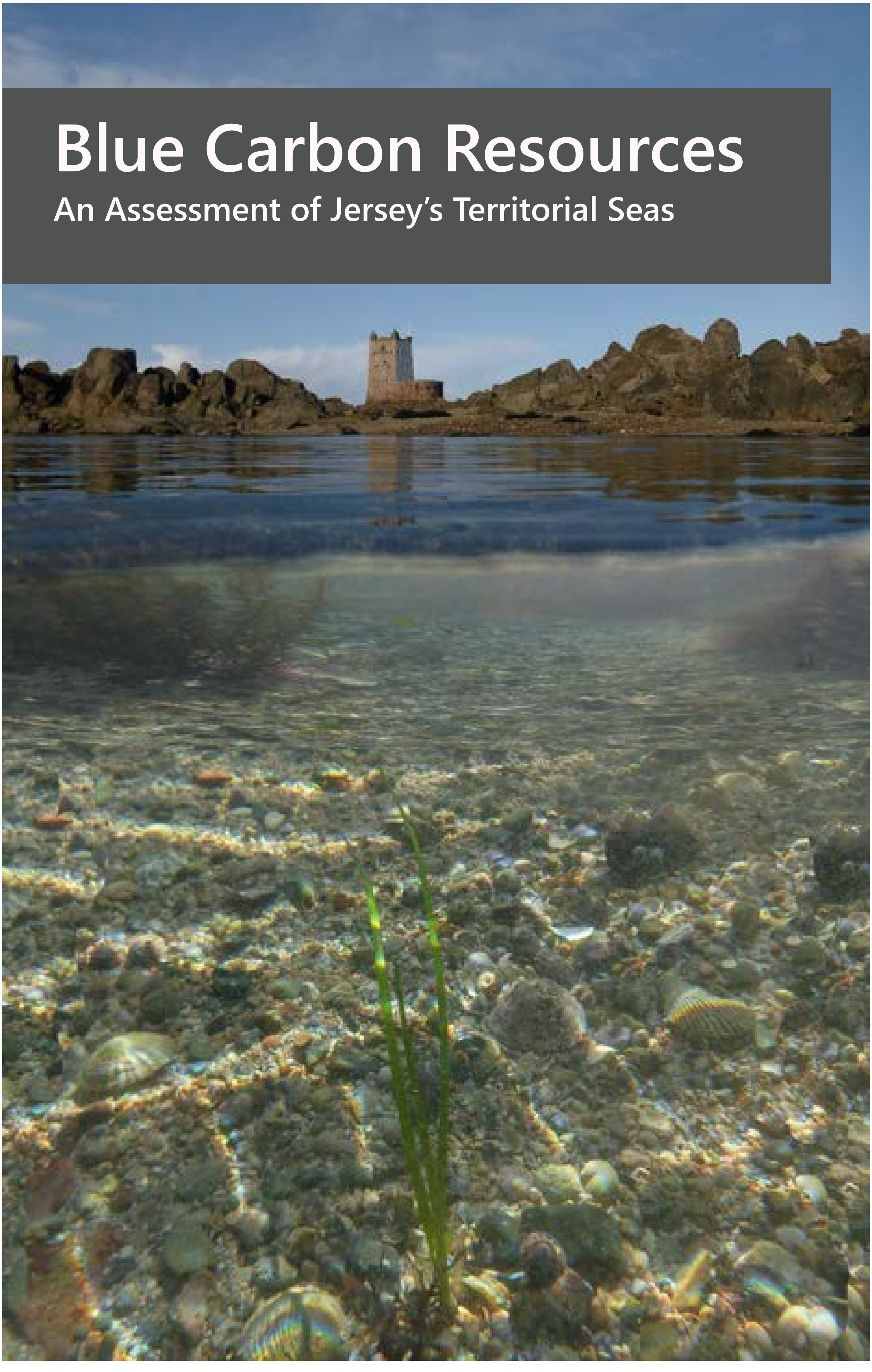

Blue Carbon Resources

An Assessment of Jersey's Territorial Seas

Climate Emergency JSY

Contents

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Summary: Blue Carbon and the Bailiwick of Jersey

What is Blue Carbon?

Carbon is a chemical building block for life on Earth and can be found in all living plants and animals. In its fossil form it is also a constituent of oil, natural gas, wood and coal which, when burned, combines with other elements to create by-products such as carbon dioxide gas. It is the burning of fossil fuels that underpins the current global climate emergency as gases such as carbon dioxide can act to trap heat in the atmosphere. Fortunately, carbon can be removed from the atmosphere by the growth of plants and animals and incorporated into their cells, bones and shells. It is therefore possible to offset some atmospheric carbon by expanding or enhancing key habitats which can soak up and store large quantities of carbon.

Terrestrial 'green carbon' habitats which can assist with atmospheric carbon reduction include forests, peat bogs and grasslands. The marine equivalent is 'blue carbon' a term which represents the weight of carbon that is found within habitats such as seaweed forests, seagrass meadows, mangrove swamps, saltmarsh and other species rich natural habitats. The study of blue carbon is a relatively new science but as the Earth's surface is mostly covered by ocean, its potential is thought to be considerable.

What is so important about blue carbon?

If correctly managed, the weight of carbon within key habitats can be quantified and used by governments, companies, etc., to offset carbon released into the atmosphere through car travel, manufacturing, energy generation, etc. Carbon offsetting using terrestrial habitats has a well-established assessment and certification framework. However, an equivalent framework for blue carbon has yet to be fully developed established but its potential is exciting, especially for places like Jersey 96% of whose territory is sea.

The States of Jersey has declared a climate emergency and has a net zero target for 2050 but at 120 km2, the island little opportunity for offsetting using land habitats. However, the seas around Jersey cover 2,500 km2 and so any blue carbon could assist with offsetting carbon dioxide produced by Jersey residents and businesses. Alternatively, part or all of Jersey's blue carbon resources could be capitalised to generate income for the island.

Does Jersey have a significant blue carbon resource?

Jersey's marine environment is shallow with a mixture of bedrock, boulders, gravel and sand that is bathed continually by nutrient rich seawater and strong tidal currents. The island possesses large areas of marine habitat that are internationally recognised for their biodiversity, complexity and sensitivity. Jersey's subsea topography is formed from shallow reefs and ridges that are separated by large geologically active sedimentary basins. These conditions are near ideal for the generation, storage and burial of blue carbon.

This report contains the results of a study into the potential and location of Jersey's blue carbon resources. The study takes new and existing scientific evidence about Jersey's natural and physical marine processes and combines them with computer models of Jersey's undersea landscape and oceanography. This provides an estimate of the weight of blue carbon in Jersey's seas and has generated maps showing where blue carbon is probably located.

At its most basic level, it is estimated that Jersey's seas have approximately 100,000 tonnes of organic carbon stored inside living plants and animals. Of this, around 1,200 tonnes a year will be permanently removed from the environment. Additional to this is inorganic carbon stored as calcium carbonate inside the hard parts of molluscs, crustaceans, corals, etc. As shells, etc., are durable, they may survive on the seabed for years or decades after the death of their host. Consequently, the weight of inorganic carbon on Jersey's seabed estimated to be some 12 million tonnes with around 10,000 tonnes a year being permanently removed from the environment.

What does this blue carbon assessment actually mean for Jersey?

Based on the figures in this report, Jersey's marine environment is estimated to remove an annual weight of carbon that is equivalent to 8.6% of the island's total carbon production. This is approximately the weight of carbon dioxide (or equivalent) produced by the island's agricultural and waste management sectors each year. However, the checks and balances associated with international accreditation means that there is still a way to go before Jersey's blue carbon resources can be accredited for offsetting purposes.

It should be noted that the estimates given in this report are deliberately conservative and, in the case of permanent burial (sequestration), based only on the carbon produced and stored in living plants and animals. Added to this must be the weight of organic carbon released into the sea as plants and animals die and their flesh breaks apart and decays. In the case of seaweeds, the annual release of dead material contains at least 80,000 tonnes of carbon whose movement and final resting place is currently unaccounted for. Establishing just how much of this dead material becomes permanently buried (sequestered) in Jersey waters is currently the subject of a separate field study.

This report concludes that the Bailiwick of Jersey is has a blue carbon reserve that could play a role in the island's pathway towards carbon neutrality. As there is a direct link between biodiversity and blue carbon, the report also highlights the extent, complexity and sensitivity of key seabed habitats and the role that undersea geology/topography plays in the distribution of plants, animals and blue carbon. Of particular interest is the identification of Jersey's offshore reefs and sedimentary basins as centres for the production, storage and burial of blue carbon. These areas area keystone in the wider health and functionality of local and regional marine processes.

What happens next?

This report is the first step toward the understanding and documentation of Jersey's blue carbon resources. Its estimates and maps will need to be better quantified through fieldwork and laboratory analysis. Such fieldwork is already in progress through projects jointly managed by the Government of Jersey, local and national universities and organisations. Assuming the results remain consistent, a process of accreditation and management will follow so that Jersey has the option of utilising its blue carbon resources as part of the wider global fight against climate change.

Acknowledgments

The authors express their gratitude to officers and staff from the Government of Jersey but especially those in Natural Environment who supported and guided this project to fruition. Many others offered invaluable assistance and advice during the preparation of this report but especially: Alderney Wildlife Trust; Blue Marine Foundation; British-Irish Council; Charles Clover; Sean Dettman; Ifremer; Catriona Jeorrett; Jersey Electricity; Jersey Fishermen's Association; Jersey Heritage; Jersey International Centre for Advanced Studies; Jersey Marine Conservation; Megan Newstead; National Trust for Jersey; Ports of Jersey; SeaSearch UK; Callum Roberts; Lauren Rose; Scottish Natural Heritage; St Andrews University; States of Guernsey, Anna Smith; Victoria Smith; Société Jersiaise; States of Guernsey; David Tudor; University of Exeter; University of Plymouth. Thank you, one and all.

Abstract

Marine ecosystems may produce and store a significant weight of carbon via the growth, accumulation and burial of organic matter in plants and animals. Carbon stored within the marine environment is known as ‘Blue Carbon’ and the world’s oceans (which cover 70% of the planet) represent the largest global natural carbon sink. Climate change and industrial greenhouse gas emissions has led to interest in the ability of coastal habitats to absorb carbon. Understanding the rate at which marine habitats capture and store Blue Carbon play a role in mitigating against anthropogenic CO$_2$ emissions.

This report details an assessment of the Blue Carbon resources within the Bailiwick of Jersey (Channel Islands). Using a combination of biological, ecological, geotechnical and oceanographic data the stored weight of carbon was estimated as was the rate of annual production and burial. These estimates were performed on 37,055 individual areas (each 0.0625 km2) for a subtidal seabed area of 2,315 km2. This is the first such study of Blue Carbon resources in the Channel Islands region.

The average production of carbon within organic material is estimated at 8,837 t OC yr-^{1} for fauna and 82,327 t OC yr-^{1} for plants. The standing stock is estimated to be 15,745 t OC yr-^{1} for animals and 87,827 t OC yr-^{1} for plants. The standing stock for inorganic (principally carbonate) material is 12,795,943 t IC yr-^{1}. The burial (sequestration) of organic carbon is estimated to be 1,283 t OC yr-^{1}, and 8,961 t IC yr-^{1} for inorganic carbon. The average overall carbon burial potential is 10,249 t C yr-^{1} which equates to 8.6% of Jersey’s annual CO$_2$ emissions (based on 2019 figures).

