.141			0	0		
	0.25-0.5	Sand and mixed sed		6794	2280	0.335			0.2	0.2	1.4	
	0.5-0.75	Coastal Mud		1892	1127	0.596	20	60	40	40	75.7	Teasdale et al 2011
	>0.75	Sea loch Mud		286	366	1.278	47	67	57	57	16.3	Smeaton et al 2021b
Clyde	<0.25	Rock and coarse sed	4112	192	31	0.163			0	0	0.0	
	0.25-0.5	Sand and mixed sed		1869	675	0.361			0.2	0.2	0.4	
	0.5-0.75	Coastal Mud		1846	1112	0.602	20	60	40	40	73.8	Teasdale et al 2011
	>0.75	Sea loch Mud		204	243	1.188	20	120	70	70	14.3	Swan et al 1982
Argyll				11639	4148	0.356				8.0	93.3	
Clyde				4112	2061	0.501				21.5	88.5	
Total, Area-weighted averages			**15751**	**15751**	**6209**	0.394			11.5	11.5	**181.8**	

Inorganic carbon

Region	Habitat C stock range (kg C/m²)	Extent (km²)	Component area (km²)	Stock (1000 t)	Stock (kg C/m²) avg	Sequestration rate (g C/m²/yr) min	max	avg	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Source
Argyll	<2.5	11421	5353	8122	1.517			0	0		
	2.5 - 5		4264	14867	3.486	5	21	13	13	54.4	
	5 - 7.5		1365	8194	6.003	9	42	26	26	34.8	
	> 7.5		438	3921	8.948	12	56	34	34	14.9	Burrows et al 2014*
Clyde	<2.5	3962	3521	2417	0.687			0	0	0.0	
	2.5 - 5		376	1263	3.362	5	21	13	13	4.8	
	5 - 7.5		48	288	5.955	9	42	26	26	1.2	
	> 7.5		17	140	8.333	12	56	34	34	0.6	Burrows et al 2014
Argyll			11421	35104	3.074				9.1	104.1	
Clyde			3962	4109	1.037				1.7	6.6	
Total, Area-weighted averages			**15383**	**39212**	2.542			7.19	7.026	**110.7**	

The carbon held in the top 10 cm of sediments in Argyll and Bute represents a significant proportion of national inventories. Recent publications provide further evidence that the region contains important carbon stocks. For example, Pace et al., (2021) found the Clyde region alone to contain 3.2 Mt OC in the top 10 cm of sediments by modelling the area.

By area, organic carbon (>0.5 OC kg/m^2) hotspots in the Argyll and Bute region make up 24% of the UK seabed that has OC content greater than 0.5 kg/m^2 despite the region making up only 2% of the UK EEZ.

2.3.2.2 Saltmarshes

The largest stores of saltmarsh carbon in Scotland are from the extensive saltmarsh areas in Dumfries and Galloway, but there is good knowledge of saltmarsh areas in Argyll and Bute and data can be downloaded from (https://data.marine.gov.scot/dataset/organic-carbon-density-surficial-soils-across-scottish-saltmarshes). By sub-sampling data from Austin et al.,

(2021) to the Argyll and Bute and Clyde regions we obtain an area of 536 ha (5.4 km^2). Using the average density of OC of 6.0 ± 1.8 Kg/m^2, the top 10 cm of saltmarsh systems in the region therefore contain 32,100 ± 9,600 t OC (Figure 22). This is the equivalent of approximately 9% of the carbon held in Scotland's saltmarsh soils (top 10 cm).

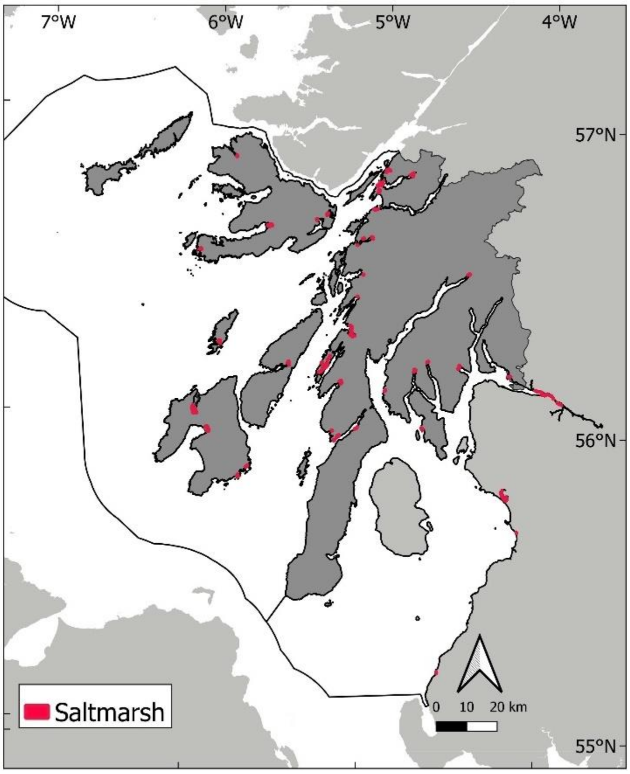

Figure 22: The locations and extent of saltmarsh systems in Argyll and Clyde regions. Combining the area of saltmarsh in the region amounts to 536 ha or 5.4 km^2

2.3.2.3 Kelp beds

Two species of kelp dominate the biomass of these seaweeds in Argyll and Bute (Figure 23). Tangle, *Laminaria hyperborea*, dominates on wave-exposed coasts, and thereby is found around the west-facing rocky coasts of the Inner Hebrides on Tiree, Coll, Iona and the Ross of Mull, and further south around Colonsay and Islay. Sugar kelp, *Saccharina latissima,* tends to be found on more wave-sheltered rocky coasts and is distributed into sealochs and sheltered bays, albeit as a narrow fringing habitat in sealochs. In the absence of detailed underwater mapping of the habitats of these species, habitat suitability modelling (Burrows et al., 2014 2017, 2018, 2021) allows estimation of the likely extent and biomass of these kelp beds (Table 15). Restricting likely kelp habitats to where models predict kelp to be more likely present than not (P(kelp) >0.5), gives total habitat extent estimates of 301km^2 for *L. hyperborea* habitat and 65 km^2 for *S. latissima* habitat in the region. Similarly, considering only those areas where models predict >5kg wet mass of kelp per m^2, the carbon stored in living kelp in the region is estimated at 126,000t and 26,000t for *L. hyperborea* and *S. latissima* respectively.

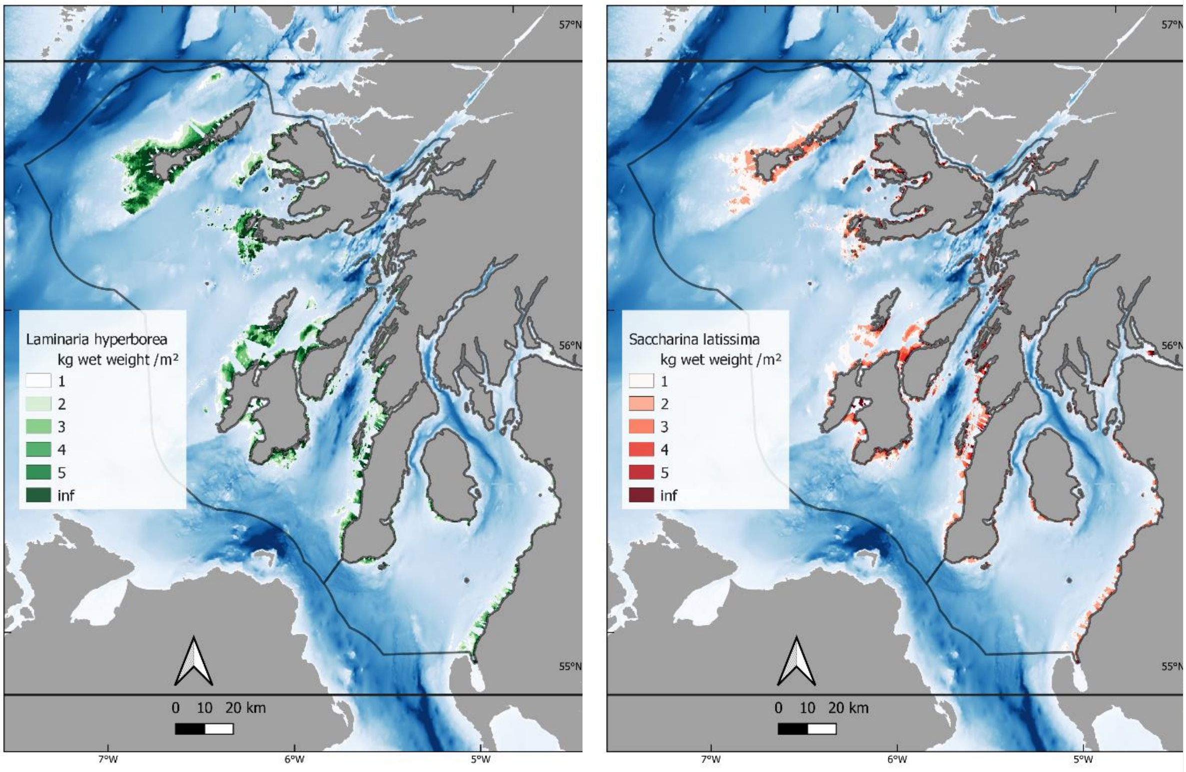

Figure 23: Predicted kelp biomass in the Argyll and Bute and Clyde marine regions. Biomass was predicted from statistical models linking observation of kelp abundance to wave exposure, depth and satellite estimates of ocean colour (Burrows et al. 2014, Burrows et al. 2018). *Laminaria hyperborea* (tangle, left) is the dominant species on wave-exposed coasts while *Saccharina latissima* (sugar kelp, right) is most abundant on wave-sheltered rock. Background shows depth with deeper areas as darker blue.

2.3.2.4 Key marine assets: summary of carbon stores and sequestration rates in Blue Carbon habitats in Argyll and Bute

The key roles played by natural marine habitats in the sequestration and storage of carbon in Argyll and Bute are summarised in quantitative form in Table 15. Two aspects of these data are most worthy of note. First of these is the overwhelming importance of phytoplankton in fixation of CO_2 and as the primary source of organic carbon exported to marine sediments. Production of organic carbon by phytoplankton is estimated as 3.3 Mt C, compared with 0.145 Mt C from coastal vegetated habitats (kelp, saltmarshes and seagrass beds), a contribution from phytoplankton over twenty times greater than from blue carbon habitats. This difference is highly likely to be robust to the considerable underlying uncertainties in the data on carbon contents, process rates and the extents of some of these shallow subtidal habitats (notably kelp and seagrasses).

Secondly, the dominance of marine sediments as carbon stores over the peripheral vegetated blue carbon habitats is considerable. Argyll and Bute's marine sediments store 6.2 Mt OC of organic carbon (Table 16) while only 0.05 Mt is stored in sediments associated with saltmarshes and seagrass beds, with the remaining 0.15Mt OC in living kelp (Table 15).

This is not to underestimate the importance of coastal vegetated habitats, since these are areas most directly associated with human activity and are potentially those that are capable of active management, but it is a reminder of the much larger capacity of the unseen elements of the ecosystem to capture and store carbon in the region.

Table 15: Carbon stocks, sequestration rates and extents of Blue Carbon habitats in the Argyll and Bute and Clyde Marine Regions. Values are summarised from literature sources and GIS data described in Sections 2.2 and 2.3 of this report.

		Organic carbon							
Habitat	Extent (km²)	Stock (1000t C)	Stock (g C/m²)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)
Phytoplankton	16324			203	3305.6	331		0	0
Vegetated habitats									
[1]Kelp beds - *S. latissima*	64.6	25.9	312	290	18.7	1.9		0	0
[1]Kelp beds - *L. hyperborea*	300.8	125.9	358	330	99.3	9.9		0	0
Intertidal macroalgae	65.5	8.0	122	378	24.8	2.5		0	0
[2]Seagrass beds - sediment	3.0	16.4	5479	274	0.8				0.8
Seagrass beds - plants		0.9	285	138	0.4	0.0			
[2]Saltmarshes	5.4	32.1	6000	129	0.7	0.1	0.7	129.0	0.7
Total (excluding phytoplankton)	439.3	209.1	12556	1539	144.7	14.4	0.7	129.0	1.5

Notes (1) Extent from P(present) > 0.5, C from habitat >5kg/m². (2) Rates from Burrows et al. 2021.

NB. Seagrass extent currently unknown but given here as likely percentage of the Scotland total of 16km² in Burrows et al. 2014.

Table 16: Overall Marine C Summary

Argyll and Bute Carbon 2022			***Organic carbon***								***Inorganic carbon***					
Habitat		Extent (km²)	Stock (Mt C) [0.1m depth]	Stock (g C/m2)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Stock (Mt C) [0.1m depth]	Stock (g C/m²) [0.1m depth]	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)
Phytoplankton	Argyll and Bute	12045			203	2439	244									
	Clyde Sea	4278			203	866	87									
All sediment	Argyll and Bute	11639	4.1	356				93	8.0	93.3	35.1	3074	9.11	104		
	Clyde Sea	4112	2.1	501				89	21.5	88.5	4.1	1037	1.67	7		
Biogenic habitats		439	0.2	12556	1539	145	14	1	129.0	1.5						
	Total / Average	16324	6.4													

2.4 Risks to Carbon stocks under Business as Usual scenarios under climate change

2.4.1 Terrestrial Environment

Despite ongoing research using both empirical and modelling approaches, there is still considerable uncertainty regarding how climate and land use change will interact and impact C stocks and biodiversity in the coming decades (Krause et al., 2018; Rees et al., 2018). Some of the key potential impacts of climate change to the terrestrial ecosystems in the UK include a higher incidence of drought stress and increased erosion associated with changing precipitation regime, increased risks of wildfire (UKCP18). In turn, these changing conditions are likely to lead to increased plant stress, reduction in crop yield, shifts in community composition and changes to species interaction, including susceptibility to pests and diseases (Häder et al., 2019). In the UK, a recent report identified that upland areas face particularly acute risks, with 75% of present-day upland species face a potential decline in climate suitability by 2100 under a medium level of warming (UK Climate Change Risk assessment, 2022). In turn, the effect of climate change felt by the terrestrial ecosystems can translate into direct economic impact on rural communities, including increased risks of water scarcity and floods, fire, coastal erosion, etc.

2.4.1.1 Risk to soil stocks

As in the rest of Scotland, the soils in Argyll and Bute are carbon-rich and therefore a key asset to the region that needs protection and sustainable management. While opportunities for improved land management to increase carbon storage and enhance GHG sequestration need to be applied strategically, it is clear from this assessment that the prevention of C losses through restoration and protection of the denser C deposits found in the peat and peaty soils (Figure 24) should be a priority, as suggested by others (Fig 3., Artz et al., 2014; Leifeld and Menichetti, 2018).

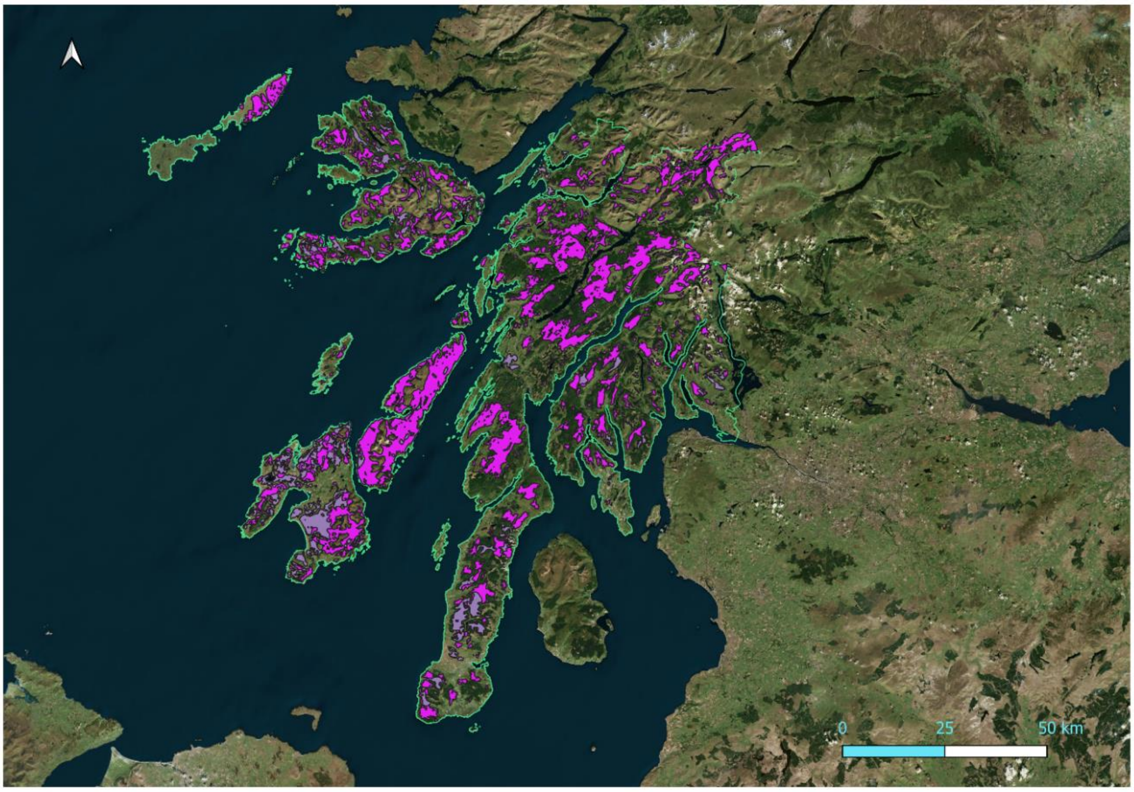

Figure 24: Areas of deep peat (purple) and Class 1 and Class 2 (Nationally important) peat soils in Argyll and Bute

The degradation of peatlands put the entire C stock at risk by causing a slow, but continuous release of CO^2, at a rate far exceeding the rate at which the C has accumulated in the first place. For that reason, losses associated with degraded peatlands have been qualified as "irrecoverable" (Goldstein et al., 2020). It is now well established that in relation to peat and peatland stocks, there are important risks in relation to climate change to consider, including:

- Continued and accelerated losses in areas impacted by drainage and erosion (Ferretto et al., 2019; Figure 25). In these cases, while the whole carbon stock is threatened, only a small fraction is emitted annual as CO^2. However, drainage triggers changes in vegetation and peat properties that can lead to the loss of the entire peat mass over decades to centuries through oxidation, increased aquatic losses, and increased erosion on sloping grounds.
- Increased risks of catastrophic losses from wildfire associated with loss of resilience mechanisms and shifts to dry-adapted or heath communities (Andersen et al., 2021). Large wildfires lead to significant losses particularly in above ground and near-surface stocks through combustion and smouldering.
- Increased risk of catastrophic failure (peat slide) associated with storms and sustained precipitations (Marshall et al., 2021) and compounded by infrastructure development on peat (Kane et al., 2019). While these events are rare and localised, where they occur, they can lead to the loss of the entire C stock (above and belowground) at once, and can have

profound reputational consequences for land managing organisations where failures happen.

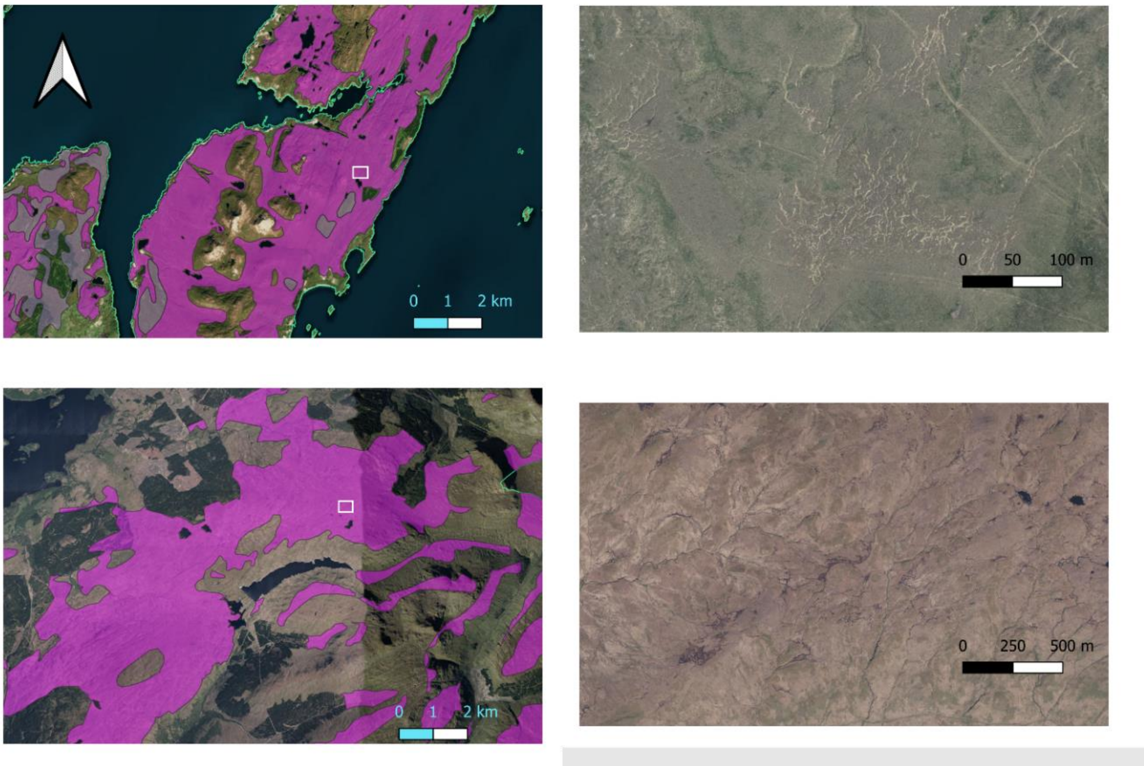

Figure 25: Examples of erosion features in peat soils (right) in two areas within Argyll and Bute (left), with small white square indicating zoomed in areas.

Current evidence suggests that losses from high organic soils underneath forestry are not always compensated by C accumulation in tree biomass, both in peatland and peat soils (Sloan et al., 2018, Sloan, 2019) and in high organic soils not classed as peat (Friggens et al., 2020). However, for shallower peat soils, however, losses associated to leaching and oxidation can be compensated particularly if limited disturbance or over multiple rotations (Vangueloval et al., 2018). Guidance on restocking on deep peat has been developed by Forestry Commission Scotland (2015b) and is regularly reviewed, and currently, none of the preferred areas for woodland expansion coincide with areas of deep peat. On the other hand, a significant proportion of the areas identified as "Preferred for woodland expansion" are also sited on peat (Figure 26), it will be important to consider potential losses from soils in the decision making process, and avoid undesirable long-term negative impacts by ensuring best-practice is followed and adapted as evidence builds up.

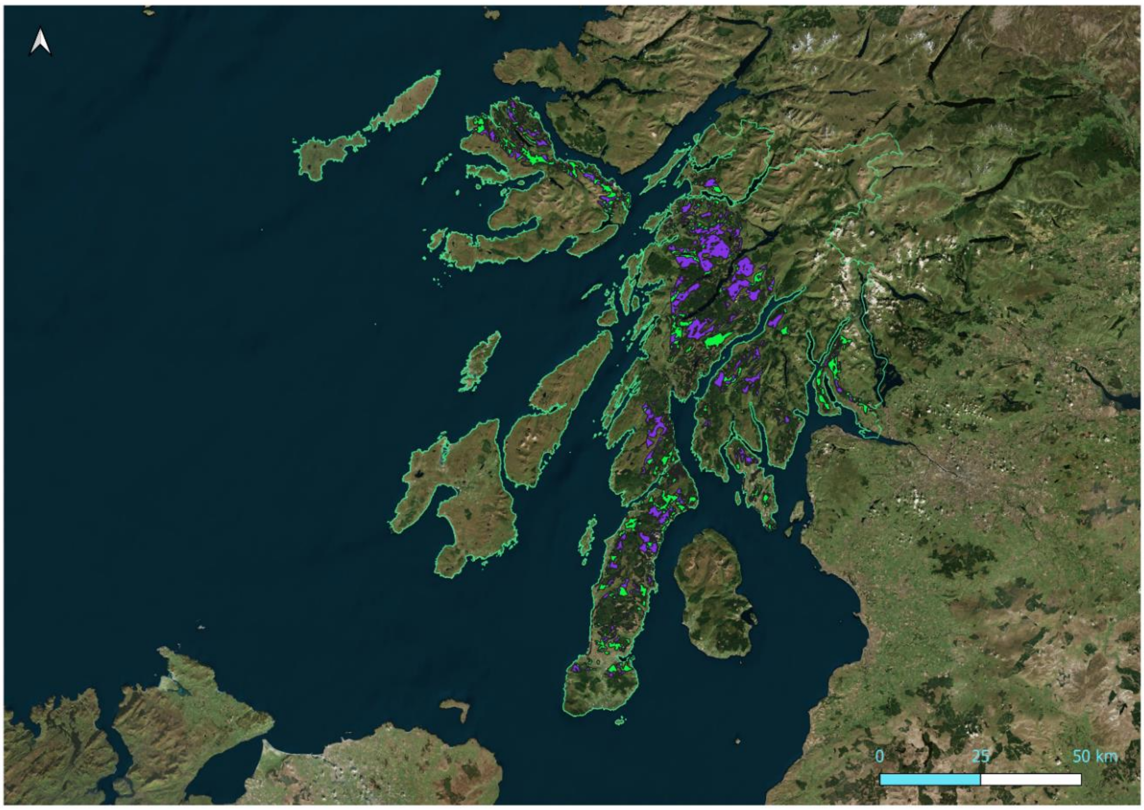

Figure 26: Areas of preferred woodland expansion overlapping with peat soils (purple). Areas overlapping with non-peat soils are shaded in green. Adapted from the Woodland and Forestry Strategy Map and the JHI Peat map.

2.4.1.2 Risks to forestry and woodlands C stocks[6]

Forests and Woodlands in Argyll and Bute (Figure 26) are not as important as soils in terms of aboveground stocks, but they play a vital role in ongoing sequestration of C, supporting economy and have a large potential for marketable Carbon in the future. Risks to C stocks under forest and woodland land use classes include risks to belowground stocks.

The expected warmer climate is anticipated to improve tree growth particularly in southern and eastern Scotland, and in particular the climate will become more favourable for growing high-quality broadleaved trees on suitable deep and fertile soils. However, climate change also bring other risks to above-ground C stocks (tree biomass), the important C sequestration function that they perform and their socio-economic benefits include:

- More frequent summer droughts, wildfires and winter flooding that may impact trees growth
- Increased susceptibility to *Phytophtora ramorum*, a fungus like pathogen causing serious damage and mortality to trees, with the Japanese, European and Hybrid larch

[6] https://www.soilassociation.org/causes-campaigns/regenerative-forestry?fbclid=IwAR3IBxDTBFeHVydOWErqb-r5VJjmgXLY11vKVIDD1lX1R8KsRnL6xxaWkMg
UK Climate Change Risk Assesment 2022 (publishing.service.gov.uk)

particularly susceptible. Across the UK, an estimated10341 ha of larch (Japanese, European and Hybrid) in the Forestry Commission Scotland's (FCS) National Forest Estate (NFE) lies within the current Risk Zone 1. Argyll and Bute sits entirely within the Zone risk 1 (higher climatic risk where infection has been or is considered to be more likely to be found on larch) based on the Forestry Commission Risk Zones (2015a)

- Increased susceptibility to other pest and diseases including Large pine weevil (*Hylobius abietis*), considered to be the largest threat to the UK's softwood timber growing industry as it threatens the establishment or replacement crops of conifer trees such as pines, spruces, first and hemlock (Forest Research[7]). Similarly, more frequent green-spruce aphid attacks may reduce growth in eastern and southern Scotland.
- Changes in frequency of extreme winds may increase risk of windthrow or storm damage (Scottish Forestry, 2008)

2.4.1.3 Risk to Agricultural soils and other stocks

Agricultural activity in Argyll and Bute can be found on a range of soil types including peat soils (Figure 27) and as such many of the risks previously outlined will be applicable.