The distribution of Blue Carbon resources suggests that Jersey’s territorial waters possess a coherent and integrated framework of natural processes linked to habitats and species. There is a correlation between habitats and Blue Carbon and it is suspected that there is a considerable movement of carbon (especially dissolved and particulate) between sea areas and habitats.

All of Jersey’s marine habitats contribute to this framework with offshore rocky reefs and sedimentary basins playing a particularly important role in terms of the production, accumulation and burial of carbon. Potential threats and pressures to Blue Carbon resources have been identified and assessed.

This report concludes that Jersey’s offshore marine habitats are productive, complex and biodiverse and there is potential for the development of accredited Blue Carbon projects. Further work will be required to ground-truth the results, identify project sites and obtain a better understanding of the generation, stock and storage of carbon in Jersey’s territorial seas plus any potential threats.

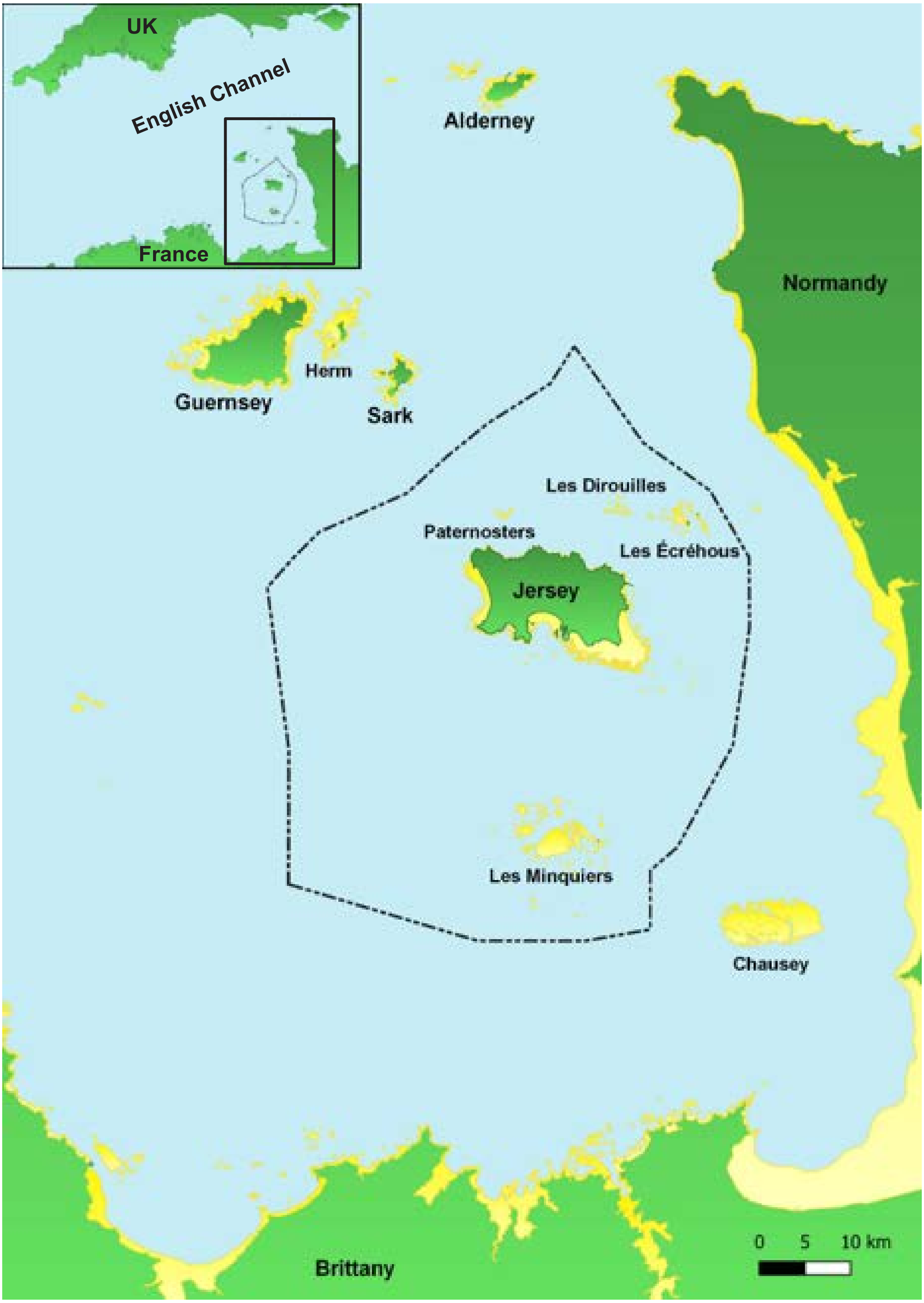


Figure 1 - A chart of the Normano-Breton Gulf (NBG) and its principal islands and reef. The NBG is in the western English Channel and is formed from the French coastlines of Normandy and Brittany. The Channel Islands sit offshore in the centre of the NBG. The territorial sea border for the Bailiwick of Jersey is shown by the dashed line. North-west of Jersey are the islands of Guernsey, Alderney, Sark and Herm which are part of the Bailiwick of Guernsey. The Archipelago of Chausey, to the south-east of Jersey, is administered by Normandy.

1.0 - Introduction

The Bailiwick of Jersey is a British Crown Dependency situated in the western English Channel adjacent to the coasts of Normandy and Brittany (Figure 1). The island is small (120 km²) and densely populated with the lowest per capita carbon emissions in the British Isles. As a signatory to the Kyoto Protocol Jersey is committed to reducing its greenhouse gas emissions to 80% of 1990 levels by 2050 and has requested that the UK (which represents Crown Dependencies on international matters) extends the 2015 Paris Agreement to the island. To date Jersey has achieved an emissions reduction of 35% against the Kyoto target of 80% (Government of Jersey, 2021).

On 2 May 2019 the States of Jersey (SoJ: the island's elected assembly) declared the existence of a climate emergency whose impact has the potential to severely affect the island. In February 2020 the States Assembly voted to adopt a Carbon Neutral Strategy which aims for Jersey to be carbon neutral by 2030. The Strategy requested the formation of a Jersey's Citizens' Assembly on Climate Change whose membership would be drawn at random from across all public sectors and age groups.

The Citizens' Assembly were presented with a wide range of evidence and tasked with answering the question: 'How should we work together to become carbon neutral?' The Citizens' Assembly published their recommendations report in June 2021 (States of Jersey, 2021). The Government of Jersey subsequently released its preferred strategy for tackling the climate change emergency in November 2021 (Government of Jersey, 2021) followed by a draft *Carbon Neutral Roadmap* setting out detailed plans and policies in December 2021.

The *Carbon Neutral Roadmap* recognises that achieving carbon neutrality will primarily require an on-island reduction in greenhouse gas emissions. However, reducing emissions is unlikely to achieve the full zero carbon target as some sectors cannot avoid the production of some greenhouse gases. Any residual emissions will therefore have to be offset through local sequestration projects and the purchase of carbon credits. On a small island like Jersey, terrestrial sequestration projects will be of limited use for offsetting as there is not enough land space to create extensive forests or marshes. Consequently, the Carbon Neutral Strategy has suggested that the island should look to its territorial seas (which form over 95% of the Bailiwick's area) to assess their potential for 'Blue Carbon' resources.

In March 2020 the Government of Jersey's Marine Resources team began investigating the Bailiwick's Blue Carbon resources using financial support from the Climate Emergency Fund. The first stage of this work has been to quantify and map the island's offshore (subtidal) Blue Carbon resources using a combination of existing and new data. This assessment was completed in 2021 and, following peer review locally and by St Andrew's University, is the subject of this report.

Other Blue Carbon research projects are also underway including an assessment of intertidal resources (started January 2021) and field/laboratory work to ground-truth the results of the offshore assessment (started July 2021). These projects are being undertaken in cooperation with the University of Plymouth, University of Exeter and the Blue Marine Foundation. It is expected that the results from this additional work will be published during 2023.

1.1 – Blue Carbon: An Introduction

Blue carbon is a recently coined term which collectively describes the processes associated with the capture and storage of carbon within the marine environment (Figure 2). To date, attention has been focused on vegetated coastal ecosystems (such as seagrass meadows, saltmarsh and mangrove swamps) which have a high carbon burial potential but are often of limited extent and threatened by anthropogenic activities associated with development, industry and leisure. In contrast, research into offshore Blue Carbon resources and their potential to mitigate climate change lags the scientific investigation of terrestrial and marginal marine ecosystems by many years.

The Blue Carbon potential for other marine habitats, especially those below the low water mark, is only beginning to be documented and there are still sizeable knowledge gaps especially in relation to sedimentation, organic and inorganic production and the flux of carbon within and between defined ecosystems. These knowledge gaps mean that potentially important benthic ecosystems, such as accreting sedimentary and biogenic habitats, are not currently recognised for offsetting purposes within accepted carbon budgeting.

The omission of shallow marine and offshore marine ecosystems from conventional carbon budgeting is a recognised issue and comprehensive research programmes are being undertaken to address scientific uncertainties and to establish appropriate policy and management frameworks. This focus of scientific and political attention on Blue Carbon is expected to produce outcomes that will lead to a greater inclusion of Blue Carbon resources in climate change planning and management (Macreadie *et al.* 2019).

Blue carbon is of particular relevance to small coastal states and island *nations* that may have a small land area in relation to that of their territorial seas. This is certainly the position of Jersey much of whose land surface is occupied by agriculture, housing and associated infrastructure. The island has a high population density (875 people/km^2) and areas of semi-natural habitat are generally of small extent, fragmented and of low ‘green carbon’ potential. This includes Jersey’s coastal fringe ecology which is dominated by coastal heath, scrub and sand dunes but devoid of recognised Blue Carbon habitats, such as saltmarsh and mangrove forests.

In contrast to its small land mass, Jersey’s territorial seas cover an area of 2,455 km^2 of which approximately 36 km^2 (1.5%) is intertidal. This marine area includes habitats of potential Blue Carbon significance such as seagrass meadows (*Zostera* spp.), maerl beds, kelp forests and species-rich accreting sedimentary habitats. This leaves the island with a low potential for offsetting using its terrestrial habitats against a high potential for any Blue Carbon held in its surrounding territorial seas.

Jersey’s annual CO_2 emissions are circa 403,000 tonnes annually (0.4 megatonnes; 2019 figures) which, due to a lack of heavy industry and the use of imported nuclear electricity, is relatively low compared with the island’s high population. In May 2019 the States of Jersey declared a Climate Emergency with the objective of Jersey aiming to be carbon neutral by 2030. With few green carbon resources to draw on, the carbon neutral strategy is reliant on achieving emissions reduction from transport, housing and other key areas with the remnant being offset through other means such as carbon credits (Government of Jersey, 2019).

Jersey’s carbon neutral strategy recognises that Blue Carbon resources may have a role to play in the island’s long-term planning and that scientific research is required to quantify this. The Government of Jersey has an active marine research programme largely coordinated through its Marine Resources team. This research includes projects that cover wide areas relating to fisheries and the environment and in March 2020 the Marine Resources team began an assessment of Jersey’s Blue Carbon resources (Marine Resources, 2020).

The first stage of this project has been to utilise existing government information and other available datasets to produce a desktop model that quantifies offshore Blue Carbon resources and maps their likely distribution. In this context, ‘offshore’ refers to those sea areas below chart datum (lowest astronomical tide). A separate intertidal (the area between high water and chart datum) Blue Carbon assessment is also being undertaken but using a different methodology. Ground-truthing the results of these desktop models is planned through a combination of field and laboratory work.

This report is concerned only with the Blue Carbon assessment undertaken for Jersey’s offshore marine area. Reports on the intertidal assessment and other work will follow later. It is expected that the offshore assessment results will contribute to Jersey's carbon management and will assist the Carbon Neutral Strategy. It will also add to the wider collective knowledge associated with Blue Carbon research including within the marine subgroups of the British-Irish Council and OSPAR within which Jersey is a participant. Finally, it is hoped that this study will provide new information relating to the nature and health Jersey’s marine ecosystems and processes plus associated pressures and threats. Such information is vital if Jersey is to create a marine and fisheries management framework that can deliver long-term sustainable benefits to all its stakeholders.

1.2 –Jersey’s Territorial Seas: Geography and Oceanography

The island Jersey is the largest and most southerly of the British Channel Islands, being situated on the southern side of the English Channel about 130 km south of England but only 30 km east of the French Normandy coast. Jersey is a self-governing British Crown Dependency with a land area of 120 km² and a permanent population of 105,000 people. The island has a temperate climate and an economy that is largely based on financial services plus smaller contributions from other sectors including tourism, agriculture and fisheries.

The Bailiwick of Jersey is located in an enclave of the English Channel formed by the coastlines of western Normandy and northern Brittany. This L-shaped sea area is known as the Norman-Breton Gulf (NBG) and, as well as Jersey, hosts the other British Channel Islands (Guernsey, Alderney, Sark and Herm), the French archipelago of Chausey and several large uninhabited offshore reefs. Four of these offshore reefs (Les Minquiers, Les Écréhous, Les Dirouilles and Paternosters) are dependencies of Jersey which, with the island of Jersey, generate a territorial sea area of 2,455 km² (Figure 1). [1]

Seabed topography within the NBG plays an important role in the generation and location of Blue Carbon resources (Section 4.2) and is reflective of region’s geological history, especially in relation to ancient tectonics and, more recently, changes in sea level.

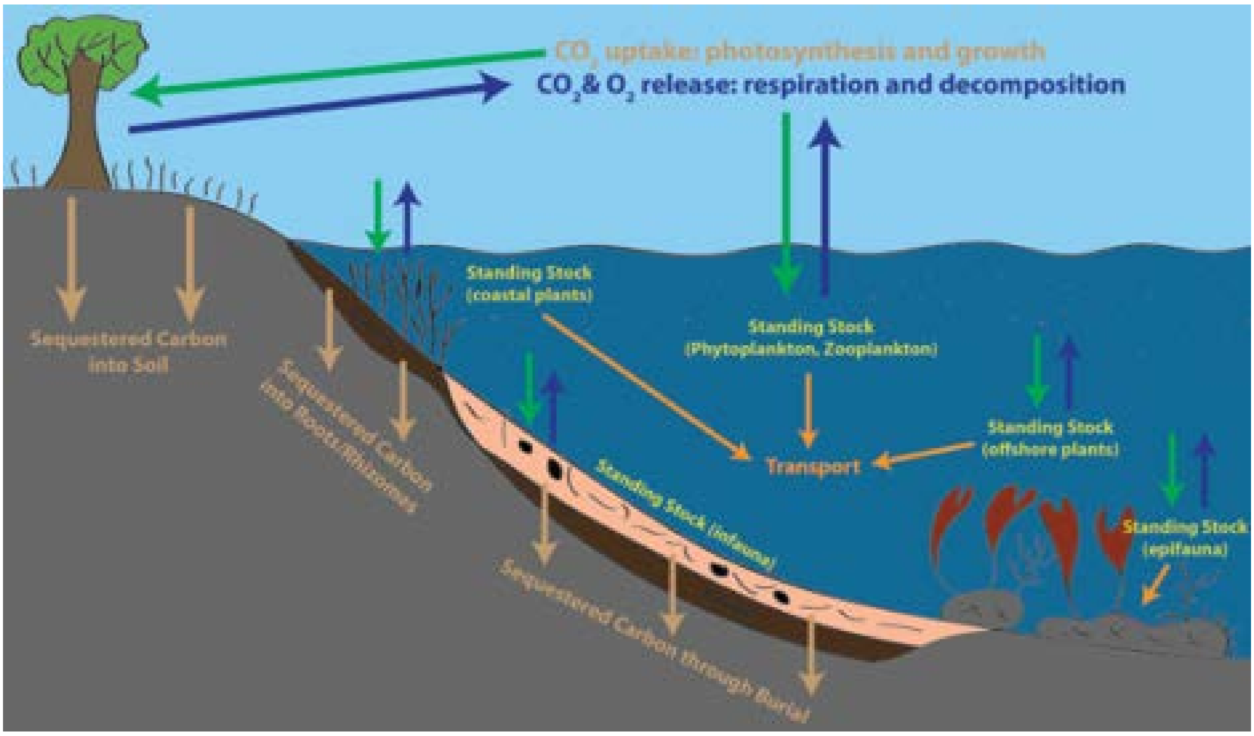


Figure 2 - A simplified diagram showing the principal sources, sinks and interactions associated with the natural carbon cycle. The green arrows represent uptake of carbon through photosynthesis (plants) and growth. The blue arrows represent release of carbon dioxide and oxygen through respiration and decomposition. Brown arrows show the burial (sequestration) of carbon. Yellow labels show where carbon is stored in living organism. The orange arrows show the transport of carbon in the form of particulate or dissolved debris/detritus.

NBG geology is formed from a combination of Precambrian basement rocks (circa 750 to 600 million years) which were overlain or intruded by Palaeozoic intruded igneous and sedimentary rocks (535 to 420 million years). Ancient tectonic activity and the later emplacement of granitic batholiths has created a patchwork of Precambrian geological provinces (defined by regional faults) and younger lower Palaeozoic and Palaeogene sediments. Erosion across millions of years has produced a network of wide sedimentary basins separated by taller topographic features. It is this arrangement of topographic highs (islands and reefs) and low, wide sedimentary basins that form the present shape of the NBG. It is probable that the erosional origin of this landscape dates back 100 million years or more (Bishop and Bisson, 1989; Nichols and Blampied, 2016).

The NBG, like all coastal areas, has been heavily influenced by sea level change over a geological timescale. Periods of higher sea levels, such as exists today, would see the NBG flooded by marine waters with just the resistant, taller igneous areas remaining as islands or intertidal reefs. Conversely, lower sea levels would leave the NBG exposed as a fully terrestrial landscape many kilometres from the coast.

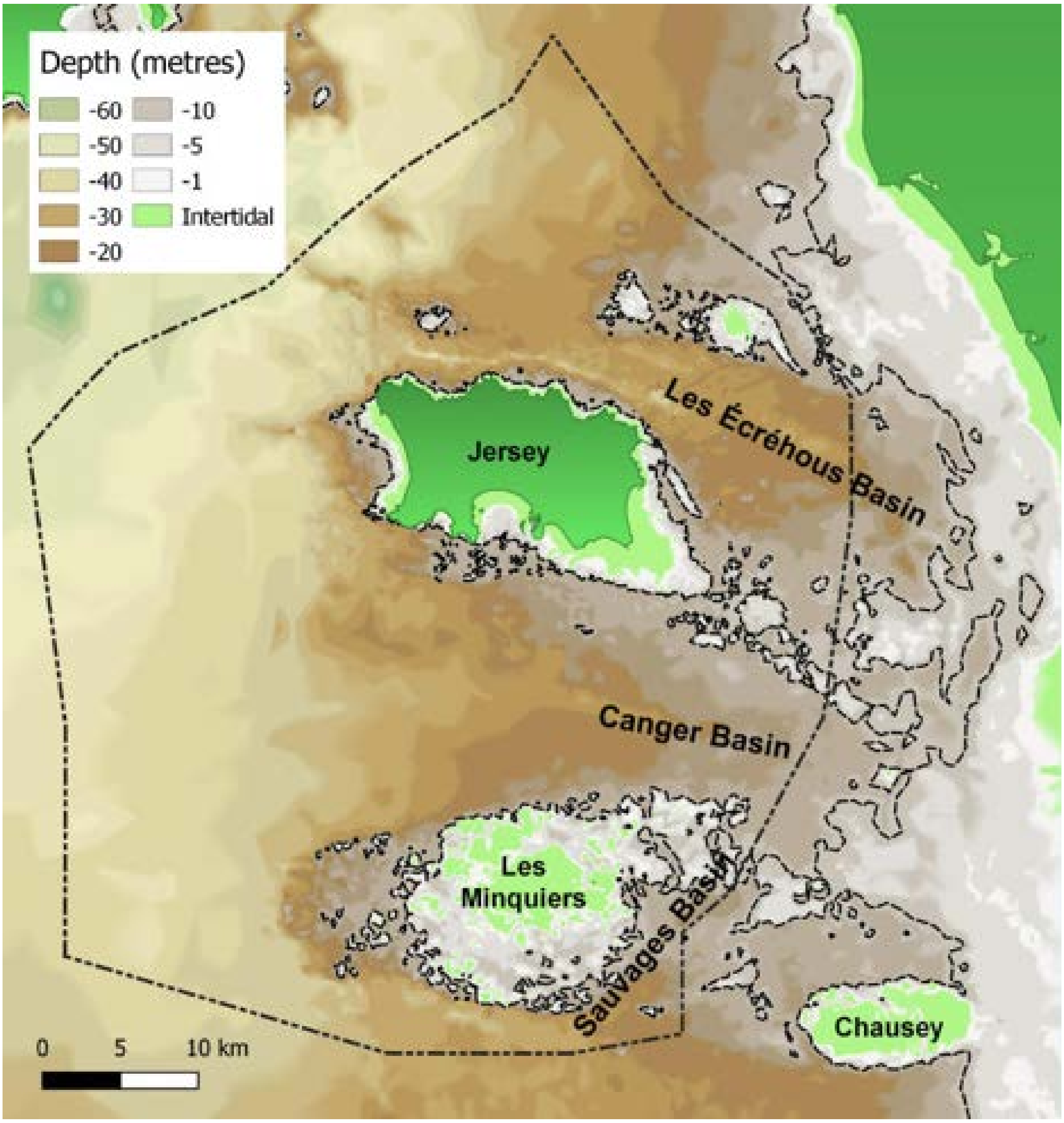


Figure 3 - A bathymetric chart of the Bailiwick of Jersey and adjacent waters. Depths are measured to chart datum. The three principal sedimentary basins are indicated as is the island of Jersey and the offshore reefs of Les Minquiers and Chausey.