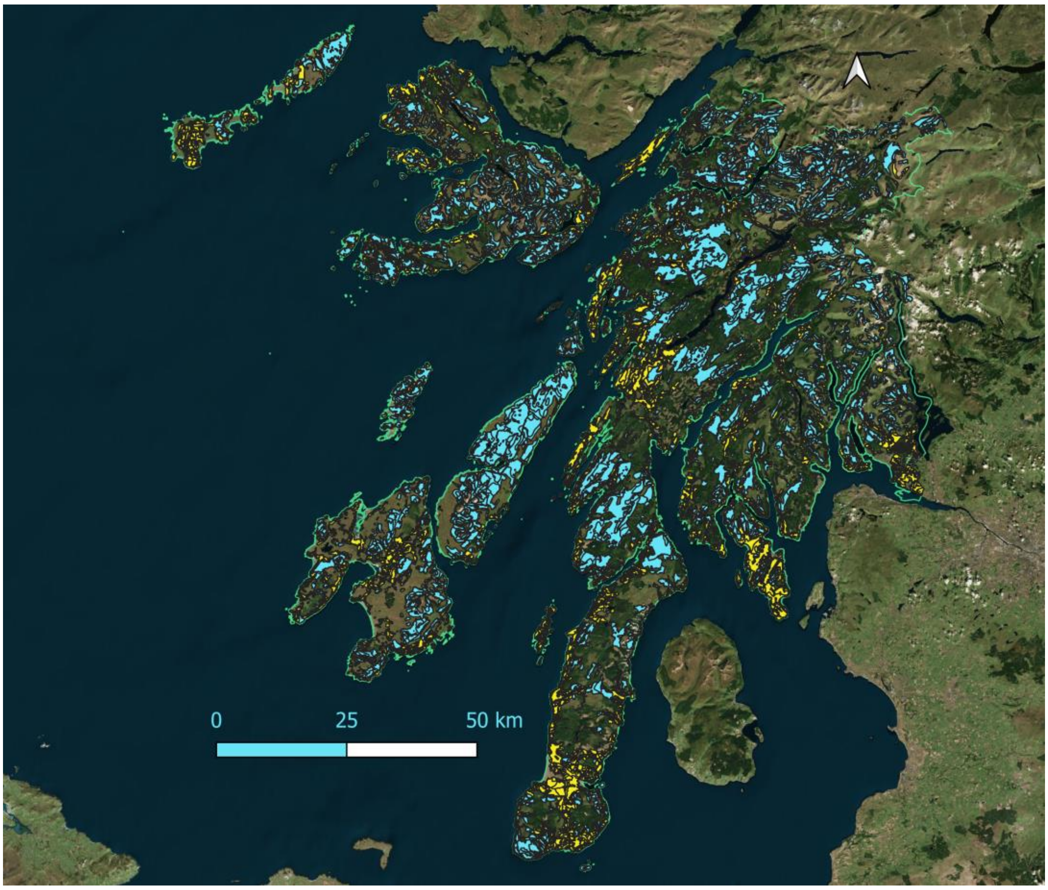

Figure 27: Map of areas associated with agriculture (yellow) and likely to be used for grazing (light blue) in Argyll and Bute, based on primary classification of the LC88 dataset.

[7] Large pine weevil (Hylobius abietis) - Forest Research

2.4.1.4 Summary

Further risks with changing climate under business as usual, but also with more limited change in climate can include:

a. Projected increase in more frequent and intense rainfall events, and winter rainfall may have negative impacts including increased loss of topsoil and nutrients due to erosion.
b. Waterlogging of soils can affect tree, crop and pasture growth, i.e. above ground carbon stocks, by restricting the flow of oxygen to the roots and therefore root function via nutrient uptake.
c. Flooding can submerge crops and pasture, preventing growth and development, and physically damage the plants and soil restricting above ground carbon sequestration.

Climate induced changes to below ground soil organic carbon content will vary with soil type and agricultural management as sequestration depends on the balance between carbon inputs and losses. Impacts on belowground soil stocks may also depend on other management regimes (e.g. grazing type and density). In general, we lack a good understanding of the interactions between the full range of land management intervention in a given system and the key biogeochemical processes and feedback leading to C emissions or sequestration over the short-, medium- and long-term. Predicting net impact on soil carbon is difficult to achieve, however climate change is likely to generally increase greenhouse gas emissions from soils (NERC 2016).

2.4.2 Marine environment

2.4.2.1 Risks to marine carbon stores in Argyll and Bute

Risks to carbon stores in Argyll and Bute come from multiple pressures. There are currently several threats which might impact the standing stock and biomass of blue carbon habitats and threaten the carbon storage they provide such as climate change, ocean acidification, diseases, invasive species, land-use change, water quality issues and damaging fishing practices (Burden et al., 2020). The premise of carbon storage and offset potential provided by blue carbon habitats depends upon a healthy system (Nellemann et al., 2009). The maximum drawdown of carbon will therefore be provided when ecosystems are functioning at a high level.

The carbon delivered to sediments is mainly allochthonous in nature (derived from outside of the sediment system). There are a variety of human-related drivers which are currently changing the way in which organic carbon is delivered to sediments which include ocean warming (related to climate change), acidification and deoxygenation, mixing and disturbance of continental margin sediments (Keil, 2017). Carbon preservation in sediments is threatened by a decreased delivery of carbon and an increased remineralization and dissolution caused by anthropogenic forcing (Aller, 1994; Burdige, 2007; Keil, 2017). The following section discusses the threats to coastal carbon stores, and the impacts which each threat will have on the function of each system.

2.4.2.1.1 Climate change

Increased seawater temperatures will likely impact the productivity, distribution, resilience and community structure of kelp forests (Smale et al., 2013), seagrass (Ondiviela et al., 2014), saltmarshes (Burden et al., 2020) and plankton (Edwards et al., 2013). Climate change is seen as a gradual pressure which can alter the condition of ecosystems and the services they provide. In general, studies have shown that carbon stocks, and sediment burial rates will decline as the impacts of climate change occur in the ocean (Burden et al., 2020; Burrows et al., 2011; Ciais et al., 2014; Hoegh-Guldberg & Bruno, 2010; Legge et al., 2020). The impacts of temperature change also induce different threats, such as invasive species, diseases and changing water chemistry (i.e., ocean acidification) which, will have impacts on the carbon storing function of species and processes.

Regular plankton blooms occur in the Clyde region and have been associated with advection from offshore, changing environmental conditions that allow seeds to propagate and excess rainfall which allows untreated wastewater to run-off shore (Hallegraeff et al., 2021). The effects of harmful species such as *Karenia mikimotoi* pose a risk to shellfish aquaculture and recreational swimmers, and can induce anoxic conditions when the blooms eventually terminate (Davidson et al., 2021; Martino et al., 2020). However, algal blooms have been related to enhanced carbon preservation in studies of historic samples which implies that in a warmer climate algal blooms will draw more carbon down to sediments (Macquaker et al., 2010). It is uncertain as to whether the negative impacts of algal bloom formation and termination outweigh the benefits of carbon preservation.

2.4.2.1.2 Invasive species

The impacts of invasive species can have severe effects on ecosystem function when a key species is removed without the replacement of the ecological niche that it holds. For example, if warm water ecosystem engineers (such as kelps) replace cold water ecosystem engineers, the habitat replacement may be functionally and structurally similar or it may lose function entirely (Smale et al., 2013). Recent observations of the warm-water kelp species *Laminaria ochroleuca* in the UK (Smale et al., 2015) and Ireland (Schoenrock et al., 2019) have driven concerns about the replacement of native species with expected elevated water temperatures. *L. ochroleuca* has been shown to degrade faster than native species and as such, may reduce carbon storage by kelps if it becomes widespread (Frontier et al., 2022). The poleward movement of warm-water-tolerant species such as *Laminaria ochroleuca* and *Undaria pinnatifida* is expected but as-yet, undocumented in Scotland (Minchin & Nunn, 2014). There are however documented occurrences of *Sargassum muticum* which has established itself in parts of the Clyde (Harries et al., 2007). *S. muticum* forms a large canopy which, can limit light availability for other intertidal and sub tidal species raising concerns that it will outcompete other fucoids. The red seaweed species *Grateloupia turuturu* has also been recorded in parts of the UK (Arenas et al., 2006).

Non-native *Spartina spp.* of saltmarsh such as *S. alterniflora* have become invasive in parts of Europe (Ainouche & Gray, 2016), where they can successfully replace native species and flourish given the lack of grazers or native pathogens which regulate their abundance. *S alterniflora* has also been used for carbon storage enhancement, coastal restoration and sediment stabilization (Yang, 2019) suggesting an invasion of *S. alterniflora* might enhance existing carbon stocks.

The spread of invasive species in the marine world is generally related to increased boat traffic, moorings, docks and recreational boating which act as vectors for the relocation of species (Ashton et al., 2006). There is an associated economic cost related to non-native species which, in the UK is estimated at £1.7 billion a year (Cook et al., 2013; Williams et al., 2010).

2.4.2.1.3 Disease

The seagrass wasting disease rapidly reduced the distribution and abundance of *Z. marina* on both sides of the Atlantic between 1930 and 1933 (Cotton, 1933). The disease was associated with *Labyrinthula zosterae* (Renn, 1937), and *Ophiobolus halim* (Wilson, 1949) and also coincided with increased use of herbicides and fertilizers as agriculture intensified at the time (Nedwell et al., 1999). There are currently four known pathogens which cause wasting disease which fall under the genera *Labyrinthula*, *Phytophthora*, *Halophytophthora*, and *Phytomyxea* (Tan et al., 2021). Pollution by nitrates, pesticides and herbicide has been shown to increases the susceptibility of *Z. marina* to infection by *L. zosterae* (Hughes et al., 2018b). Any restoration of seagrass habitats, therefore, will need to be accompanied by wastewater and agricultural run-off management. There has been considerable effort to restore seagrass beds which have been lost historically, in Argyll and Bute active projects include those of Project Seagrass (www.projectseagrass.org) in the Clyde region and Seawilding (www.seawilding.org).

Increased aquaculture activity (including seaweed farms) will have associated risks (Campbell et al., 2019). Disease introduction can have impacts on the ecosystem function to native stocks (Campbell et al., 2020). It is important to maintain biosecurity measures for all nature-based climate action that is taken.

2.4.2.1.4 Coastal squeeze

Intertidal habitats which grow on sediments or mudflats generally move and evolve over time as the shape and expansion of their substrate changes, these changes can be more obvious in a time of rising sea-levels ((Torio & Chmura, 2013). Coastal development such as roads, buildings, levees and defensive barriers prevent the natural expansion and retraction of habitats such as saltmarshes, seagrass meadows (Pontee, 2013) and intertidal seaweed species (Martins et al., 2019). The ecological impacts of coastal squeeze have been modelled in Scotland (Jackson & McIlvenny, 2011). With a sea-level rise of 0.3 m, intertidal extents will likely decrease by 10-27%, a sea-level rise of 1.9 m will decrease intertidal areas by 26-50% (Jackson & McIlvenny, 2011), thus reducing the extent to which coastal vegetated habitats can survive. The protection of natural coastal carbon storing systems will therefore conflict with plans to protect infrastructure and coastal development schemes in Argyll and Bute (see Argyll and Bute Coastal Development Plan 2015, Argyll and Bute Coastal Defence Plan 2015). In 2016 a total of 249 saltmarsh sites were surveyed across Scotland and 7,704 ha of saltmarsh were mapped and recorded (Haynes, 2016). The survey purpose was to assess the status of saltmarshes in Scotland against the Habitats Directive (The Habitats Directive, 1992). A total of 67% of saltmarshes surveyed failed one or more condition targets mainly due to built structures, lack of landward transition habitats, negative impacts of grazing and pollution (Haynes, 2016).

2.4.2.1.5 Land use change

Saltmarsh areas continue to decline globally (Mcowen et al., 2017). Historically, saltmarsh cover has reduced by between 25% and 50% (Duarte et al., 2008). Most losses can be attributed to land-use change. For example, agricultural practices, development of industry, urbanization, land claim for ports and industry and transport infrastructure are all responsible for the conversion of saltmarsh habitats away from their natural state (Gedan et al., 2009). Saltmarshes are particularly susceptible to the effects of coastal squeeze and protective infrastructure around roads and development (Wolters et al., 2005).

2.4.2.1.6 Fishing practices

Coastal sediments represent significant stores of carbon. The organic carbon held within the top 10 cm of sediments is converted back into CO_2 (remineralised) when it is disturbed by trawling (Sala et al., 2021). Despite the importance of marine sediments as a carbon store, they remain largely unprotected. Globally, approximately 2% of marine sediments are located in highly protected areas (Atwood et al., 2020). In Scotland, the only MPA established to protect sediments is within the Rockall trough, and the sediment stores are protected for the habitat that they provide, not for the carbon within them. Disturbance of sediments occurs with dredging (van de Velde et al., 2018), trawling (O'Neill & Summerbell, 2011) and through input of nutrients which alters the sediment chemistry (Cotano & Villate, 2006). Trawling is likely to have profound effects on the functional processes of soft sediment systems by; 1) reducing the amount of bioturbating organisms and 2) increasing the amount of aerobic CO_2 production, thus altering the carbon storage capacity of sediments (Duplisea et al., 2001; Paradis et al., 2021). A recent review estimated that globally, trawling just 1.3% of the ocean floor produces the equivalent of 1.47 Pg of aqueous CO_2 annually (Sala et al., 2021). The monetary value of anthropogenic and changing-climate pressures on sediment carbon stores in the UK, due to carbon released during trawling, has been estimated in the region of US$ 12.5 billion within a 25-year timeframe (Luisetti et al., 2019). Temporary protection of sediments (closure from trawling for up to two months) have been shown to be ineffective against the impacts (Paradis et al., 2021).

The effect of demersal fishing gear on sensitive features such as maerl can be severe. In 5-year experiment, it was shown that a 70% reduction in cover occurred on live coraline algae in sites where trawling was trialled, compared to control sites (Hall-Spencer, 1999). Furthermore, no sign of recovery occurred over the following 5 years after experimentation, suggesting the effects of demersal fishing will impact maerl long-term.

Combined impacts related to elevated levels of atmospheric CO_2 will likely have a profound effect on the fauna, and ecosystem services of natural habitats in the northeast Atlantic (Brodie et al., 2014). By allowing natural (landward or seaward) migration of coastal habitats, maintaining sediment stocks and supply, restoring lost areas and improving water quality, the carbon sequestration capacity of the ocean can be enhanced (Lovelock & Reef, 2020).