During periods of lower sea level, rivers running off the Normandy and Brittany mainland would pick out weaker rocks and fault lines, eroding them into wide, shallow river valleys. By the end of the last Ice Age, around 12,000 BP, the NBG had a topography in which tall, flat plateaus of igneous rock were separated by a series of drainage basins and river terraces. A rapid sea level rise during the Holocene led to a progressive drowning of these drainage basins until, around 2,000 BP, the NBG assumed its current seascape of islands and reefs separated by wide tracts of fully marine waters. This means that the marine sediments in Jersey's territorial seas were deposited during the past 8,000 years (Chambers and Nichols, 2014).

The modern regional undersea topography is reflective of this Ice Age drainage network and within Jersey waters what were river basins have been drowned by the sea to create three distinct sedimentary basins, lying wholly or partially within the island's territorial borders. The importance of these sedimentary basins (and the reefs that separate them) to regional biodiversity and ecology has only recently been recognised. They may also play a major role in the regional Blue Carbon framework and will be referred to later in this report. The basins have no official names and so for the purposes of this report they have been labelled as: Les Écréhous Basin; Canger Basin; and Les Sauvages Basin.

The edges of these four sedimentary basins are defined either by emergent coastlines (e.g. Jersey and Normandy) or by prominent subtidal ridges of rock with an approximate east-west trend. Water depths within the basins are generally shallow (<20 metres) and shallower still over the ridges that separate them. All the basins are in the eastern part of Jersey's territorial seas (Figure 3).

These basins remain tectonically active producing regular earthquakes including some which have caused minor structural damage. Regional tectonics and a rising sea level mean that Jersey's sedimentary basins are actively accumulating sediment with geotechnical surveys reporting sedimentary thicknesses of 40+ metres between the east coast of Jersey and Normandy (Figure 4). Coring work suggests that Holocene marine sediments occupy the top one to four metres (depending on location) of seabed thickness below which occur Pleistocene rivers terrace deposits (Lefort *et al.* 2020).

The seabed area to the west of Jersey is flatter and less complex with a greater exposure to high energy weather, waves and currents. Water depths are greater but remain relatively shallow (<50 metres below chart datum) with a westward sloping seabed that is flatter and dominated by bedrock, cobble which, in places, is covered by patches of mobile sand and gravel. In these areas a predominance of rocky seabed and mobile coarse sediments creates a different ecology to Jersey's sedimentary basins and therefore also gives them a differing role in the regional Blue Carbon framework.

Additional to Jersey's subsea topography is an unusual oceanographic regime which is controlled by the island's location in relation to the Normandy and Brittany coastlines. The L-shape formed by the Normandy and Brittany coasts creates a dead end for tidal waters entering the NBG from the English Channel. This causes the incoming tidal wave to push up against the French coastline producing some of the largest tidal ranges in the world (12.2 metres at St Helier but up to 13 metres around St Malo). The squeeze of sea water towards the Bay of Mont St Michel and the presence of so many islands and reefs create strong tidal currents (>5 knots) and a complicated circulation pattern around the reefs and islands.

For sea water to navigate its way into, across and then out of the NBG entails it passing through a network of gyres and eddies generated around topographic features such the offshore reefs and islands. Computer modelling and drogue surveys suggest that sea water entering the Jersey area from the English Channel may circulate around the island for up to eight weeks before being pushed out into the Channel (Greenaway, 2001; Jegou and Salomon, 1990).

The combination of long residency times, complex residual currents, a high tidal range and a paucity of freshwater from rivers, serve to homogenise the salinity and temperature of the marine waters around Jersey. This creates a distinct and largely separate water body in the south-east part of the NBG which is demarcated by a sharp tidal front (sometimes called the Guernsey Front) that almost exactly follows the sea border between Jersey and Guernsey. This division of sea waters is well defined by differences in temperature, productivity and turbidity, so much so that the two waters bodies may be clearly visible on satellite images.

The northern water body around Guernsey is deeper, clearer, colder and more stratified while the southern water body around Jersey and the Bay of Granville is warmer, more turbid and without stratification. This division and its associated oceanographic properties has an influence on regional sedimentary, productivity and biodiversity patterns which will likely be reflected in the generation, distribution and storage of organic and inorganic carbon resources.

The important role that local topography and oceanography plays in maintaining the health of Jersey's marine environment is only starting to be appreciated and recognition of connectivity between ecosystem functions and services (such as biodiversity, pollution, fisheries and Blue Carbon) is at an early stage. The definition, quantification and holistic modelling of Jersey's marine resources is no small task but is important if the island is to ensure that its maritime environment is to remain ecologically and economically productive and sustainable for the long-term.

This report summarises the results of an assessment of Jersey's Blue Carbon resources. The assessment builds upon spatial modelling work undertaken by the Government of Jersey over several years and touches on wider areas of the marine environment such as benthic habitats and undersea topography. The results quantify Jersey's Blue Carbon potential and start to define the interdependence of local and regional marine processes. It is hoped that modelling work such as this provides information that meets the project's core objectives and goes beyond this into related areas of interest.

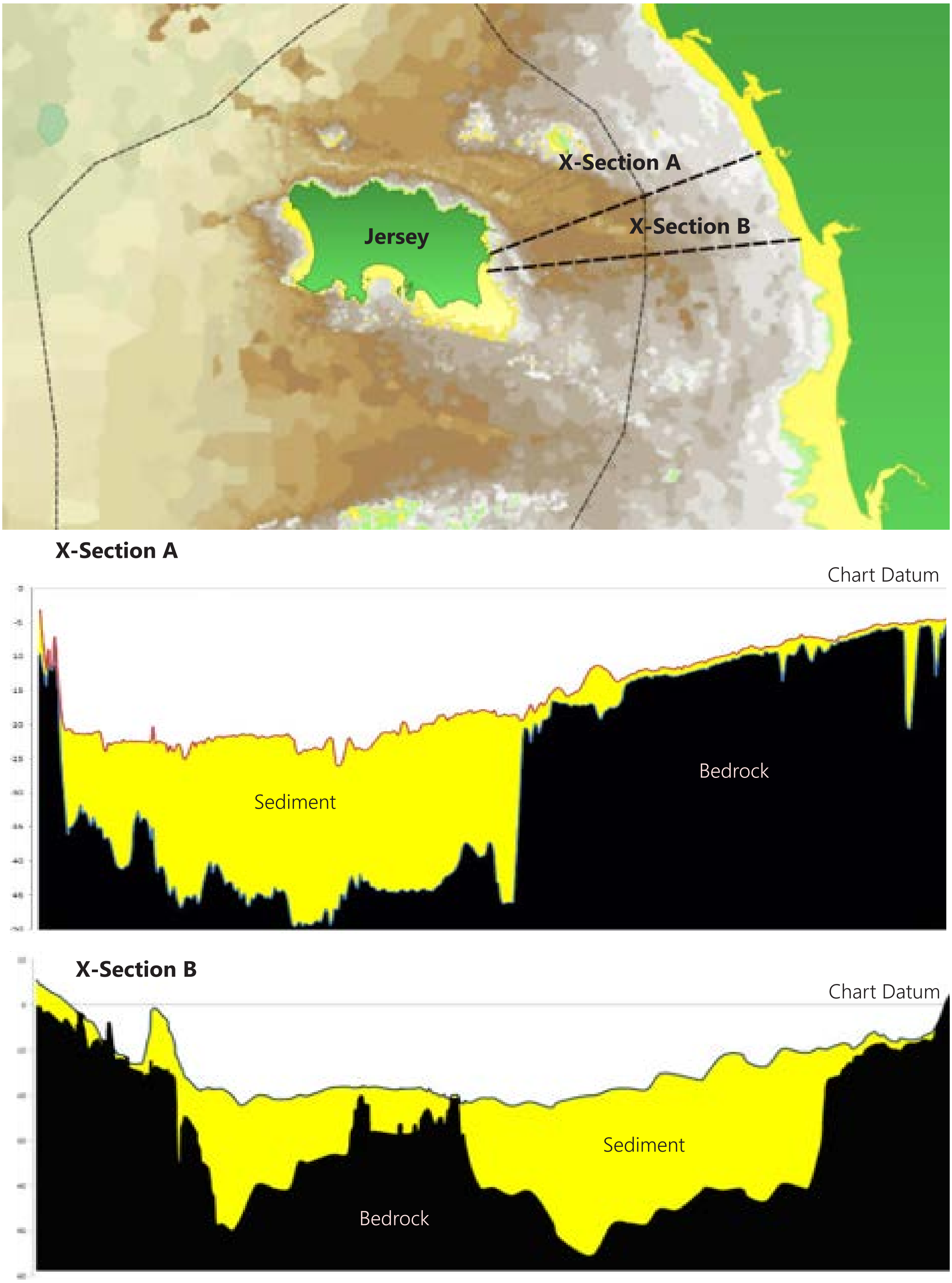


Figure 4 - Two cross-sections taken across Les Écréhous Basin showing sediment thickness (metres) and bedrock between the coasts of Jersey and Normandy. The sediment thickness is more than 30 metres in the centre of the basin becoming much thinner along the coastal fringe. A study of fossils from sediment cores taken along X-Section B suggest that only the top 1 to 4 metres of sediment represent the modern (Holocene) marine environment with deeper sediment being Ice Age (Pleistocene) or older. Based on geophysics data collected in association with sub-sea electricity cables N1 and N3 and geological studies by the Société Jersiaise. Depths are in metres. (Courtesy Jersey Electricity/Société Jersiaise).

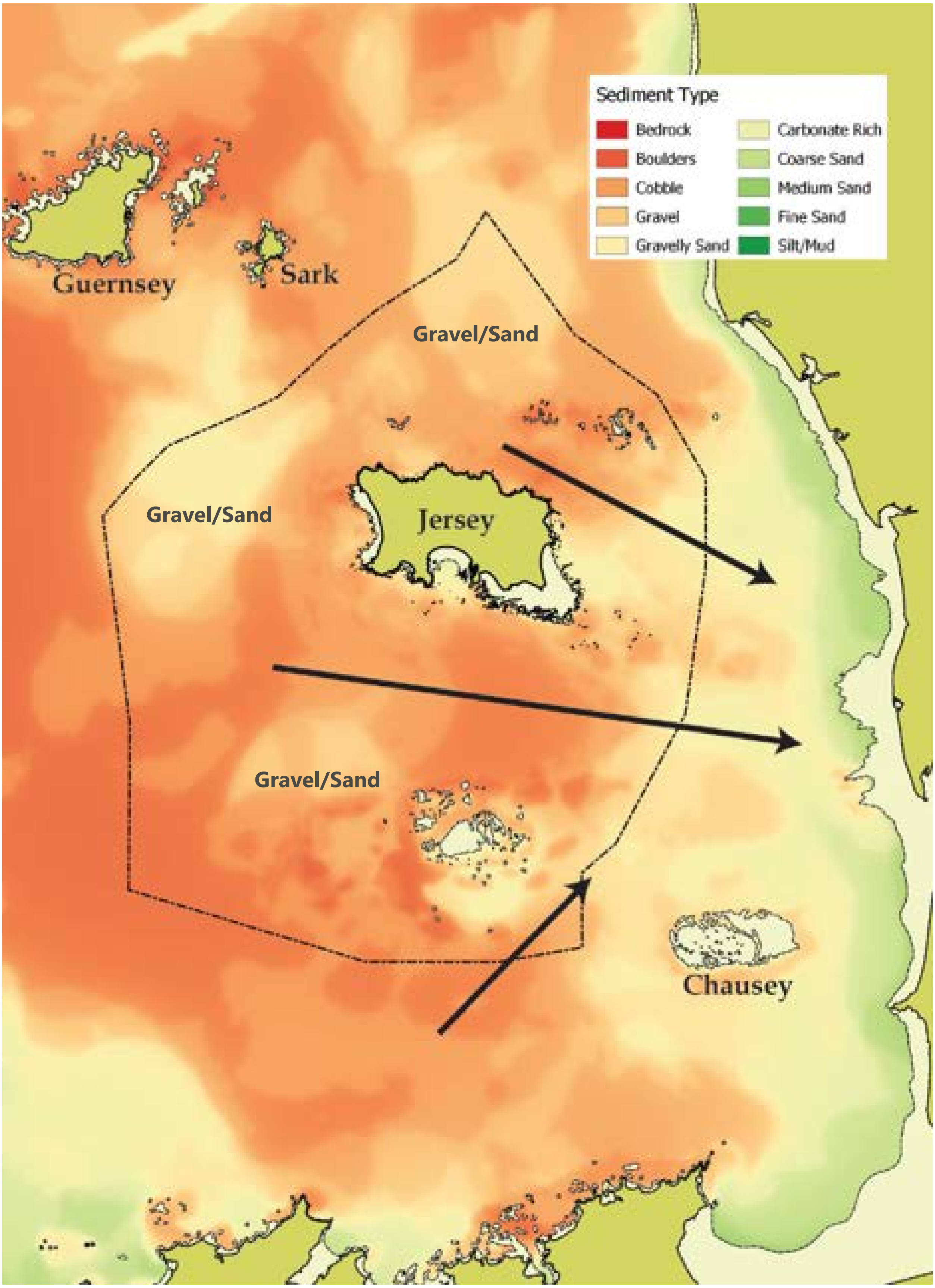


Figure 5 - A Seafloor sedimentary map for the Normano-Breton Gulf using a classification adapted from Folk (1954). The arrows indicate a fining of sediment from cobble to sand. This illustrates a general west to east fining sequence within Jersey territorial seas. Exceptions are the sand/gravel patches/banks (labelled) to the north and west of the Bailiwick. These are coarse and often unstable deposits formed downstream from obstacles or where tidal currents meet (see also Figure 8)

2.0 – Methodology

This assessment of the carbon resources in Jersey's offshore marine waters was adapted from the methodology used by Scottish National Heritage (SNH) which used an area-based approach to estimate the Blue Carbon potential of defined benthic habitats (Burrows *et al*. 2014, 2017; Smeaton *et al*. 2020). Both the SNH and Jersey assessments were achieved by extracting data from GIS models relating to the classification, properties and extents of benthic habitats and combining these with data relating to the biomass and production of organic and inorganic carbon and various sedimentary properties, including an approximate rate of sedimentation.

This report therefore takes a spatial approach underpinned by mapping the extent of benthic habitats and the acquisition of detailed biological and sedimentological data. There are some departures from the SNH methodology, the most notable of which are the higher resolution mapping of habitats (producing 37,055 individual assessment areas) and the availability of local data relating to the biomass and production potential of benthic habitats and associated algae/plants.

The Jersey Blue Carbon assessment proceeded in stages beginning with an extensive data survey ahead of the creation of a GIS model and then, via a series of calculations incorporating biomass and other figures, the delivery of Blue Carbon budget estimates for Jersey's territorial waters. This methodology is described in detail below.

It should be noted that the shallow water depth (<55 metres), large tidal range (over 12 metres) and strong tidal currents associated with Jersey's marine environment create a highly mixed water column with no permanent thermocline (Le Hir *et al*. 1986; Jersey Marine Resources, pers. comm.). Satellite data measuring the concentration of chlorophyll-a in surface waters also suggest that the resuspension of benthic sediment during the tidal cycle may place an important role in primary productivity in Jersey waters. Strong vertical mixing, the absence of a thermocline and resuspension of pelagic-derived material may reduce the potential for the burial of organic/inorganic material derived from phytoplankton, zooplankton and suspended sources (Burrows *et al*., 2014). A lack of accurate data in this area means that this report does not attempt to model the organic contribution to the seabed from pelagic abiotic sources such as dissolved and particulate organic carbon. This aspect of the local carbon budget will require further study to determine its significance.

2.1 - Benthic Habitat Classification

The assessment of Blue Carbon resources in Jersey waters utilised a recently completed benthic biotope (habitat) GIS model covering 2,313 km^2 of the island's subtidal (below chart datum) marine waters. (Definition of the terms 'habitat' and 'biotope' is given in Appendix I.) This model includes Jersey's offshore reefs and islets but excludes intertidal areas as this is the subject of a separate and more detailed assessment process.

The benthic habitat GIS modelling began with a systematic survey of data sources relating to Jersey's territorial waters but especially those concerning physical, biological and oceanographic properties. This survey included data from several regional studies from the 1960s, 1970s and 1980s as well as localised information from Admiralty charts, oceanographic surveys, etc. Data from these sources (whether in the form of lists, tables, maps or charts) were digitised and georeferenced using open-source GIS software (QGIS 3.16).

The datasets obtained during the survey often used differing classification schemes, scales and units to describe the same parameters. Water depth, for example, might be expressed in fathoms, feet or metres and could be measured against the lowest astronomical tide (LAT) or Jersey datum (5.88 metres above LAT) while seabed sediment could be classified according to differing but broadly compatible grain-size distribution schemes. To integrate these data, imperial units were converted to metric and differing sedimentary classifications, etc., were reclassified using numerical scales where integers were used to represent defined classes.

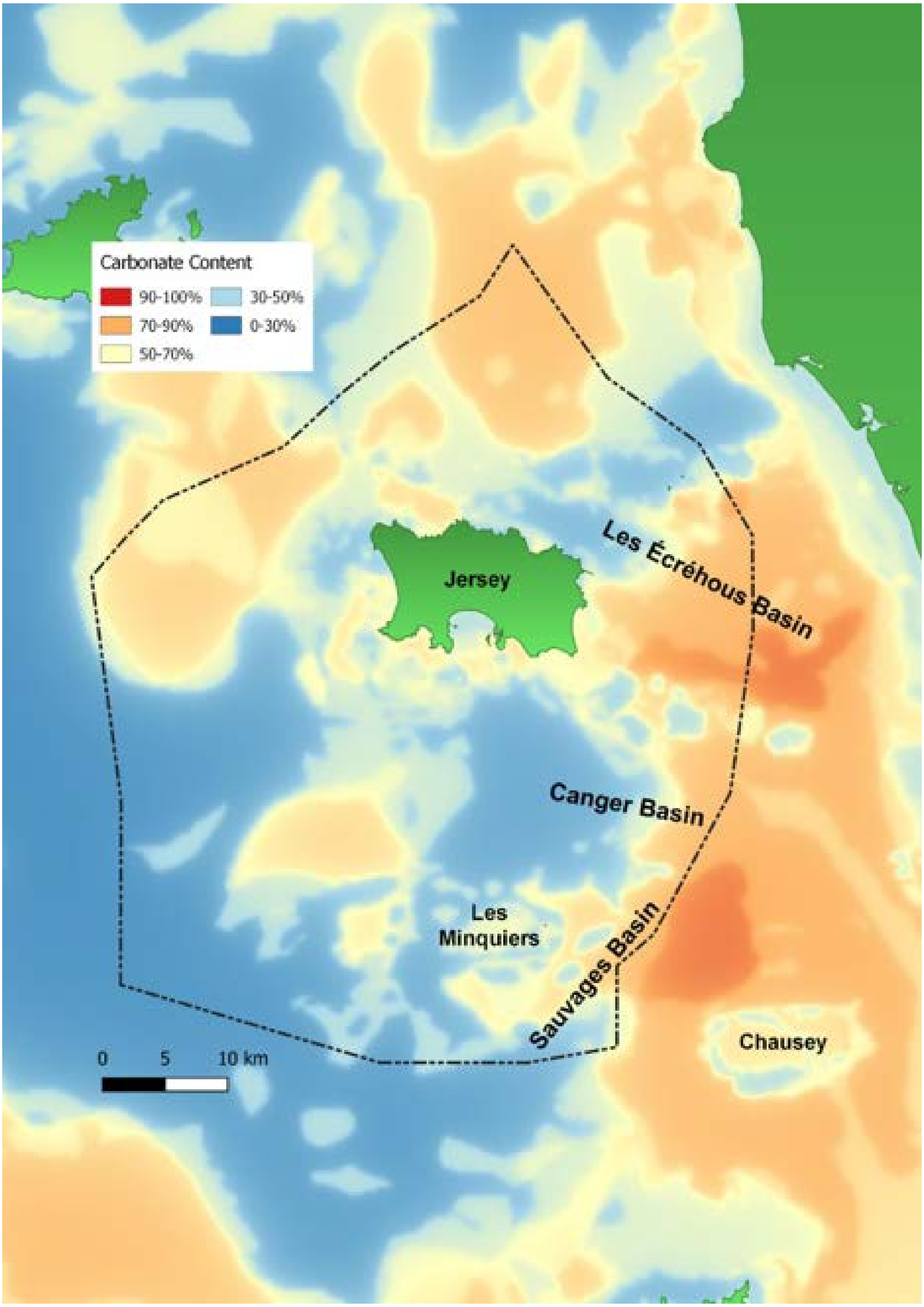


Figure 6 – A chart showing the carbonate content (by weight) for Jersey's sedimentary areas. Areas of high carbonate occur in the sedimentary basins and offshore sandbanks/patches. Very high areas of carbonate (>90%) are generally indicative of biogenic habitats such as maerl.

The sediment grain-size classification scale used is, for example, based on Folk (1954) and uses integers to represent broad sediment/substrate descriptions from bedrock (1) through to silt/mud (10) (Figure 5). Reclassifying datasets in this manner allowed the results from different regional surveys to be combined to provide a wider coverage and greater detail than any one individual dataset. Once the reclassification had been completed, the datasets were merged to form single GIS point datasets relating to individual parameters such as water depth, substrate grain-size and carbonate content (Figure 6).

The point data within each GIS dataset were interpolated (via inverse distance weighting) into a raster file with cell dimensions equivalent to 50 x 50 metres. A GIS point grid (250 metres on the x and y-axes) was used to resample the interpolated raster files to provide values for 37,055 points covering all of Jersey's offshore waters. Additional GIS processing (using standard software tools) included using selected raster files to estimate seabed slope, roughness, distance from shore and exposure to wave/wind energy. Additional data relating to tidal current velocity, wind strength/ direction, wave height, temperature, productivity, etc., were obtained from open-source datasets available from NASA, ESA and the UK Renewables Atlas.

At the end of this process the GIS model contained point datasets with standardised values for a range of biological, geological, oceanographic and other parameters. These datasets are useful for modelling individual aspects of the local marine environment but could also be used to classify and spatially map benthic habitats.