2.4.2.1.7 Summary

Risks to marine carbon stores in Argyll and Bute include:

- Climate-change related shifts in the abundance and distribution of carbon-fixing organisms including kelp forests, saltmarshes and seagrass beds. Increased threats from harmful algae with climate warming have been suggested.
- Invasive carbon-fixing species may replace native ones in blue carbon habitats and would alter rates of carbon accumulation. Boating and aquaculture can be important vectors for such invasions.
- Seagrass is threatened by “wasting” disease. The susceptibility of these plants (and other organisms) to such diseases is increased by pollution from excess nitrates, herbicides and pesticides from agriculture and aquaculture.
- Coastal squeeze, the process by which habitats on the seaward side of coastal defences are lost to sea level rise. It has been estimated that intertidal areas will decrease by 10-30% as a result.
- Land use change threatens saltmarshes through changing farming practices and construction of defensive infrastructure for roads and ports, for example.
- Fishing using mobile gears such as bottom trawls and scallop dredges resuspends stored carbon in sediments, resulting in CO2 emissions, and damages habitats for blue carbon species such as maerl and other biogenic-reef-forming species.

2.5 Identification of drivers and trends in the demand for C trading

2.5.1 Terrestrial environment

2.5.1.1 Scotland Carbon Market SWOT Analysis

Drawing from our extensive experience and discussions with stakeholder groups, landowners, the IUCN Peatland CODE team, NatureScot’s Peatland ACTION team and land agents as part of other projects, we identified Strengths, Weaknesses, Opportunities and Threats to Scotland Carbon Market specifically in relation to peatland and forestry.

Strengths	Weaknesses
• Supportive net-zero policy environment • Existing schemes for peatland and woodland • Scale of landholdings • Support of public landowners (FIS) • Possibility to combine schemes (e.g. Peatland CODE + Peatland ACTION or Peatland ACTION + AECS) • Shared carbon registry has been set up in 2020 for the Woodland Carbon and Peatland Codes	• Mixed public perception • Complicated process through multiple agencies • Limited applicability of Peatland CODE to large-scale programme due to field-based validation methods vs small profit margin for small projects • Need for upfront capital for some schemes
Opportunities	**Threats**
• Net-zero targets • Increasing global market for carbon offsets • Charismatic Carbon (i.e. carbon associated with biodiversity and water benefits) • New technologies available to support landscape-scale delivery • Development of a range of skilled jobs associated with expansion of land-based interventions	a. Weak global carbon price b. Competition from international sellers c. Climate change (i.e. compromising delivery of outcome, increasing intervention costs, reducing profit margins) d. Mismatch between supply and demand

2.5.1.2 Public sector drivers and demand

Scotland's Landscapes have a vital role to play in supporting the ambitious targets for climate change mitigation, and the importance of land-use change in delivering emission reduction targets has been highlighted by the UK Climate Change Committee already. The two pillars of Land-Use, Land-Use Change and Forestry (LULUCF) and key **Nature Based Solutions** to climate change in the UK are **large-scale restoration of degraded peatlands** and **woodland expansion** (Scotland's Climate change plan 2018-2032) – and the public sector demand is clearly aligned with funding and policy.

In 2020, a £250 million ten-year funding package to support the restoration of 250,000 hectares of degraded peat by 2030 through Peatland ACTION. Across Scotland, the highest annual delivery was 6000 hectares in 2019-20. Achieving the current target of 20,000 hectare per annum will require a step-change (source: Peatland ACTION). As part of the Scottish Government's Low Carbon Fund, the public forestry sector will receive £130M boost to expand Scotland's National Forest and land, supported with further investment in nurseries. There, the goal is to increase woodland creation from the level of 12,000 hectares in 2020/21 up to 18,000 hectares per year in 2024/25.

As well as restoration, the need to protect existing C store is recognised by the public sector, for example with a strengthening of controls on development on peatland and facilitation of restoration through permitted development rights within the National Planning Framework 4.

Ultimately, determining the optimal mix of land use involves a complex set of interlinked considerations and goals that require careful trade-offs and understanding of tensions, which include potential:

- Trade-offs between land productivity for food security and land set aside for carbon and biodiversity
- Trade-offs between biodiversity and carbon, e.g. increased carbon sink strengths that negatively impact biodiversity
- Tensions around transition away from traditional management and landscape perceptions
- Tensions around perceived incompatibility of re-wilding and re-peopling

2.5.1.3 Private & NGO sector drivers and demand

Both the UK and Scottish Governments have set out their net-zero targets for 2050 (Scotland's Climate change plan 2018-2032; Scottish Government, 2020a) and 2045 respectively. Whilst government targets set the road for public sector pathways to net-zero they also give the private sector confidence and steer towards similar targets. Corporations are a significant contributor to emissions in Scotland and customers, shareholders, employees, and the public, add to growing pressure to decarbonise business activity (Bidwells, 2022). Many sectors, industries, and businesses currently do not feel that net-zero can be achieved without a route to offset emissions for which there is no clear pathway to decarbonisation yet. There is debate around the scale of emissions which can be reduced or offset and concern that offsetting can be used by companies, and other emitters, to continue business as usual without reducing emissions first. Irrespective of the debate around offsetting as a meaningful way for businesses to achieve net-zero it is clear that offsetting will be required for some emissions and that private sector voluntary carbon offsets will continue to be a driver for land use change towards marketable carbon.

While there may be a high demand from the private sector, it is likely that NGOs could become a key supplier of landscape scale restoration utilising marketable carbon. There is already evidence of engagement from some NGOs with the existing CODES. However, and while NGOs can supply high integrity verified emission reductions, it is likely that NGOs may not engage with businesses that don't demonstrate willingness to reduce their emissions through other means than engaging with offsetting schemes.

2.5.1.4 Future plausible trade scenario

It is recognised that delivering on the 2032 emissions reductions on the road to Net Zero, these targets will not only need to be met, but exceeded. This can only be achieved by blending of public (Peatland ACTION, Forestry Grants, AECS) and private finances (Peatland CODE, Woodland Carbon CODE).

Some of the likely future plausible trade scenario include:

1. NGOs and private estates continuing to engage with Forestry grants and Peatland ACTION but scoping out Peatland CODE and Woodland Carbon Code to develop and roll out medium-to-large projects in a "blended" model

2. Multi-stakeholder partnerships facilitating development of large-scale programmes blending income streams supported by large investments from the private sector, enabling multi-year planning
3. Increased government support and financial incentives for the maintenance and management of stocks for which there is no need for intervention (e.g. peatlands in good conditions)

2.5.2 Marine Environment

There is significant demand and opportunity for carbon trading based on BC, however there are also significant risks and technical difficulties in the direct translation of the terrestrial market to the marine environment.

Strengths	Weaknesses
• Huge demand for ESG investment in the marine environment • Huge potential to scale (largest habitat globally) • Alignment with other conservation/sustainability goals • Highly productive ecosystems • Market already developing	• Complex ownership of marine space • Existing traditional and new uses for marine environment • Hydrodynamic movement of carbon makes attribution difficult • Lack of maturity of market • Lack of robust quantification methods
Opportunities	**Threats**
• Growing demand for sustainable investment in Marine Environment • Clear political drive for net zero • Seaweed aquaculture is rapidly growing globally • There is political movement for the development of schemes that allow payment for ecosystem services • Community ownership of projects linking to greater devolution of natural asset management	• Climate change increasing storminess and sea surface temperature • Reputational damage from poorly developed schemes connected to an immature market • Complexity of the science, and possible poor communication to investors and policy makers • Singular focus on carbon dioxide

The marine economy is worth approximately $1.5-2 trillion USD. However, despite its size there is a recognised lack of capital flowing into the marine economy and a lack of recognised ESG investment locations. The development of accredited and professionally run BC trading schemes offers an opportunity for direct investment into the marine economy in line with ESG objectives. It is estimated that ESG investment will grow to $53 trillion USD by 2025. Drawing parallels from the more mature markets can help to understand likely trajectories for the development of BC markets. It is widely recognised that land use change emits GHGs and reduces the capacity to store carbon but effective terrestrial conservation through the protection of functioning ecosystems, the improvement of land management, or the engineering of ecosystems to sequester carbon can be an effective tool to mitigate climate change (Seddon et al., 2021). These three activities are reflected in a typology of Nature-based Solutions (Figure 28).

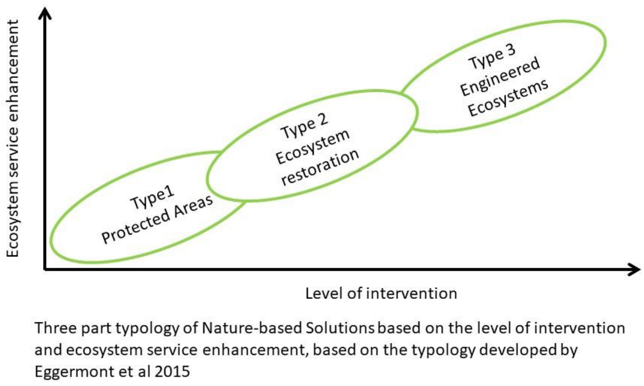

Figure 28: *Schematic representation of the range of nature-based solution approaches. Three main types of NBS are defined, differing in the level of engendering or managing applied to biodiversity and ecosystems (x-axis, and in the numbers of services to be delivered, the number of stakeholder groups targeted, and the likely level of maximisation of the delivery of the targeted services (y-axis) (Eggermont et al. 2015)*

Within the terrestrial environment this range of NbS has been successfully integrated into the carbon markets, with NbS potentially accounting for two thirds of the voluntary carbon market by 2030. This approach could also be applied to the development of BC markets, using marine based NbS that are using a similar typology.

- Type 1 Marine protected areas that prevent BC habitat loss such as dredge fishing, seaweed harvesting, and seagrass bed degradation
- Type 2 Restoration of BC habitats such as seagrass beds or native oyster beds
- Type 3 Seaweed aquaculture

As discussed earlier even within this framework, there are major problems with the quantification and verification of BC relating to the export of carbon outside the project area. Possible solutions to these could be developed from terrestrial environments, where there are moves away from a project-based approach to a “jurisdictional approach” where the carbon stocks are managed and valued at the scale of legally defined territories. Working at such scales makes the estimation of carbon fixing and storage much more robust (Steer & Hanson 2021). Using the NbS framework to allow a jurisdictional approach may be particularly appropriate for the Argyll and Bute region.

3 IDENTIFICATION OF PRIORITY CARBON TRADE OPPORTUNITIES WITHIN EXISTING WOODLAND AND PEATLAND CODE TRADE SYSTEM

3.1 Terrestrial environment - Peatland opportunities

As highlighted in WP1, there are currently three main mechanisms available to landowners and land managers to access funding in relation to peatlands: the Scottish Government's Peatland ACTION programme, some of the options in the Scottish Agri-Environment Scheme, and the Peatland CODE (Table 17). Only some of the management options in AECS relate to intact areas of peatlands and only the Peatland CODE involves the accounting and trading of carbon associated with specific cases of degraded peatlands targeted by peatland restoration interventions.

From initial mapping and visual inspection of polygons in WP1, it is clear that there is scope for all of these options to be used to increase peatland restoration in Argyll and Bute and support sustainable management of near natural peatlands where most of the soil C stocks are found. However, it is not possible to derive a spatially explicit map of where each of these options would be most appropriate, because this would require GIS mapping and ground validation beyond the scope of this report.

In terms of priority carbon trade opportunities, we believe that the most likely "win-win" options will be:

- Peatland CODE applications developed for areas of actively eroding peatlands
- Peatland ACTION and/or Peatland CODE for restoration of extensive areas of drained peatlands
- Peatland ACTION for small areas of drained/modified peatlands, afforested peatlands outside of renewable energy development sites and/or other eligible activities complimentary to restoration management
- AECS applications for sustainable management on peatlands where restoration options are limited (e.g. hand cut peat, modified but not drained, near natural)

Table 17: Details of funding mechanisms currently available for the restoration and management of Scottish peatlands

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
Peatland ACTION	Subsidise peatland restoration intervention.	Combined ditch/grip blocking and reprofiling; ditch blocking, although preference on combined blocking and reprofiling; gully re-profiling and blocking; bunding; bare peat restoration; surface smoothing on previously forested sites; hag restoration; installation of sediment traps; scrub/woodland removal; mulching; re-use of felled to waste material; peat depth and peatland condition surveys; interpretative materials; community initiatives; professional fees.	The majority of the peatland within a project area must have a peat depth of over 50cm, but peat depths down to 30cm will be considered for restoration if they form an intrinsic component of the peat hydrological unit. Projects to be greater than 10 ha with a cost over £10,000 however smaller projects can link with other landholders to create a larger project.	There are no geographical restrictions or target areas for Peatland Action funding.	No.	No.	1 year for spending, 10 years for maintaining condition.
Peatland CODE	Attract carbon funding to support peatland restoration projects.	Restoration and management activities. Restoration activities shall revegetate and/or re-wet the peatland (excluding removal of plantation forest) and shall result in a change to a condition category with a lower associated emission factor. Management activities shall maintain or enhance the condition category change.	Eligible activities shall be those relating to restoration of either blanket bog or raised bog with an associated baseline condition category of 'Actively Eroding' or 'Drained' and a minimum peat depth of 50 cm. Baseline condition category and peat depth shall be determined using the Peatland Code Field	Legal ownership, or tenure of the land for the duration of the project, shall be demonstrated for the project area. No new activity to drain or remove vegetation since November 2015.	Yes.	No.	Minimum duration of 30 years.

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
			Protocol. durations greater than 55 years, evidence shall be submitted to demonstrate that the duration shall not exceed complete loss of the peatland resource.				
AECS – Upland, peatland, moorland and heath options **Moorland management**	Benefit a range of moorland habitats by maintaining appropriate levels of wild and domestic stocks on land that is rough grazing	Maintenance/reduction in livestock; deer census (helicopter count) and deer management; deer impact assessment; ditch blocking (including forest-to-bog furrows);heather/bracken control; heather restoration; stock bridges for bog, fen or wetland management.	Moorland management plan using template provided, including details of current livestock number, location, cull target. Management plans that relate to any options (e.g. peatland restoration plan, deer management plan)	Land that is rough grazing and where livestock and / or deer are present is eligible.	No.	Yes.	Annual payment.
AECS – Upland, peatland, moorland and heath options **Stock Disposal**	Benefit the condition of moorland habitats by reducing grazing or trampling pressure.	Reduction in sheep numbers.	Moorland management plan with the number of ewes and gimmers that are proposed to be disposed of. The plan must take into account the need to avoid under and overgrazing.	Land that is rough grazing is eligible.	No	Yes	Annual payment
AECS – Upland, peatland, moorland and heath options **Away Wintering Sheep**	Maintain or improve the condition of moorland by away-wintering sheep which would usually graze the moorland.	Reduction in sheep numbers over the winter (1st Nov to 1st Mar).	Detail in moorland management plan the number of ewes, gimmers and / or hoggs that are proposed to away winter, and that these numbers will benefit the moorland habitat.	Land that is rough grazing is eligible.	No	Yes	Annual payment for duration of contract

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
AECS – Upland, peatland, moorland and heath options **Summer Hill Grazing of Cattle**	Maintain or improve the quality of the moorland habitat by grazing with cattle during the summer.	Graze cattle for at least 12 weeks between 1st May and 31st August.	Detail in moorland management plan the number of cattle that are proposed to summer on the hill, and how this will benefit the moorland habitat.	Land that is rough grazing is eligible.	No	Yes	Annual payment for duration of contract
AECS – Wetland and bog options **Wetland Management**	Benefit a range of existing or newly created wetland habitats by maintaining appropriate grazing regimes.	Creation of new wetland, creation of new low-input grassland, grazing or cutting area.	Identification on a map the locations of any existing or proposed wetland to be managed. Where new wetland is created it must be specified in application how water levels will be raised or reinstate floodplain in order to create the wetland. Recommended grazing management plan.	Land that contains either an existing wetland or is where it is proposed to create a new wetland is eligible. This includes fen meadow, reed beds and salt marsh.	No	Yes	Annual payment

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
AECS – Wetland and bog options **Lowland Bog Management**	Benefit lowland bogs, by keeping the bog surface (both the vegetation and the peat) as intact, undisturbed and as wet as possible.	Grazing management, stock bridges, ditch blocking, scrub control, grazing.	Prepare and submit for approval a bog management plan. The plan must include a map showing the location of the bog to be managed, the current grazing regime, the location of any ditches that have already been dammed and where appropriate, the location of all proposed new capital item works.	Any land with lowland bog is eligible but it must be combined with ditch blocking and control of scrub or woody vegetation unless it can be proven that the capital works are not required.	No	Yes	Annual Payment
AECS – Wetland and bog options **Management of Buffer Areas for Fens and Lowland Bogs**	Benefit fens and lowland bogs by increasing the water levels and creating an effective buffer area of longer vegetation. Buffer areas also contribute to flood management, soil protection and carbon storage.	Capital works including field drain breaking, pipe sluices, ditch blocking, ditch moving or realignment, creation of buffer areas, grazing management.	Identification on a map the locations of the bog or fen, and the buffer area to be managed. Adherence to an approved grazing regime in the buffer area and/or fen or bog habitat defining the stocking density and grazing dates	Land that is immediately adjacent to a fen or lowland bog is eligible.	No	Yes	Annual Payment

3.2 Terrestrial environment – Woodland opportunities

As highlighted in WP1, there are currently three main mechanisms available to landowners and land managers to access funding in relation to woodlands: the Scottish Government's Forestry Grant Scheme, some of the options in the Scottish Agri-Environment Scheme, and the Woodland Carbon Code (Table 18). Only some of the management options in AECS relate to intact areas of woodland and only the Woodland Carbon Code involves the accounting and trading of carbon associated with specific cases of woodland creation. In addition, there are smaller funding streams available which help to facilitate the use of particularly FGS and Woodland Carbon Code.

From initial mapping and visual inspection of polygons in WP1, it is clear that there is scope for all of these options to be used to increase woodland creation and support sustainable management of woodlands in Argyll and Bute. When considering the Land Capability for Forestry (Figure 29), which provides information on the potential for land to grow trees based on a number of factors including soil, climate and topography, it is apparent that areas earmarked for preferred woodland expansion in Argyll and Bute overlap to some extent with areas identified as having limited to very limited flexibility for tree, as well as land considered to be unsuitable for trees. It also identifies clearly that the areas with the highest potential for woodland expansion (Excellent, good, very good and moderate flexibility for trees) are mostly found on coastal areas or along water bodies and water courses. These areas align with those identified in the Native woodland target map (Scottish Forestry)[8].

[8] Native woodland target maps (forestry.gov.scot)

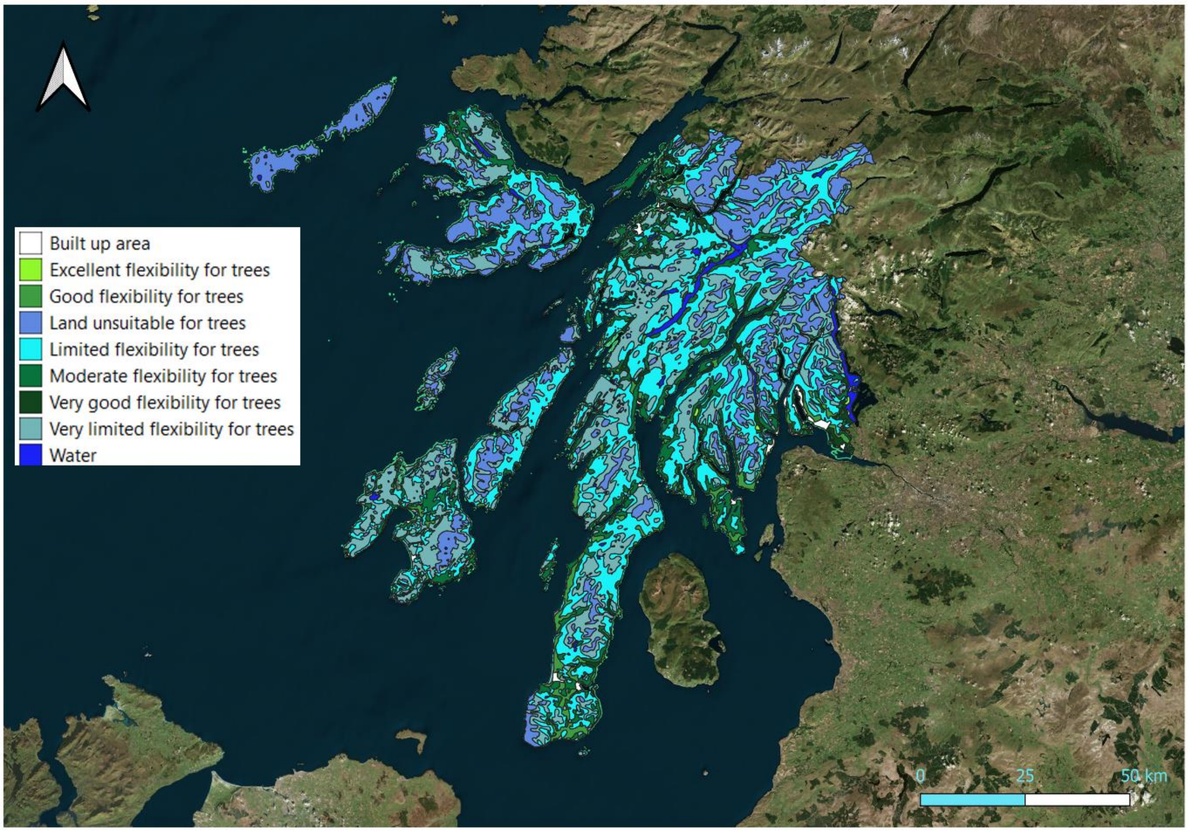

Figure 29: Land capability for forestry in Argyll and Bute. Adapted from 1:250,000 Land Capability for Forestry (JHI)

In terms of priority carbon trade opportunities, we believe that the most likely "win-win" options will be:

a. Forestry Grant Scheme and Woodland Carbon Code for woodland creation and marketable carbon, in particular in areas identified as having moderate to excellent flexibility for trees
b. Forestry Grant Scheme for management of woodland
c. Small Woodland Loan Scheme and Forestry Grant Scheme for small woodland creation
d. The Future Woodlands Trust for low-risk marketable carbon

In all those scenarios, the decisions around which trees where will consider planting more resilient forests, using a wider range of species and a broader range of genetic material and will adopt low-impact silvicultural systems where possible (Ray, 2008).

Table 18: Details of current funding mechanisms supporting woodland expansion in Scotland

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
Forestry Grant Scheme Woodland Creation	To support the creation of new woodland that will bring economic, environmental and social benefits.	Grant support for nine woodland creation options: Conifer, Diverse Conifer, Broadleaves, Native Scots Pine, Native Upland Birch, Native Broadleaves, Native Low-Density Broadleaves, Small or Farm Woodland, Native Broadleaves in N&W Isles.	The following supporting documents must be submitted with application: Woodland Creation Operational Plan; Map(s); Landlord's consent (if appropriate); Woodland Creation Component Areas table.	Fits with local woodland strategy; Tree species must be suitable; avoids deep peat; target areas at higher rate.	No	Yes	Initial planting payment and an annual maintenance payment for five years. Higher payments in target areas.
Forestry Grant Scheme Agroforestry	An integrated approach to land management, where trees and agriculture co-exist to provide multiple benefits	Planting at 400 or 200 trees per hectare. Rate covers purchase of trees and stakes; appropriate protection; planning, assessment, ground preparation, planting; contribution to beating up and weeding.	Application and proposed work must comply with the UK Forestry Standard. If a tenant then a landlord's declaration must be provided with application. The control of the land must extend for the duration of the proposed contract.	Minimum and maximum areas; on permanent grassland pasture, temporary grassland or arable land (Class 1.1 to 4.2 inclusive); specific stock; protections; suitable tree species.	No	Yes	Initial planting payment (£3,600 or £1,860) and an annual maintenance payment (£84 or £48) for five years. 20-year contract

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
Forestry Grant Scheme Woodland Improvement Grant	To provide capital grants for a range of activities that improve woodland.	Encourage natural regeneration and benefit priority habitats and species; increase species and structural diversity through low impact silvicultural systems management; contribute to the sustainable management of urban woodlands and improve public access; support the preparation of forest and / or management plans that set out management objectives for the woodland; improve the biodiversity, resilience, and structural diversity of even aged woodlands	Application and proposed management work must comply with the UK Forestry Standard. If a tenant, then a landlord's declaration must be provided with application. The control of the land must extend for the duration of the proposed contract.	A range of eligibility criteria depending on grant support provided.	No	Yes	The grant support for this category includes a range of Woodland Improvement Grant options.
Forestry Grant Scheme Sustainable Management of Forests	To support a range of sustainable management activities in existing woodlands.	Increase species and structural diversity through low impact silvicultural systems management; encourage natural regeneration to expand native woodlands;	Application and proposed management work must comply with the UK Forestry Standard. If a tenant, then a landlord's	Claimed on Single Application Form. May need to submit other documents annually to	No	Yes	The grant support for this category includes nine Sustainable Management of Forests options. Grants available under this category are paid annually.

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
		bring native woodlands and designated woodland features into active management and good ecological condition; support management of rural and urban woodlands for public access; control grey squirrels where they are a threat to the red squirrel population; control predators to benefit capercaillie and black grouse; reduce deer impacts to a level that will allow regeneration of conifer and broadleaved species	declaration must be provided with application. The control of the land must extend for the duration of the proposed contract.	support Single Application Form claim.			All payments are made for up to a maximum of five years.
Forestry Grant Scheme Tree Health	This option provides support to prevent the spread of *Phytophthora ramorum* (*P. ramorum)*.	Helps with the restoration of forests affected by *P. ramorum* by supporting the work to remove affected trees and carry out subsequent replanting. Grant support consists of a number of standard cost capital items.	Application and proposed work must comply with the UK Forestry Standard.	A range of eligibility criteria depending on grant support provided. Must be or have a Scottish Forestry approved agent to qualify	No	Yes	Grant support consists of a number of standard cost capital items.

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
				for the Agent Services capital items.			
Forestry Grant Scheme Harvesting and Processing	To support investments in harvesting and processing.	New specialised equipment which will increase the local small-scale harvesting and processing capacity; new specialised equipment for forest tree nurseries, including tree seed supply businesses and equipment for afforestation ground preparation projects, including forestry fencing projects; support for the mobile equipment to help forestry businesses or enterprises to adapt and recover from Covid-19.	One application round will be run each year with a closing date of 31 January for the submission of applications. Submission of a clear business plan as per provided FGS template.	Applicants must be based in Scotland, with equipment purchased for use in Scotland. Additional requirements against respective aims.	No	Yes	Grant support is based on actual costs with a maximum contribution of 40 per cent. Minimum and maximum grant award totals applicable to respective aims.
Forestry Grant Scheme Forest Infrastructure	To support new access for forest infrastructure	To provide support for new access infrastructure that will bring small scale, undermanaged or inaccessible existing woodlands back into active management; to provide support for new	Application and proposed work must comply with the UK Forestry Standard. Must have an approved Forest Plan for woodland	For the Sheep and Trees grant package, the applicant must be an upland livestock farmer with sheep being a	No	Yes	Grant support is available for a number of capital grant operations associated with new forest infrastructure.

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
		access infrastructure to new woodlands as part of the Sheep and Trees initiative.	areas of 100 hectares or more, unless in exceptional circumstances a Management Plan is deemed suitable. Must conclude any relevant requirements such as Environmental Impact Assessment (EIA) or prior notification before submitting application	key part of the farm.			
Forestry Grant Scheme Forestry Co-operation	To support forestry co-operation between landowners.	To encourage landscape-scale collaborative projects between two or more landowners by providing support for project facilitation and co-ordination.	A supporting information including final project plan, including a map, must be submitted to and approved by Scottish Forestry.	The proposal must be over a landscape scale involving two or more adjoining or nearby land holdings. For woodland creation there must be a minimum of four participating owners with scope for a	No	Yes	Grant support of £250 per day is available for up to 40 days, or up to 10 days for small-scale (<10ha) woodland creation schemes, to support the cost of a project co-ordinator for the following stages of a project:

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
				significant area of woodland creation. Common Grazings with more than four members are eligible.			
Woodland Carbon Code	Attract carbon funding to support woodland creation projects.	Woodlands can be established by planting, direct seeding or natural colonisation/regeneration.	Registration of the project with location and objectives; meet national forestry standards; have a long-term management plan; use standard carbon estimating methods; delivers additional carbon benefits; maintain verification for duration.	New woodland creation (planting or natural regen)	Yes	Yes	Carbon income from the sale of carbon units are expected to cover the costs of involvement in the programme. Projects shall have a clearly defined duration and shall not exceed a hundred years.
AECS Managing Scrub for Conservation Value	Maintain, enhance or extend areas of native scrub by supporting appropriate grazing and management	Restricting or removing grazing pressure from both wild and domestic herbivores at certain times of the year.	Identification on a map the location of the area to be managed and management of the same area for each year of the contract duration.	This option is available throughout Scotland.	No	Yes	£74.16 per hectare per year.
Small Woodland	Allow work required to create new,	Provides towards the value of capital items in	Must have approved Forestry Grant Scheme	Only available for new applicants top	No	Yes	50% of the value of the capital items in approved

Funding mechanism	Aim	Activities eligible for funding or payment	Application requirement	Eligibility	Marketable carbon	Income to landowner	Contracts / T&C
Loan Scheme	small woodlands before financial support from the Forestry Grant Scheme is available.	approved FGS contract.	Contract and meet the woodland creation eligibility criteria.	the FGS and no greater than 50 hectares.			Forestry Grant Scheme contract.
The Future Woodlands Fund	Offers land managers in Scotland a simple, low risk way to plant or regenerate native trees.	Woodland creation - small area payment option; woodland creation – annual payments option; woodland creation – carbon ownership option	Various requirements against each respective option. Must be registered with Rural Payments with Scottish Government. Must meet WCC criteria. Must be eligible for FGS. Must sign agreement.	Must be native woodland or formerly wooded site, various size restrictions, must be a new scheme, must not be a legal requirement	Yes (for carbon ownership option)	Yes	Various payments, schedules, and contract periods.