2.1.1 – Benthic Habitat Identification

Low-resolution maps exist showing benthic habitats for all of Jersey's subtidal waters (e.g. Retière, 1979; Le Hir *et al.* 1986) but with so much additional physical and environmental data available in the GIS model, it was felt that an opportunity existed to identify and map habitats in greater detail using GIS modelling. The objective was to identify benthic habitats that could be matched to the JNCC's marine biotope classification scheme. This was achieved in two stages, the first of which was to use a select range of parameters to identify broad habitats and then to use additional data to refine these onto the JNCC biotope scheme.

The initial stage selected key parameters used by the JNCC in the creation of their biotope scheme (Connor *et al.* 2004). These were: water depth, substrate, exposure to wave energy and tidal current velocity. However, a high degree of correlation between wave exposure and tidal current led to the latter being dropped from the query.

For each of the 37,055 points in the GIS model, the following layers were queried. Water depth (assigned 1 for depths below 20 metres and 2 for depths above 20 metres), substrate type (using the 1 to 10 scale discussed previously) and wave exposure (1 to 4, adapted from Connor *et al.* 2004). A combination of these three values (e.g. 1:3:2) acted as an environmental summary for each point on the 250 x 250 metre grid.

The dataset was cross-tabulated to identify individual parameter combinations and, for each of these, the number of grid squares represented by them. This process produced a list of 35 different parameter combinations which could be matched to broad benthic habitat types most of which could be matched to at least level 3 of the JNCC biotope scheme.

Although the process had achieved an initial match between the GIS model and the JNCC's biotope classification, an extended assessment process was required to further refine the classification, to identify problem areas and to match these broad benthic habitats more precisely to the JNCC biotope classification.

The initial stage of refinement determined the number of data points represented by each of the 35 parameter combinations. Those combinations with fewer than 100 data points (0.27% of the total dataset) were merged with the nearest category (in environmental terms). This reduced the number of different combinations from 35 to 25.

A further refinement of the dataset was undertaken using additional parameter values that were thought to represent the characteristics of individual JNCC biotopes. This matching process was similar to the one used for the broad habitat but required more precision to account for the more detailed definition of individual biotopes.

It began with the additional processing of the datasets using specialist parameters. For example, areas of probable kelp forest were identified using parameter values which indicated that individual points were infralittoral (< 20 metres below chart datum), on bedrock or boulders and on a steep slope. These could be further refined by relabelling kelp forest (IR.MIR.KR.Lhyp) with a water depth greater than 12 metres as kelp park (IR.MIR.KR.Lhyp.Pk).

Similarly, identifying areas of coarse sediment with a high carbonate content might indicate maerl (SS.SMp.Mrl) or bivalve beds (SS.SCS.ICS.MoeVen). By this means hard substrates could be matched with a reasonable level of confidence to biotopes at level five in the JNCC scheme. However, sedimentary substrates were generally more difficult to classify remotely and were usually matched to biotopes at JNCC level three.

A further stage of verification required the use of georeferenced field data that had not been included in the original systematic survey. Much of this was localised data from commercial surveys, student research and/or work by NGOs. This included 24,937 habitat and species records gathered by the Société Jersiaise and SeaSearch UK since 1997, side-scan sonar surveys by Ports of Jersey and Jersey Electricity, underwater video footage from divers and towed cameras, aerial photographs, sediment and biological data from a variety of EIAs and other surveys associated with commercial projects.

The level five and level three initial biotope assignments were cross-referenced against these detailed survey data and, where necessary, manual adjustments were made. Other adjustments came from the use of specialist survey data relating to specific biogenic habitats whose extent had been mapped with precision. This included seagrass (*Zostera marina*) meadows, high density maerl beds, kelp forest (*Laminaria* spp.), slipper limpet (*Crepidula fornicata*) beds, sandmason (*Lanice conchilega*) beds and some types of bivalve bed (e.g. *Venus verrucosa*, *Glycymeris glycymeris*, *Tapes* spp.). These habitats generally occur in shallow water and are of scientific interest for reasons of biodiversity (including non-native species), ecosystem service and natural capital provision.

JNCC Biotope	Description	Substrate Stability	Extent (km^2)
IR.HIR.Ksed	Offshore rock with sand	Unstable: Sand & Gravel	81.9
IR.HIR.KSed.XKScrR	Shallow reef with sand	Unstable: Sand & Gravel	185.5
IR.MIR.KR.Lhyp	Kelp forest	Stable: Hard Substrate	74.3
IR.MIR.KR.Lhyp.Pk	Kelp park	Stable: Hard Substrate	54.1
CR.HCR.Xfa	Hard ground	Stable: Hard Substrate	414.9
SS.SCS.ICS.MoeVen	Basin gravel/sand	Stable: Sand & Gravel	53.2
SS.SCS.ICS.Glap	Offshore gravel/sand	Stable: Sand & Gravel	284.1
SS.SCS.ICS.Slan	Fringe stable sand	Stable: Sand & Gravel	14.4
SS.SCS.CCS.PomB	Hard ground	Stable: Hard Substrate	463.2
SS.SCS.CCS.MedLumVen	Basin gravel/sand	Stable Sand & Gravel	90.1
SS.SCS.CCS.Blan	Offshore gravel/sand	Unstable: Sand & Gravel	275.9
SS.SSa.IFiSa	Fringe stable sand	Stable: Sand & Gravel	4.0
SS.SSa.IFiSa.IMoSa	Mobile gravel/sand	Unstable: Sand & Gravel	196.6
SS.SSa.IMuSa	Fringe stable sand	Stable: Sand & Gravel	0.3
SS.SMx.IMx.CreAsAn	Slipper Limpets	Stable: Biogenic Seabed	18.2
SS.SMx.OMx.PoVen	Basin gravel/sand	Stable: Sand & Gravel	42.6
SS.SMp.Mrl	Maerl	Stable: Biogenic Seabed	56.4
SS.SMp.SSgr.Zmar	Seagrass	Stable: Biogenic Seabed	3.2

Table 1 – The JNCC biotopes identified in Jersey waters and displayed in Figure 7. Substrate stability refers to Figure 8. For more details on each biotope see Appendix I.

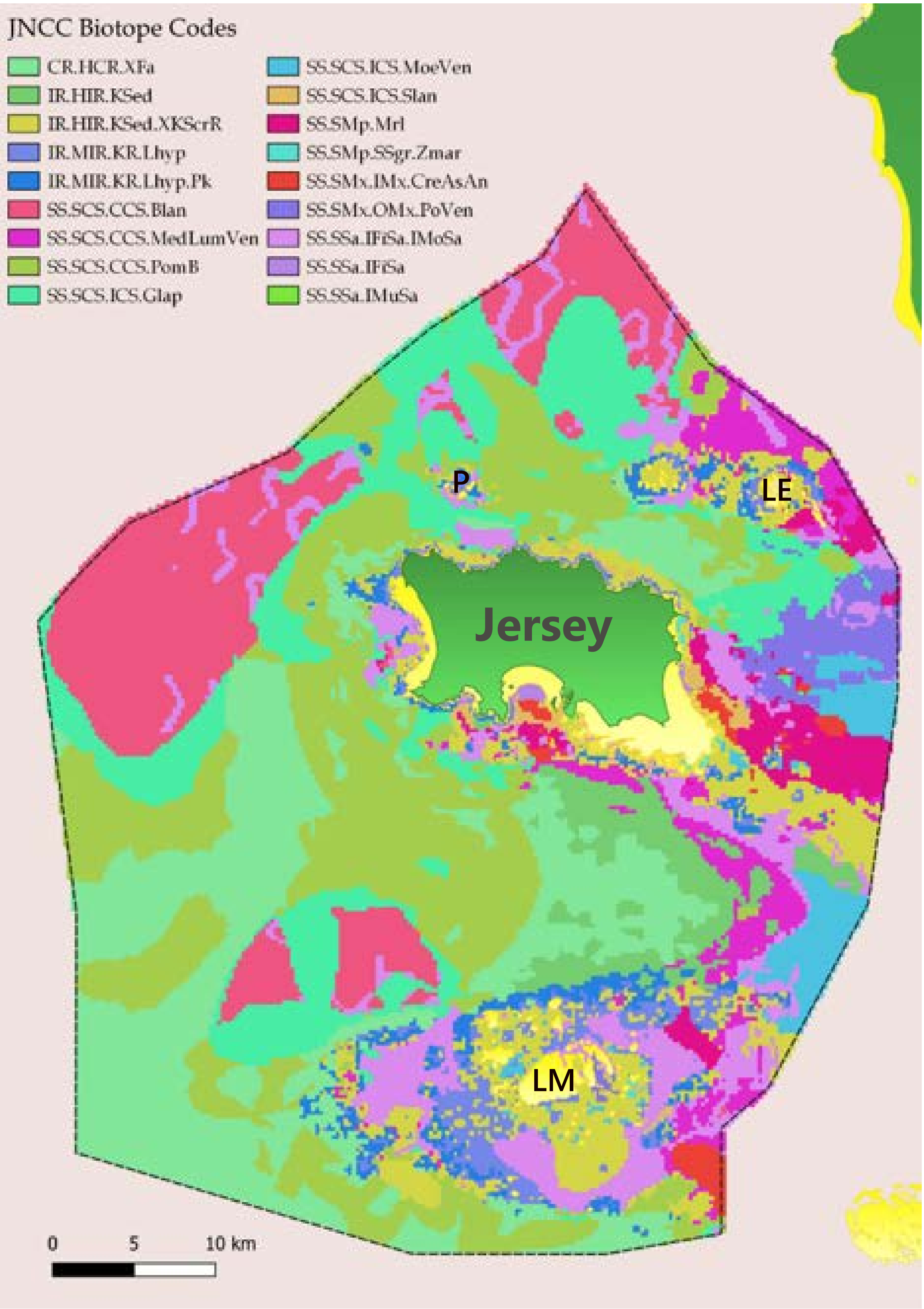


Figure 7 – A chart showing the extent of JNCC marine biotopes identified for Jersey's offshore territorial seas. For an explanation of the biotope codes see Table 1 and Appendix I. For a simplified chart based on a general seabed habitat description for see Figure 25. LM = Les Minquiers; LE = Les Écréhous; P = Paternosters.

On completing this work, the seabed habitat map covering Jersey offshore waters consisted of 37,055 points each of which had been classified to one of 18 JNCC biotopes. These biotopes, and the area they occupy, are summarised in Table 1, displayed in Figure 7 and described in detail in Appendix I. Additionally, Figure 8 displays the stability of seabed areas within Jersey's territorial seas based on generalised biotope properties and substrate type. Superimposed on Figure 8 are Jersey's marine protected areas (MPAs) where mobile fishing (principally dredging and trawling) are prohibited. These equate to 151 km^2 (6.5%) of the Bailiwick sea area (Figure 8; see Chambers *et al.* 2019).