3.3 Barriers and issues with Woodland Carbon Code and other schemes

As highlighted in Section 2.1, there has been uptake of the Peatland CODE and Woodland CODE within Argyll and Bute already, suggesting an appetite for C trading opportunities. However, as highlighted in the SWOT analysis, there are also several barriers that are currently preventing more rapid or widespread uptake of some of the schemes, including barriers that cut across other funding streams. Again, based on extensive discussions with a range of stakeholders, we have summarised the main barriers in Table 19.

Table 19: Barriers and issues with codes/schemes

Barrier or Issue	Consequence	Applies to	Potential solution
Lack of skilled contractors to deliver peatland restoration on the ground	Failure to meet restoration targets	All peatland schemes	Development of dedicated training
Lack of skilled land agents and advisors to support applications	Failure to meet restoration targets	All peatland schemes	Development of dedicated training
Limited supply of trees from nurseries	Failure to meet woodland expansion targets	All Forestry schemes	
Constraints of timing of restoration delivery (e.g. snow, bird breeding season)	Periods without income for contractors	All peatland schemes	Combine multiple projects/areas, combine peatland and forestry work
Varying complexity of application process, not streamlined for combined applications across schemes	Need for advisors to support landowner	All schemes	Build up skilled workforce, improve application process
Lack of understanding around carbon finance and carbon markets for land-owners and land managers	Hesitancy, potential to become involved in poor deals	Peatland CODE & Woodland Carbon Code	Education
Need for upfront capital (to prepare applications, pay for AECS capital work, etc)	Potential to exclude key grounds inc. crofters	AECS, Peatland CODE, Woodland Carbon Code	Potential to combine with Peatland ACTION in flexible way
Not as cost-effective over small areas	Potential to put off smaller landowners/managers	All schemes	Prepare joint- or multi-owner applications
Mismatch in growth between C market supply/demand, e.g. high demand low supply	Potential to miss out on opportunities from big private investors	Peatland CODE	Manage investors' expectation, continue to develop codes to adapt the supply
Potential issues about legal ownership of the C for applicants who are not landowners	Perverse outcome of C sale that takes away benefits from e.g. crofters and/or local community	Peatland CODE	Develop understanding of legal issues
Ground-based validation approaches limit landscape scale applicability	Potential to miss out on large investments	Peatland CODE	Identify remote-sensing solutions that can become accredited for verification and certification

3.4 Additional Barriers for Terrestrial Carbon Market

3.4.1 Social Perceptions

Carbon offsetting, particularly by the private sector and often characterised as 'Green Lairds' is facing increasing public scrutiny (Macfarlane, 2021) and in late 2021 was debated in the Scottish Parliament with the motion from Rhoda Grant MSP with concerns around concentration of land ownership, lack of regulation in the Scottish land market, public funding and tax arrangements, and the financialisaton of the climate emergency through the market for land (Scottish Parliament, 2021).

Quantifying the impact of marketable carbon, or other natural capital benefits, has yet to be done at scale in Scotland however a major report has been commissioned and is being undertaken to:

1. analyse and report on the current pattern of activity within Scotland's rural land market to provide an accurate picture of landowner, buyer, and seller motivations, with a specific focus on understanding of how increased demand for natural capital investment is driving activity in the land market
2. develop a replicable methodology for gathering robust quantitative and qualitative data about land market activity in the future

The work, commissioned by the Scottish Land Commission, is being delivered by Scotland's Rural College (SRUC) in partnership with land agents Savills and Strutt and Parker, and support from the Royal Institution of Chartered Surveyors (RICS) (SRUC 2021).

Any development of carbon markets in Argyll and Bute will need to be considered against the backdrop of increased public scrutiny for the acquisition of land by corporates for offsetting business emissions.

3.4.2 Crofting

Argyll is one of the traditional crofting counties and since 2010 Scottish Government Ministers designated parts of Bute as areas where new crofts can be created, thus extending crofting tenure across Argyll and Bute (Scottish Government, 2021b).

Common grazings which have a Business Reference Number (BRN) are eligible to apply for FGS grants with Scottish Forestry (Crofting Commission, 2021a) identifying the Forestry Co-operation Grant, the Woodland Creation grant, the Natural Regeneration Establishment grant, and the Woodland Improvement Grants and Sustainable Management of Forests, as appropriate.

As of 2021 the Crofting Commission have set out thinking on peatland restoration and suggested two main routes including Peatland ACTION and a combination of Peatland ACTION and finance through the Peatland Carbon CODE although as an emerging sector there are crofting law considerations which have yet to be fully understood (Crofting Commission, 2021b). Any development of carbon markets on land under crofting tenure will face addition, but not insurmountable, complexity.

3.4.3 Caution on Selling Carbon Rights

Against the backdrop of uncertainty in a nascent sector there have been moves to express caution around land owners and managers marketing or selling carbon rights. A statement released by the Scottish Land Commission (2021c) chair Andrew Thin suggested that "*risk decisions are being made without full awareness of the implications for individual land managers*" and "*to exercise caution when considering transferring carbon rights or options until there is greater clarity over issues such as ownership of the rights and the need to retain them in offsetting their own business emissions in the future."* Whilst there may be enthusiasm from owners and managers to fund and capitalise on restoration there is increasing warning to not exercise rights prematurely without fully understanding future implications.

3.5 The identification of needs and opportunities for additional trading codes in intact and transformed ecosystems, including terrestrial, marine, freshwater, estuarine and agricultural systems

3.5.1 Additional trading codes in the terrestrial environment

To summarise, in this report, we have demonstrated that the Argyll and Bute region has both appetite and potential for increase of the use of current schemes supporting the two pillars of the Scottish Government Climate Change Plan in the land use sector: the restoration of peatlands and the expansion of woodland and forestry cover. We have also highlighted the complex processed involved, and the wide range of eligible activities, including through the combination of schemes.

There are currently no such schemes for agriculture, but The Allerton farm project[9] received a government grant of £81,561 in 2021 from the Natural Environment Investment Readiness Fund. The project seeks to unlock the environmental potential of hedgerows, through the development of a **Hedgerow Carbon Code**, developed by the Game and Wildlife Conservation Trust. Similar to the Woodland Carbon Code and Petland CODE, the Hedgerow Carbon Code would provide a tool to calculate the carbon capture potential of hedgerow habitat improvements.

Similarly, the Sustainable Soils Alliance is working with a consortium of leading experts to develop a **UK Farm Soil Carbon Code**[10], a set of formal protocols that allow farmers to quantify, qualify and verify reduced GHG emissions and/or soil carbon capture as a result of adopting regenerative farming practices. Although still in early days, the Sustainable Soils Alliance claims that its Code will be straightforward, practical, free to use and open access to all farmers. As with the existing Peatland CODE and Woodland Carbon Code, these new tools would potentially bring in significant private investment into the mix and provide an alternative or a complement to public funding.

[9] The Allerton Project | Game & Wildlife Conservation Trust (allertontrust.org.uk)
[10] Sustainable Soils News | All about Soil

In front of the potential multiplication of codes, each with its own application process and practical limitations and in front of a potentially rapid growth in demand, we recommend that the government:

- Supports education or knowledge exchange programmes enabling landowners, farmers, land managing organisations to make informed decisions about which, if any of these options they should engage with
- Considers a unified framework for applications where multiple projects under different codes could be possible
- Provides guiding principles around ethical carbon offsetting

3.5.2 Suitability for private and public sector investment

The account holders of projects involving marketable carbon and attracting private sector investment through the Peatland CODE and the Woodland CODE in Argyll and Bute are also predominantly from the private sector. It is recognised that this may be a consequence of the capital needed to support the development stages of the applications and/or the maintenance of projects developed through the Codes. The uptake of publicly funded schemes (Forestry Grants, Peatland ACTION, AECS) also includes privately owned land, but attracts a wider range of landownership models, which may be facilitated by the provision of services e.g. Peatland ACTION officers that take away the cost associated with application development.

It is in the interest of the government, if it is to meets its ambitious Net Zero target, to facilitate the blending of public and private finances and attract private investment in Nature-Base solutions. To achieve this, and increase the uptake of the Peatland and Woodland Carbon Code, we recommend that the government:

- Considers investing in advisory roles for the development of applications for marketable carbon mirroring e.g. the Peatland ACTION project officer roles, as proportionally small investments in people on the ground working with landowners could unlock much larger investment from the private sector

3.5.3 Options for the intact natural assets on the terrestrial environment

There are some limited options for landowners to derive an income from maintaining a near-natural habitat in good condition. Similarly, there are potential limitations with the current schemes for landowners who were early adopters of Peatland ACTION to be able to claim C credit retrospectively, or be rewarded for early action. However, it is evident from the C stock calculation that Argyll and Bute's soils, in particularly peat soils, are an important asset worth protecting, and so are the existing woodlands and forests. In terms of options for the intact natural assets, we recommend that the government:

1. Uses the opportunity around development of new agri-environment schemes to consider mechanisms to support financial rewards for landowners and land managers who already manage their C-rich land sustainably
2. Ensures that policy incentive for intervention associated with targets do not undermine existing C stocks with perverse outcomes for climate

3.6 Marine environment

As discussed in section 2.1.2.4 the requirement for inclusion of seaweed and shellfish aquaculture within a Blue Carbon trading scheme rely both on the quantification of the pools and fluxes and also verification of those pools and fluxes within the defined area. Currently we do not have sufficient scientific understanding, the technical capability to measure or model, nor a bespoke framework for verification within the aquaculture domain. Given these constraints there may be value in taking a less market orientated approach to allow the application of other frameworks to value the climate adaption or mitigation goods and services that these operations deliver. There are a number of such frameworks currently in use or under development, but in general they have their theoretical background based in the concept of ecosystem services.

3.6.1 Ecosystem services and seaweed and shellfish aquaculture

Ecosystems services can be described as the benefits that individuals, communities, or society as the whole gain from ecosystems. These are split into 4 categories (Provisioning, Regulating, Cultural and Supporting service – see Figure 30 [Millennium, Ecosystem Assessment, 2005])

Provisioning
Products obtained from ecosystems
- Food
- Fresh water
- Fuel
- Biochemicals
- Genetic resources

Regulating Services
Benefits from ecosystem processes
- Climate regulation
- Disease regulation
- Water purification

Cultural Services
Nonmaterial benefits
- Spiritual and religious
- Recreational
- Cultural heritage
- Education

Supporting services
Services necessary to produce all other ecosystem services
Soil formation, nutrient cycling, primary production

Figure 30: Ecosystem Services

It is clear that in terms of Blue Carbon, regulating and supporting services are the principal categories of ecosystem services, specifically climate regulation (regulating services) and nutrient cycling (supporting services). This framework has been widely applied to aquaculture with most studies concentrating on provisioning and regulating services (Weitzman, 2019). Furthermore, it has been demonstrated that aquaculture can contribute to the enhancement of ecosystem services connected to climate regulation through the process of carbon sequestration (Gentry et al., 2020). This framework can be further extended to allow valuation of ecosystems services. This can be done both in terms of monetary and non-monetary value but as our focus is on carbon markets, we will concentrate on monetary valuations of ecosystem services relating to aquaculture and climate change (Christie et al., 2012; Custódio et al., 2020). In order to value ecosystem services a range of economic tools have been developed that centre on the concept of Payment for Ecosystem Services (PES) which allow for the financial reward for the delivery of public good through the enhancement of ecosystem services. In an analogue to the polluter pays, PES is based on the concept that the beneficiary pays the resource owner or manager for the enhanced provision of ecosystem services. In terms of climate changes, the parallels with carbon trading schemes are apparent, and payment for ecosystem services suffers from some of the same problems of quantification and verification. These shortcomings can to a degree be mitigated through the coupling of blue carbon habitats within marine protected areas that do deliver quantifiable and verifiable ecosystems benefits, such as flood protection or fisheries enhancement (OECD, 2017). This addressing of multiple societal challenges while contributing to human wellbeing is reflected in the Nature-based Solutions (NbS) approach developed by the IUCN.

3.6.2 Nature-based Solutions

The concept of NbS was first developed by the World Bank in 2008 and linked human economic development with biodiversity and ecosystem management. IUCN has recently developed a global standard for NbS as an attempt to codify the concept to allow clearer categorisation of activities that can legitimately be labelled as NbS. Part of the motivation for this process is to allow more direct investment into NbS including those that relate into climate mitigation and blue carbon (Mansouri et al., 2020). Currently (2020) $ USD 113 Billion is being invested in NbS, the vast majority of which is being carried out by domestic governments, while private capital only represents 17% of this investment. It has been estimated that this investment will need to treble by 2030 (United Nations Environment Programme 2021). There is also specific opportunity in the marine economy which is suffering from a recognised lack of investment despite its size. A primary reason for this given by financial institutions was a lack of clear definition of sustainability and which activities, projects or sectors can be termed sustainable (Suisse, 2020). Low trophic aquaculture such as seaweed and shellfish production, when consciously designed to meet multiple criteria such as reducing climate and biodiversity risk, clearly fit within the definition of NbS and this may allow the unlocking of investment linked to the enhancement of ecosystem services such as climate mitigation through assimilation of blue carbon (Hughes, 2021).

In addition to the NbS there are other emerging frameworks that provide an operationalised definition of sustainability that allows specific sectors or activities within the marine environment to be assessed against. Some of these frameworks are specific to the marine environment and can be applied to blue carbon projects based on seaweed and shellfish, whilst others are more generic sustainability frameworks.

3.6.3 The UN Environment Programme's Sustainable Blue Economy Finance Initiative (UNEPFI SBE)

The UN Environment Programme's Sustainable Blue Economy Finance Initiative (UNEPFI SBE) is a platform focused on banks, insurers and investors to help them develop lending, insurance and investment which supports the sustainable activity within the marine environment. The UNEPFI SBE was founded in 2019 and in its first iteration it concentrated on five marine sectors including seafood and within this, aquaculture. For each of the sectors, the platform lays out a series of indicators and criteria. Depending on how a business' operations are assessed against the criteria, banks, insurers and investors have recommendations to avoid, challenge or seek out these businesses for investment. The current framework while having criteria on carbon emissions does not specifically include climate mitigation. However, the guidelines are set to go through multiple iterations and such ecosystem services could be included in the future.

3.6.4 The European Union Taxonomy for Sustainable Activities

To create a common understanding of sustainability to support the EU's targets for climate and energy the EU has created a taxonomy or definition of sustainable economic activity. It sets conditions that an economic activity has to meet to qualify as environmentally sustainable: (https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en). The economic activity must make a substantive contribution to at least one of six objectives: climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, a transition to a circular economy, pollution prevention and control and the protection and restoration of biodiversity and ecosystems. In addition, the economic activity must do no significant harm to any of the other five objectives and comply with minimum existing safeguards. Financial market participants and large companies will be required to disclose the proportion of the turnover, capex and opex that is aligned with the Taxonomy. Currently the Taxonomy covers the fisheries sector, but not aquaculture, but there is an expectation it will be expanded to include aquaculture.

3.7 Market development requirement

3.7.1 Terrestrial environment

3.7.1.1 Community Ownership

There is increased focus on community ownership in Scotland and a National Indicator on community ownership was developed and included in the National Performance Framework in 2019 at the behest of the Scottish Land Commission (Scottish Government, 2020b). The Commission[11] outline that community ownership is integral to the sustainable development and regeneration of rural Scotland and seeks to make community ownership a routine and normal land ownership model.

[11] https://www.landcommission.gov.scot/our-work/ownership/community-ownership

Community Land Scotland, the membership organisation responsible for the representation and development of community landowners in Scotland believe that we cannot create a more socially just Scotland without tackling land ownership. In 2021 Community Land Scotland, in partnership with Community Energy Scotland, the Community Woodlands Association and the Woodland Crofts Partnership. commissioned the report (Macaulay and Dalglish) *Community Landowners and the Climate Emergency* (Community Land Scotland, 2021a) which set out community land owners contribution towards Scotland becoming net-zero by 2045.

The work sets out that Scotland's Community land owners are delivering climate measures in all eight climate action sectors as set out by the Scottish Government Climate Change Adaption Programme, including *caring for carbon sinks*. One of the six case studies, *Managing Peatland Carbon Sinks* (Community Land Scotland, 2021b), highlights peatland restoration and community landowners use of Peatland Action whilst woodland creation and management features throughout the main report.

There is a policy and legislative move towards land reform and community landownership in Scotland, and evidence of contribution and desire towards climate mitigation and adaption, increased community ownership of land assets can be considered as a key driver in the move towards realising carbon.

Community Wealth Building

Community Wealth Building is described a relatively new concept towards a people-centred approach to local economic development, redirecting wealth back into local economies, and placing control and benefits into the hands of local people (CLES, n.d). One of the five key principles is socially productive use of land and property and is increasingly being identified as a means to deliver local community benefit from the transition towards net-zero (Community Land Scotland, 2021c). Community Wealth Building, developed in a rural context, with an emphasis on plural ownership of the carbon economy and progressive procurement of the goods and services require to develop it.

Blended Ownership Models

Blended ownership models, beyond traditional private, public, or community owned of land assets have been identified as a potential route to achieving better shared benefit from land use change and natural capital for net-zero. In 2021 the Scottish Land Commission (Scottish Land Commission 2021b) positioned some of their own research from 2020 (Scottish Land Commission 2020) in the context of the rapidly developing carbon sector framing a shift away from land as a commodity to land as a shared set of rights for holders to use the land in a certain way. International experience can be used to inform potential routes to share ownership of natural capital resources in favour of business and community.

Argyll and Bute Community Wealth Fund

Voluntary community wealth funds are being associated with the development of carbon markets, at single development scale right through to landscape or regional scales. These could potentially operate in a similar manner to onshore wind community benefit funds, however there are points of difference. There may also be a risk that as an 'easy route' to community benefit, this option would take precedent over other higher impacting options such as blended ownership models.

3.7.1.2 Key recommendation for government role in facilitation and incentivising market growth

Without capacity to develop a pipeline of projects and deliver them on the ground, there is limited scope for market growth. Thus, one of the most immediate barriers and a recognised bottleneck on delivery is also currently limiting the Scottish Government's capacity to meet the annual targets for restoration: the lack of skilled workforce, from contractors on the ground to advisors educated in carbon finance. The government should have a role in supporting the development of training programme fit for purpose.

The current bureaucratic-heavy and layered processes with different applications forms, requirement, contracts, etc. for all the different options reduces the efficiency of delivery. The government should support the streamlining of the application processes, particularly where multiple streams of funding are pulled together to deliver a landscape-scale project where economies of scale are likely.

Overall, the rapid growth in demand for marketable carbon unmatched by supply could lead to perverse outcomes such as soaring prices for carbon credits, if not appropriately managed. In the UK, there is a strong potential through Nature Base Solution to produce high-integrity carbon credits, and therefore to bring to the global market verified emission reductions (VER) that may be more expensive - a premium justified by guaranteeing integrity and transparency across the market[12]. The government should ensure that the supply chain continues to provide high integrity VER by supporting the establishment of multi-stakeholder partnerships for the governance of landscape scale projects.

In turn, the verification and certification of carbon credits generated from landscape-scale projects most likely to attract large private investment are unlikely to be cost-effectively monitored on the ground. There are several remote sensing solutions at various stages of development that could be applied to marketable carbon projects, both at the project development stage and at the verification stage. It is likely that the best remote sensing tool will come from a combination of different solutions. The government should support and facilitate the development and integration of these tools with the schemes in a transparent process.

Moves towards market growth in carbon sequestration in Argyll and Bute should be considered in conjunction with, and respective of, the principles of a Just Transition. As an emerging sector, with an insufficient evidence base in setting out the social, economic, and cultural implications of marketisation, there are however relatively clear policy and legislative measures already in place which could help steer the facilitation of greater opportunities for the rejuvenation of rural communities which could help to alleviate rather than exacerbate existing inequalities and injustices.

In summary, the key recommendations for the group are:

1) Short-term

[12] https://www.bidwells.co.uk/what-we-think/rural-outlook-2022/rural-outlook-carbon-capture/

   a. Advocacy to the Scottish Government about the need to support capacity building and to streamline application processes where multiple income streams could be combined
   b. Engage with other landscape partnerships where similar work is being undertaken (e.g. Flow Country Partnership, Cairngorm Connect, Forth Era) and identify lessons that can be applicable to Argyll and Bute
   c. Develop Pilot Projects around key opportunities (see Implementation Strategy)
   d. Educate landowners about opportunities and identify barriers to uptake
2) Medium term
   a. Consider investing in advisory services complementary to existing roles (e.g. Peatland ACTION officer) to unlock supply
   b. Engage with existing CODE to support implementation and improvements relevant to Argyll and Bute and to address barriers identified by landowners
   c. Consult with stakeholder to develop long-term landscape vision for Argyll and Bute, including models to translate investments into community benefits
   d. Scope out potential long-term investment strategy
   e. Continue to develop pilot projects
3) Long term
   a. Implement long term vision supported by increased capacity and improved delivery of actions of the ground
   b. Monitor how investments and pilot projects are delivering on community benefits and carbon emission reductions

3.7.2 Marine environment

Carbon markets and trading are complex with multiple classifications and within these multiple strands and schemes. In the development of any scheme there are a number of scoping questions that need to be addressed:

- Defining the motivation for the BC scheme, whether it is to meet net zero targets, to generate value for local communities or to fund wider biodiversity conservation activities
- Defining which carbon market is being targeted. Although the various types, strands and schemes have significant overlap, the steps need for development of A&Bs BC market is dependent on the criteria for entry into that market

This scoping exercise needs to be done before any implementation strategy can be developed in detail and needs to be part of a stakeholder engagement process to ensure that future expectations are clearly understood.

Given the above constraints there is value in looking at one specific scenario to understand how the process may play out. If we choose one such possible market we can use it as a case study for the development of such implementation strategies. If we look at the voluntary offsetting market, even within this scenario there are a wide range of possible offsetting mechanisms and in order to make a systematic choice it might be useful to use a pre-existing framework for the classification of offsetting mechanisms such as Oxford Principles for Net Zero Aligned Carbon Offsetting. These principles contain a typology that is useful both in defining the mechanisms for offsetting but also provide guidance as to which mechanisms will deliver desired outcomes.

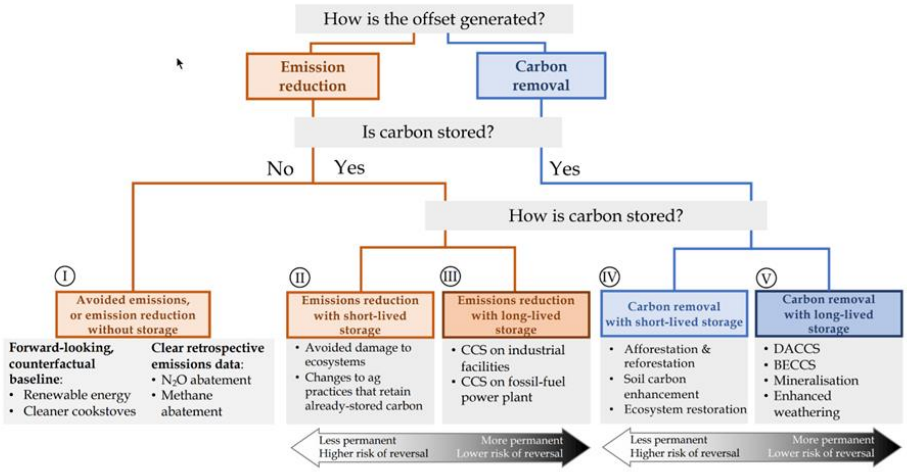

Figure 31: Taxonomy of Carbon Offsets (Allen et al., 2020)

The Oxford Offsetting typology showing 5 different types of carbon offsetting based on their carbon storage characteristics (Allen et al., 2020). The Oxford principles for net zero aligned carbon offsetting. *University of Oxford*.

If we use the Oxford typology of carbon offsetting then BC projects could be developed to fit within a number of different classification (see Table 20), and these could be piloted as the first steps in an A&B BC scheme.

Table 20: Within the Oxford typology examples of how BC projects could be included within a carbon offsetting scheme

Oxford classification	Description	Project type
1) Avoided emissions, or emission reduction without storage	N_2O abatement	Seaweed farming reducing nutrient loading, benthic habitats such as oyster beds reducing nitrification
2) Emissions reduction with short-lived storage	Avoided damage to ecosystems	MPAs to prevent dredging, coastal creep into salt marshes, protection of seagrass and kelp beds
4) Carbon removal with short-lived storage	Ecosystem restoration, carbon storage in sediments	Oyster, seagrass and kelp habitat restoration

Also within these principles are 4 characteristics which the BC projects would need to conform to ensure credibility (Table 21).

Table 21: Characteristics to ensure credibility

Condition	Descriptor	Implementation Actions
Verifiable	Effects can be calculated with scientific rigour and be monitored and audited	1) Align with existing creditable trading schemes 2) Develop science base to measure or model carbon impact
Additional	The effect is over and above the baseline	1) Creation of baseline data for selected habitats/projects 2) Measurement or modelling of new state
Permanence	The effect must last over time and not be at significant risk of reversal	1) Development of ownership or leasing that allows long term assurance of the activity 2) Monitoring and management to ensure longevity of effects
Avoidance of unintended consequences	Concentration on carbon may increase risk of biodiversity or amenity loss	1) Explore the use of the IUCN Global Standard for NbS when developing BC project which have mechanisms to avoid unintended consequences

In addition, it also suggested that BC projects within A&B take a regional or jurisdictional approach to developing BC markets. Although the concept is still in development, such approaches are characterised by:

- Bringing together all relevant stakeholders from a landscape defined by political boundaries that are usually at the local government level,
- co-development of objectives aimed at promoting sustainable practices in this landscape,
- exhibit strong subnational government leadership.

3.8 Implementation strategy

3.8.1 Terrestrial environment

Two key opportunities have been identified for the development of pilot projects in the near future around the two existing codes relating to terrestrial carbon markets in Argyll and Bute: the expansion of woodland on farmland (sheep) and the restoration of peatland on Islay. The implementation pathways for both are discussed briefly below.

3.8.1.1 Woodland Carbon Code opportunity: agro-forestry

The first opportunity focuses on a combined land-use of sheep production and forestry, which could involve a significant percentage of Argyll and Bute farmers, or agro-forestry.

Increasing the tree cover in agricultural landscape could generate carbon credits under the WCC, which could be traded for offsetting or used for insetting. The decision to offset or inset needs to be informed from the top down, and future proof. If farmers are expected to become carbon neutral, it will be essential to develop systems analysis looking at the farm carbon balance before any trading of new carbon from forestry takes place, to avoid trading away carbon essential for insetting. At the moment, there are no clear guidance or rules around when and how the agricultural supply chain will be expected to demonstrate carbon neutrality, making it more difficult for farmers to take informed decisions around what to do with any carbon credits generated through diversification of their activities. It is possible that some of these activities could also be subsidised through agri-environment schemes.

Under the WCC, projects can be developed by individuals or by groups, but these require to be legally constituted able to receive funding. As these groups tend to take a long time to develop from scratch, a key recommendation would be to identify existing groups or association within the agriculture sector that could take on the leadership responsibilities, either individual farmers, community benefit societies such as the Black-faced breeders association, or organisation such as the NFU or Highland Agri Ring.

Given the potential substantial shift in practice and income streams that a move towards agro-forestry would involve, it might provide an opportunity to explore ways to ensure equitable benefit sharing. However, to maximise the opportunity, there are also potential understanding and skills gap that need to be filled. We believe that HIE's role here could be one of facilitation, providing support around the development of business plans, community frameworks and social enterprise around a WCC project(s) in agro-forestry and potentially supporting capacity building. There are a wide range of existing contractors with expertise in the development of application and the brokerage of carbon for WCC projects, with whom the project leaders should engage. However, this might be best achieved through advisors bridging the gap, understanding both farmers, crofters and organisations needs and WCC project requirement and C trading opportunities. This is a model that has been used by Peatland ACTION to stimulate the uptake of subsidies for peatland restoration, with dedicated regional advisory officers paid by the Peatland ACTION project to deliver free (subsidised) advice and support.