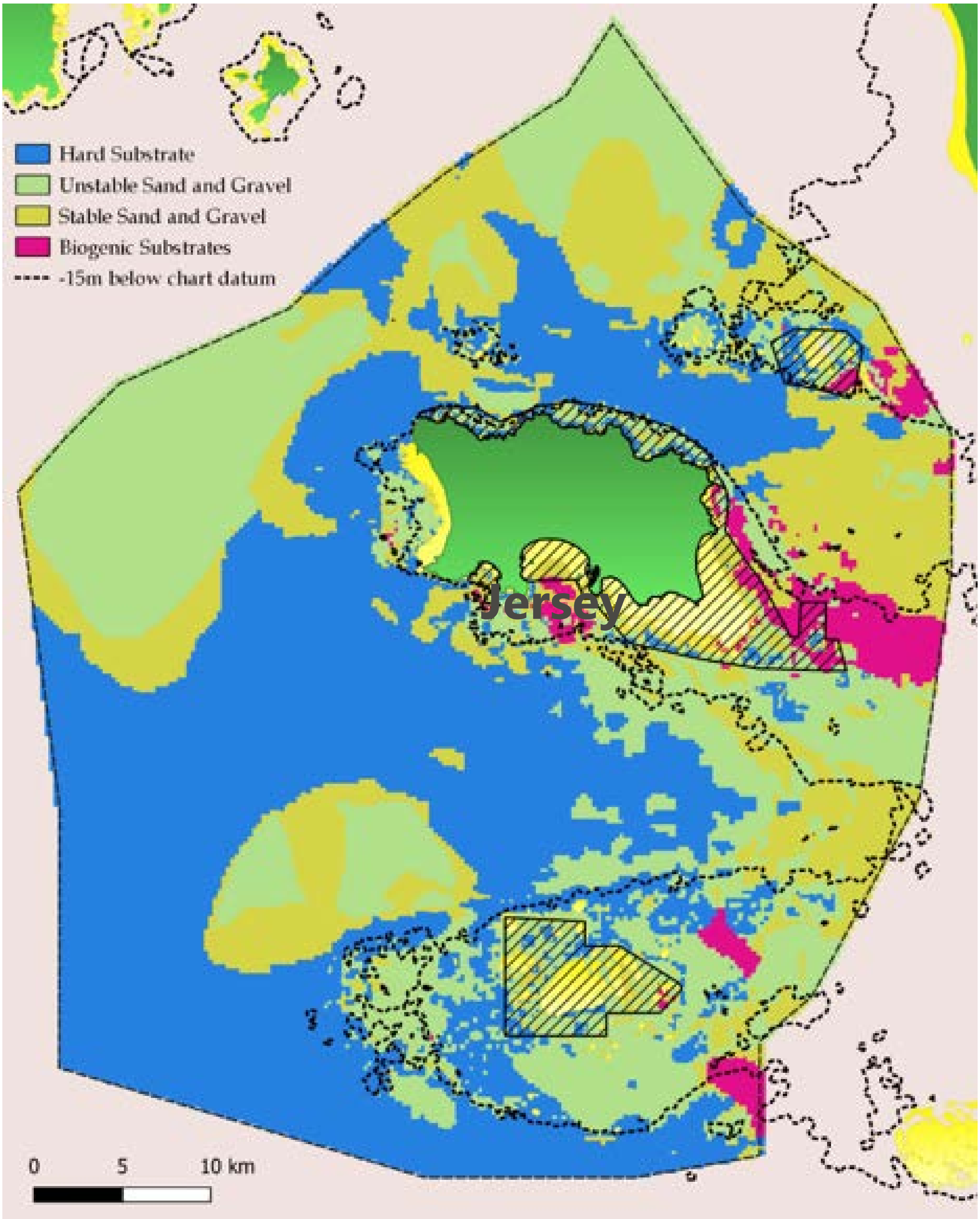


Figure 8 - The stability of seabed areas based on JNCC biotope properties (see Table 1). This indicates those areas where sediment is most liable accumulate such as is in the sedimentary basins indicated in Figure 3. The hatched areas show the extent of Jersey's MPA network.

2.1.2 – Independent Ground-truthing and Validation

The spatial habitat data and habitat locations on the completed biotope map were evaluated against recent underwater towed video surveys undertaken as part of a separate doctoral research project in Jersey waters.

The towed video sequences used in the evaluation of the habitat map were filmed between 2017 and 2020 mostly in areas to the north, east and south of Jersey. The videos were taken with GoPro cameras (in a SpotX Pro Squid (SpotXTM Underwater Vision) housing) and contained high quality seabed footage from which habitat types and extents can be visually classified and accurately located. The tow paths were geolocated and the seabed habitats categorised using the EUNIS classification which is directly comparable to JNCC biotope codes. It should be noted that the towed video dataset did not include all the biotopes used in the modelled data but enough were included to be able to assess the model's accuracy. The modelled habitat data has a spatial resolution of 250 metres, meaning the maximum distance within one cell is 354 metres. The cut off distance for accuracy within one cell was therefore set at 354 metres.

Of the EUNIS habitat positions identified from the towed videos, 75% occurred within 354 metres of the modelled habitats (Figure 9). This accuracy increased to 82% within two cells (i.e. 708 metres). As most towed videos cover a 100 metre transect with a 0.4 metre field of view (i.e. 40 m^2) within habitat map cells that are 250 x 250 metres (0.0625 km^2), it is possible that some habitats were missed. The least accurately predicted EUNIS habitat is A5.2 (coarse/medium sand; Figure 9) which was often in map cells that were assigned to habitats containing a mix of bedrock and sand. This may have been a function of the limited coverage of a towed video within the wider area of the cell.

The results suggest that for those areas where towed videos were evaluated the model is 75% accurate at a one cell resolution (354 metres). Given the number of cells (37,055) covering Jersey's territorial waters, this assessed level of accuracy should be sufficient when running queries for physical and biological information. As such, it is a potentially useful tool for high level decision-making and, as more information is added into the model, so its use for marine management and spatial planning will increase. However, for the purposes of this report, data extracted from this model will be used to provide a Blue Carbon assessment of Jersey's territorial waters.

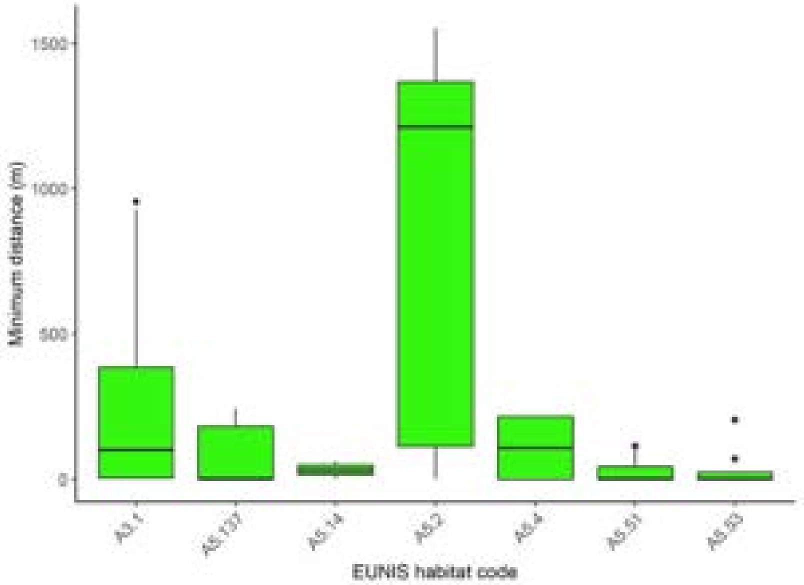


Figure 9 - Distance of towed video habitat location to nearest modelled corresponding habitat in metres, showing the median, interquartile range and minimum and maximum values. Outliers are shown by filled circles. A3.1 = rock/cobble; A5.137 = sand and polychaetes; A5.14 = gravelly sand; A5.2 = coarse to medium sand; A5.4 = mixed sediments; A5.51 = maerl beds; A5.53 = seagrass meadows.

2.2 – Biomass and Production

Obtaining an accurate estimation of the Blue Carbon resources in Jersey waters requires knowing the weight of organic material represented by benthic living plants and animals (the dry weight biomass) and their rate of biological production (i.e. the biomass produced for a given area over a given time). It also requires knowing the weight of inorganic carbon stored as carbonate in the form of shells, corals, maerl and other biogenic material (often expressed as a percentage of overall sediment unit weight). [2]

Obtaining accurate biomass and carbonate content data across extensive sea areas is an expensive and technical undertaking. For many sea areas such information is not readily available but for the Normano-Breton Gulf benthic biomass data are available from three historical sources (two relating to sediment; one for benthic algae) and the carbonate content of sediment available from one source.

Dry weight biomass measurements were collected from grab samples by Retière (1979) and by Le Hir *et al.* (1986) as part of regional studies into benthic biodiversity and ecology. Retière took 573 grab and dredge samples from across the Normano-Breton Gulf which were analysed for their biological and sedimentological properties. This included determining the living infaunal biomass of 13 grab samples that were considered representative of benthic 'facies' (i.e. habitats/biotopes) identified by Retière.

A decade later saw a similar benthic survey by Le Hir *et al.* (1986) conducted as part of a wider marine study during which seven facies were identified and 36 biomass measurements made. Le Hir *et al.* used the combination of biomass data and facies area to estimate a total benthic infaunal biomass of 181,132 tonnes for the Normano-Breton Gulf. The annual production rate (P/B) for each facies was also calculated and their sedimentological with their biological results being cross-referenced against those of Retière.

Figures measuring the dry weight biomass of key marine plants (algae and *Zostera* species) are available in Kerambrun (1984). This study documented the distribution, density and biomass of principal littoral and sublittoral plant species to evaluate seaweed harvesting potential along the north Brittany coast. Kerambrun calculated the plant biomass per m² for differing habitats and environmental parameters (e.g. seasons, water depth), the percentage of carbon within key species and their annual production (P/B) rate.

Hommeril (1967) measured the percentage of carbonate (by unit weight) within sediment from 584 dredge and grab samples from across the Normano-Breton Gulf and created a regional map of sedimentary carbonate content for the central and northern parts of the Gulf. This map was digitised, georeferenced and converted to a GIS layer as part of the systematic survey outlined in Section 2.1.

Biomass data from Retière, Le Hir *et al.*, and Kerambrun were included as parameters in the original systematic survey and so could be matched to the JNCC biotopes in the benthic habitat (biotope) map described in Section 2.1. This synthesis of datasets offers a regional overview of biomass distribution (and therefore also organic carbon content) in Jersey waters. The production (P/B) values from Le Hir *et al.* and Kerambrun also allow annual production (in terms of biomass) to be estimated for each JNCC biotope (Table 2).

Some of the JNCC biotopes identified for this study could not be directly matched to the broad facies' types listed by Retière and Le Hir *et al.* These are generally biotopes associated with individual species such as sandmason worm beds (SS.SCS.ICS.Slan), slipper limpet beds (SS.SMx.IMx.CreAsAn) and seagrass meadows (SS.SMp.SSgr.Zmar). For these biotopes, biomass production and other information was obtained from other studies undertaken within the Channel Islands region and added to the GIS model (De Smet *et al.* 2013; Leloup *et al.* 2008; Jacobs, 1979) .