It is likely that the WCC will continue to develop and evolve, and it is essential to engage with the process and help shape it in a way that benefits local communities and enables farmers and crofters to make informed decisions about land management changes and trading of carbon.

3.8.1.2 Peatland CODE opportunity: Peatland restoration in Islay

Given that the carbon credits from Peatland CODE and WCC are currently both hosted together under the UK carbon land registry, and operate with similar processes of project development, brokerage and validation, many of the supporting functions identified in the WCC pilot project scenario are somewhat similar.

For example, as in the WCC, the Peatland CODE projects need to be led by individuals or groups that can receive funding and are legally constituted. The carbon credits generated from emission reduction following peatland restoration activities can also be traded for offsetting or used for insetting, and the decision to do either also needs to be informed by clear guidance around individual farmers/crofters need to demonstrate carbon neutrality.

There are existing advisory officers (Peatland ACTION) and consultant who are developing expertise in applications for PA and/or PC projects and it is essential to engage with the existing resources to identify key gaps in capacity that can be filled in the medium term.

In terms of specific implementation on Islay, it is clear from the Peatland CODE that areas with active erosion is the most viable option for projects to generate a profit (i.e. get a bigger return than the project development and maintenance activities might cost). They are also the areas with the highest emissions so strategically are important to tackle to achieve emission reduction targets. On Islay, it may be possible to develop Peatland CODE applications with applicants who already have capital (e.g. private estates) or with distilleries that own land, as they have identified the need to address issues of peatland restoration as part of the wider sustainability strategy. However, it might also be possible to engage with crofters and farmers and combine Peatland ACTION and Peatland CODE applications where there is a lack of capital for project development.

If engaging with crofters, it will be essential to understand and address issues around ownership of the carbon, and right to sell or use for insetting – some of these issues are currently being investigated by the Flow Country Green Finance Project, managed by the Flow Country partnership, and there may be benefits in engaging and learning to maximise efficiency.

As with the WCC pilot project, a clear objective is the delivery of community benefits, and the mapping of both direct monetary and non-monetary benefits could help support a wider engagement, particularly where non-monetary benefits may translate in e.g. increase carbon value (e.g. “charismatic carbon”) on the market.

3.8.1.3 Summary

In summary, for both pilot projects, the implementation strategy requires:

1) Understanding of the process of application and engagement with existing support mechanisms where they exist
2) Identification of project lead(s) (individuals/organisations)
3) Understanding/addressing needs/issues of insetting vs offsetting to derive best investment models
4) Facilitating capacity building and knowledge exchange across stakeholders to identify and tackle barriers to uptake
5) Mapping of a pathway to delivering community benefits

3.8.2 Marine environment

3.8.2.1 Blue Carbon (BC) market

As discussed, marine carbon markets are in their infancy. Blue carbon is a relatively new term which has drawn attention to the potential carbon offset offered by coastal vegetation. There is good understanding of the value of CO_2 (in 2022, £248 (range £124-373))

(Department for Business, Energy and Industrial Strategy, 2020; Department of Energy & Climate Change, 2009). Estimating emissions offset by restoration schemes can be calculated as per Turrell, (2020).

BC scheme (Weight C/m^2/year) = Area protected (m^2) x (C stored + C sequestered)

Carbon opportunity assessments have recently been formed (Siikamäki et al., 2013). With a simple budget for the costs of restoration schemes.

BC restoration cost = Value of land use + cost of initial protection + Annual continuous costs
(£/hectare) (£/hectare) (£/hectare) (£/year)

There are additional benefits that can be subtracted from the costs on the right of the above equation. For example, the socio-economic costs which communities derive from restoration projects and industry from the creation of new funding streams (Bullock et al., 2011). There is also considerable value to be gained in the associated biodiversity enhancement that coastal vegetated habitats offer (Hanley & Perrings, 2019; Hughes et al., 2018a). Carbon storage alone should not be the deciding factor for restoration projects, identifying 'hotspots' where multiple ecosystem services will be restored is key (Gilby et al., 2020).

3.8.2.2 Marine sediments

It is clear, from this analysis, that the majority of blue carbon within Argyll and Bute is stored in marine sediments, particularly within sea lochs. As this carbon is derived from various natural sources, the potential value is therefore in its protection and/or management, rather than enhancement or restoration, as is possible with vegetated habitats. Blue carbon should therefore be incorporated into marine spatial planning and considered in Marine Protected Area (MPA) designation and management locally.

Though blue carbon is a rapidly growing area of research, guidance for how to apply blue carbon information in MPA management is lacking. To ensure that nationally significant blue carbon habitats and processes continue to sequester carbon rather than become sources of emissions, it is critical that marine spatial planning and the designation of new MPAs consider the presence of blue carbon and apply relevant management measures as informed by the developing science.

The Orkney Islands blue carbon audit, for example, demonstrates this novel approach to MPA designation by prioritizing carbon-rich areas, although it aimed at improving protections for maerl beds, kelp forests, and seagrass habitats in this instance. For marine sediments, it is likely that abrasion and disturbance from towed fishing gears and other offshore developments represent the largest risk to carbon stores. However, interactions between fishing gear and remineralisation (i.e. release) of carbon from marine sediments is poorly understood and highly contentious. Further work will therefore be required in order to understand the implications of fishing and other demersal activity on carbon storage and sequestration potential in order to assess and implement possible management measures.

The potential to leverage financing mechanisms with respect to blue carbon in marine sediments not currently possible, and may not be relevant for some time. Should our understanding of management measures on carbon stocks and fluxes continue to improve, it may be possible to utilise some form of blue bond or mitigation banking. However, at present, it is not clear what tangible benefits this would bring to the existing marine sediment carbon stores identified within this report.

Overall, the field of blue carbon as a whole must expand its scope to recognise the important mitigation potential of marine sediments. In the short-term, it is recommended that research is applied to improve our understanding of management measures on carbon stocks within marine sediments, including the implications of high (towed) and low (static) impact fishing gears and offshore development that may occur in the region, such as offshore wind. In turn, this will allow for blue carbon to be incorporated effectively into marine spatial planning frameworks locally and nationally.

3.8.2.3 Macroalgae

There is currently little regulation of seaweed farming practices and no governing body or organisation which oversees the coordination and infrastructure related to macroalgal aquaculture in Argyll and Bute. Current carbon offset markets with relation to macroalgal aquaculture are in the research and development stage. There are no standards or regulations which assert; a) the amount of carbon that is potentially offset by macroalgal aquaculture, and b) the value CO_2 drawn down by these farms. With limited information available, it is not possible to assert CO_2 offset values, or assign related economic values to macroalgal aquaculture. It is not therefore, possible to accurately assess the value chain or subsequent end-market for macroalgal aquaculture carbon.

Integrating the potential carbon value of seaweed aquaculture into decisions relating to marine management and spatial planning may enhance the capacity of the marine environment to act as a carbon sink in Argyll and Bute. To support this, targeted research is needed to better understand the carbon sequestration processes within seaweed aquaculture, particularly at scales to which the industry has ambition to develop. Prioritised areas of future research, which should be closely integrated with research that focuses on other benefits associated with seaweed aquaculture (e.g., nutrient remediation), must address the following:

- **Rate and fate of carbon export and sequestration** – standardised methods for identifying macroalgae-derived carbon and tracing it back to its source are lacking, thereby making it difficult to quantify carbon flows between cultivation sites and sequestering sediments/habitats. This has been identified as a key knowledge gap that must be addressed and modelled with growth scenarios for the industry locally, under varying management scenarios.
- **Life-cycle accounting of carbon emissions and benefits from seaweed cultivation** – Life-cycle assessments (LCAs) enable end to end quantification of carbon from macroalgal biomass once it has been harvested. As markets continue to develop for seaweed-derived products, it is important to account for the overall

environmental performance compared to non-renewable or fossil-based products that they may replace (e.g., biofuels, fertilisers, polymers, etc), to fully understand the carbon implications of macroalgal aquaculture.

Overall, the role that seaweed aquaculture may play in carbon sequestration within the marine environment is small, as farms will likely be managed accordingly to minimise biomass losses and therefore, carbon exported from the farm. However, seaweed aquaculture has substantial merits when accounting for carbon gains and losses across its life cycle, providing a useful biomass with a multitude of end-uses that has potential to replace higher carbon alternatives.

Effective restoration of kelp forests has been performed previously with 62% of successful programmes being performed by academic institutes (Eger et al., 2021). Restoration of wild macroalgal habitats is (at present and to the best of our knowledge) unnecessary in Argyll and Bute, however, monitoring of existing forests, invasive species and water quality as well as active identification of deforested areas, and climate change mitigation will ensure macroalgae remain functioning at high levels. There is however, current societal willingness to act and be involved with kelp forest restoration in parts of Europe (Hynes et al., 2021). The benefits of biodiversity enhancement again, are the most highly valued factors associated with restoration of kelp forests. *Establishing a flow of funds to facilitate the maintenance of macroalgal habitats and continued active research into carbon offset potential is recommended.*

3.8.2.4 Seagrass

A recent nature restoration fund provided by NatureScot has allowed limited marine restoration programmes to be conducted in Scotland. Future guidance for grant applications to the Scottish Marine Environmental Enhancement Funds (SMEEF) are expected to be released later in 2022 also by NatureScot. The establishment of seagrass patches in carefully selected locations may have a positive effect on carbon drawdown, biodiversity, water quality and sediment stability (Greiner et al., 2013; Orth et al., 2020). To date, there have been limited funding pools for this type of work which have been supplied either by non-profit organisations (i.e., Project Seagrass®) or from government organisations such as Marine Scotland and NatureScot as well as charities (i.e., WWF®) and some private grant foundations. An example of a successful restoration project which has actively pursued funds for seagrass and oyster enhancement, driven community engagement and enhanced the wealth of a small community is that of Seawilding ® in Loch Craignish. The group in Loch Craignish are actively pursuing restoration of seagrass while at the same time coupling the project with research to provide empirical evidence of change. It can be recommended that Loch Craignish be used as a case study which examines the economic, social and environmental change that is brought about by community driven restoration projects.

The infrastructure, coordination and research and development of restoration and protection of seagrass habitats is well established (Orth et al., 2020). Information on restoration practices, standards and regulations is also available in recent seagrass restoration handbooks for the UK and Ireland established by the Environment Agency (Gamble et al., 2021). *The value chain for seagrass projects depends on research and* *development to identify regions where restoration is necessary and/or will be effective as well as the establishment of funding for projects to go ahead, both of which can be encouraged from HIE.*

3.8.2.5 Saltmarsh

Restoration projects have been successful in the past for saltmarsh areas, however, it is expected that the full benefits from restoration of saltmarsh areas will not occur in less than 100 years (Burden et al., 2013, 2019). Carbon accumulation has been shown to be initially rapid in the first 20 years (~1 t C/hectare/year, approximately 3.7 t CO_2, economic value of £909/hectare/year) (Burden et al., 2019). In the U.S. there are market-based policy solutions including a Verified Carbon Standard (VCS) methodology for wetland restoration (Sutton-Grier & Moore, 2016).

Similarly, there is a planned development of the UK Saltmarsh Carbon Code, which is hoped will operate on a similar basis to the Peatland Code and Woodland Code, securing private investment for restoration projects. Indeed, a partnership of scientists, charities, and financial experts, led by the UK Centre for Ecology & Hydrology, has secured a grant from the Government's new Natural Environment Investment Readiness Fund to develop scientific and revenue models plus a certification scheme for UK projects wanting to attract private investment by selling companies the carbon benefits that will result from restoring saltmarshes.

Furthermore, the saltmarsh restoration handbook provides information on restoration practices and management (Hudson et al., 2021) and there is good knowledge of existing saltmarsh regions in Argyll and Bute which could be targeted for enhanced restoration (Austin, 2021). *It is therefore important for HIE to confirm potential locations that could benefit from this code, and, if possible, to engage in the project to ensure that both environmental and monetary benefits from its utilisation would occur locally.*

3.8.2.6 Who is going to pay?

Initial investment in restoration projects can be high with costs currently in the six-figure region per hectare of habitat (Eger et al., 2021). Furthermore, there is no immediate/direct return of economic investment to the investing organisation. Therefore, the value of BC restoration is difficult to market/sell and currently global funds allocated to the protection and restoration of BC habitats are not considered enough to be effective (Vanderklift et al., 2019). However, the popularity of BC habitats has drawn attention to coastal vegetation and with it private investment from companies hoping to achieve a marketable, 'green image' and the generation of a voluntary carbon market (Kreibich & Hermwille, 2021). There is a strong need to regulate and legitimise this voluntary carbon market in order to ensure the feasibility and effectiveness of expenditure (Kreibich & Hermwille, 2021).

The end market as a result of restoration programmes and protection of carbon stores is essentially the drawdown of atmospheric CO_2. The benefits of CO_2 removal will have a global impact. *Potentially the most important factor for BC restoration, sediment protection and coastal management is the sourcing and allocation of funds from parties willing to allocate a large amount of resources to carbon mitigation with little return of investment.*

3.8.2.7 Summary

The development of marine blue carbon markets lags far behind the terrestrial equivalent. For the marine sector to move forward this requires:

- The production of equivalents to the Woodland and Peatland Codes. This process has begun with the development of the "UK Saltmarsh Code[13]". Engagement with this research group may expedite the local application and benefits of the resulting code.
- Incorporation of blue carbon within marine spatial planning frameworks, informing national, regional, and local scale management measures to protect existing carbon stocks. The potential application of spatial/temporal management measures must be explored to distinguish the implications on carbon stocks within designated areas weighed against necessary trade-offs (e.g. exclusion of towed fishing and/or offshore development) to incorporate these measures into the establishment of new marine protected areas.
- Pursue the implementation of carbon offsetting schemes, potentially linked to community-driven habitat restoration projects (such as the Seawilding effort to restore seagrass meadows).
- Applied research is required to understand the potential benefits of seaweed aquaculture on various scales, investigating the rate and fate of carbon export and sequestration as well as the overall environmental sustainability when incorporating various end-uses and markets.

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13 https://www.wwt.org.uk/news-and-stories/news/wwt-joins-group-helping-to-unlock-1bn-investment-in-restoration-of-saltmarshes

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