A summary of the biomass and production figures associated with the JNCC habitats is given in Table 2. Some of these datasets are more than three decades old but being local studies makes them a better choice than using data from wider regional or international studies. Despite their age, these studies are likely to reflect the unusual biological and oceanographic properties of the Normano-Breton Gulf such as its 13 metre tidal range and strong tidal currents.

2.3 – Sediment Properties

Marine sediment is subject to oceanographic processes such as transport/erosion/deposition by tidal currents and weather events, biological re-suspension, chemical dissolution, erosion/extraction by anthropogenic actions (mining, dredging, etc.) and accumulation. The rates at which sediment is transported, eroded, deposited and accumulated will have an important bearing on the physical properties of the seabed and its benthic ecology. It will therefore also have a bearing on its potential to accumulate and sequester organic carbon.

The linking of biomass and production data to individual JNCC biotopes provides an estimate of standing stock (i.e. the weight of organic/inorganic carbon stored in an area at any one time) and the production of organic and inorganic carbon in Jersey's territorial seas. However, to estimate the weight of carbon that permanently accumulates in sedimentary habitats requires data relating to the annual accumulation and burial potential of individual biotopes or data relating to sediment properties for defined areas. In both instances, locally relevant data are rarely available as obtaining it through fieldwork can be technically challenging and expensive.

In the absence of local field data, Blue Carbon assessments often obtain the weight of carbon permanently buried annually (usually per m^2 to a given depth of sediment) for defined biotopes through a literature search. These produce rates of burial (sequestration) from studies of comparable habitats that can be applied to the assessment on the assumption that local sequestration processes are comparable. A caveat to this is that these studies may have been conducted in areas where oceanographic and other circumstances differ (e.g. warmer or colder water temperature) although an absence of local data often means such approximation may be the only available option.

JNCC Biotope	Fauna			Flora	
	Le Hir	Retière	P/B	Algae	P/B
IR.HIR.Ksed	3.83	6.703	0.584	160	0.5
IR.HIR.KSed.XKScrR	3.83	6.703	0.584	600	1.5
IR.MIR.KR.Lhyp	9.49	9.139	0.491	1500	0.65
IR.MIR.KR.Lhyp.Pk	9.49	9.139	0.491	850	0.5
CR.HCR.Xfa	7.24	9.139	0.86	0	0
SS.SCS.ICS.MoeVen	51.4	17.242	0.609	80	0.5
SS.SCS.ICS.Glap	51.4	14.132	0.457	0	0
SS.SCS.ICS.Slan	49.7*	49.7*	0.703*	0	0
SS.SCS.CCS.PomB	9.49	9.139	0.86	0	0
SS.SCS.CCS.MedLumVen	51.4	23.242	0.457	0	0
SS.SCS.CCS.Blan	51.4	14.132	0.457	0	0
SS.SSa.IFiSa	3.84	13.515	0.725	0	0
SS.SSa.IFiSa.IMoSa	3.84	6.703	0.457	0	0
SS.SSa.IMuSa	30.43	2.657	0.725	0	0
SS.SMx.IMx.CreAsAn	5.78*1	5.78*1	0.3*1	0	0
SS.SMx.OMx.PoVen	51.4	17.242	0.457	30	0.5
SS.SMp.Mrl	49.29	23.768	0.609	200	0.5
SS.SMp.SSgr.Zmar	51.4	17.242	0.609	200*2	0.5*2

*Table 2 – Biomass and P/B measurements assigned to the JNCC biotopes identified in Jersey waters. Biomass measurements are in g/m2. Sources for faunal biomass and P/B are: Le Hir et al. (1986); Retiere (1979); * De Smet et al. (2013); *1 = Leloup et al. (2008). Sources for algae/plant biomass and P/B are: Kermabrun (1984); *2 = Jacobs (1979).*

A literature search for measured sequestration rates within the Normano-Breton Gulf was attempted for this report but produced a paucity of relevant data. However, there are datasets available on the physical properties of marine sediments from around Jersey. Jersey's shallow waters and the availability of habitat, biomass and geophysical data parallels the work of Burrows *et al.* (2017) which assessed the Blue Carbon resource for inshore MPAs in Scotland using sedimentary data to obtain carbon accumulation rates (CARs) for differing benthic habitats. Rather than using data from remote locations, local sedimentary data were used to calculate CARs following the methodology of Burrows *et al.* (2017).

Understanding, quantifying and modelling sediment accumulation rates (SARs) for marine areas is an important prerequisite to being able to model and quantify the net CAR. In general, seabed areas that have a higher SAR will have a higher net CAR as this facilitates the burial and preservation of organic material. To calculate the CAR for individual areas/habitats requires obtaining data relating to sediment: porosity (PU); dry and wet bulk density (g cm-3); carbon content (%C); and annual accumulation rate (cm yr-^{1}).

For Jersey waters, data concerning grain-size distribution, porosity and the bulk density of surface sediments (<20 cm depth) were available from geotechnical reports associated with the emplacement of an undersea cable between Jersey and France (Fugro, 2009). The porosity and bulk density data associated with individual sediment classifications were applied to the biotopes identified during the mapping phase of this project.

Obtaining an accurate sediment accumulation rate (SAR) requires specialist fieldwork using sediment traps and/or the collection of sediment cores which are then dated isotopically using ^{210}Pb or ^{14}C techniques. However, sediment transport, deposition and accumulation may be affected by many localised factors related to biology (bioturbation, growth rates, primary and secondary planktonic production), oceanography (sea level rise, sediment supply, water depth, hydrodynamic regimes, topography), seasonality (storms, wave height) and anthropogenic activity (dredging/trawling, mining, reclamation, deposition). This means that SARs will vary considerably between locations, even within relatively small areas, and so the figures given (and especially those covering wide geographic areas) will often only be an averaged indication of the SAR.

No field-derived SAR data were available for Jersey waters and SAR measurements made regionally were located in coastal estuaries which limits their application to offshore sediments. However, the oceanography and sedimentary regime of the Normano-Breton Gulf has been well-documented and this, together with some approximate figures calculated from sediment core data, were used to estimate SAR rates for Jersey's offshore waters. To achieve this, Jersey's offshore waters were divided into three broad sedimentary regions: (1) hard ground with minimal or no sediment cover; (2) offshore mobile sand areas (often with megaripples) and sandbanks dominated by coarse sediments; and (3) basins where medium to coarse sediments may accumulate to a depth of several tens of metres. The characteristics of these regions are described below.

On areas of 'hard ground', high current velocities, low angle seabed gradients and/or limited sediment supply create patches of permanently or periodically mobile coarse sediments of limited thickness. This will limit permanent sediment deposition and produce annual SARs which are expected to be zero or negligible.

Offshore mobile sand and sandbanks will typically form downstream of topographic obstacles such as rocks, reefs, shoals or islands. The principal areas of mobile sand and sandbanks are to the west and the north of the island where long, linear banks of coarse sand and gravel form south of Guernsey, Sark, Herm and Alderney. Modelling by Le Hir *et al.* (1986) suggests that these banks are unstable and that the surface sediments are subject to movement especially during spring tides.

The mobility of sediment on sandbanks to the north-west of Jersey is confirmed by geophysical studies along the GJ3 subsea electricity cable which recorded patchy, coarse, rippled, mobile sediment of shallow thickness (Jersey Electricity, pers. comm.). With no actual SAR measurements, a token accumulation rate of 0.1 cm yr-^{1} was assumed to allow for a slow baseline accumulation over prolonged time periods deriving primarily from a regional rising sea level trend. Jersey's estimated annual sea level rise is 3 mm, a figure which includes potential tectonic movement (Prime, 2018). Over time this will raise the base of the seabed accumulation and so is a factor within local the SAR.

Smaller linear sandbanks ('banner banks') are associated with inshore areas off Jersey (Corbière and Le Banc du Château), Les Écréhous (L'Écrivière Bank) and Les Minquiers (several examples). The depth and general shape of these banks has been measured by chart makers since the mid-nineteenth century and, with some localised exceptions, their profiles (including height/depth relative to chart datum) have remained consistent to the present day. This suggests that while the sediment that constitutes these banks may be unstable and periodically mobile, the accumulation rate is controlled by hydrodynamic factors that remain constant. As the measured depth has remained consistent for over a century, as with offshore mobile sediments, a low SAR of 0.1 cm yr-^{1} is presumed.

The sedimentary basins that lie to the east and south of Jersey (Les Écréhous and Canger Basins), to the south-east of Les Minquiers (Les Sauvages Basin) and the north of Les Écréhous hold significant sedimentary deposits that are transported from the north and west by tidal currents (Figures 5 and 8; Le Hir *et al.*, 1986; Greenaway, 2001). Geophysical surveys in Les Écréhous Basin have measured sediment thicknesses of 30+ metres (Fugro, 2009) although palaeoenvironmental analyses on long vibrocores suggest that only the top few metres (at most) represent marine sediments deposited during the Holocene Epoch (Figure 4; Chambers and Nichols, 2014).

Studies on these sedimentary cores indicate that sediment is actively accumulating within Les Écréhous Basin where they were taken. No isotopic dates are available for the core material and so an attempt was made to estimate SARs using the American slipper limpet (*Crepidula fornicata*) as a stratigraphic marker. *Crepidula fornicata* is a non-native species which arrived in Europe during the 1870s (States of Jersey, 2017). However, *Crepidula fornicata* was not recorded from the Channel Islands region until the 1970s (Retière, 1979) and was not common until the early 1980s (Bréhaut, 1975; Chambers, 2008). By the mid-1980s *Crepidula fornicata* was well-established and had begun to form expansive biogenic beds off the Brittany and Normandy coasts. These beds often overwhelm pre-existing habitats and present a threat to local biodiversity and fisheries (Blanchard, 1995; Leloup *et al.* 2008; States of Jersey, 2017).

Of the 48 seabed cores taken between the east coast of Jersey and Normandy, 16 had *Crepidula fornicata* specimens buried to a maximum depth of between 2 and 40 cm. To estimate the SAR, it was assumed (using biological records) that *Crepidula fornicata* had become regionally widespread prior to 1980 and that, as the vibrocores cores were taken in 2008, the deepest occurring examples of *Crepidula fornicata* were circa 30 years old. The SAR was calculated by dividing the depth of the deepest *Crepidula fornicata* specimen by 30 to give an approximate accumulation rate in cm yr-^{1}. This produced estimated SARs of between 0.1 and 1.3 cm yr-^{1} with lower SAR figures generally being in cores taken close to the coast of Jersey where sediment thicknesses (measured during the geophysical survey) were shallower (<2 metres). The highest SARs were offshore towards the centre of the Écréhous Basin where geophysical surveys have measured sediment thicknesses between 10 and at least 30 metres. Using the *Crepidula fornicata* data, an average SAR of 0.55 cm yr-^{1} was afforded to sediments within the basin areas.

Confidence in the estimated SAR figures is enhanced by the results from a study of microplastic abundance in the top 50 cm of four of the cores which were (made available to this study just before publication. These show a decreasing concentration of microplastic particulates with increased depth with the deepest recorded microplastics being at a similar depth to the deepest *Crepidula fornicata* specimens. As marine microplastics in general and *Crepidula fornicata* in the NBG are thought to date from the 1960s into the marine environment, this adds weight to SARs being potentially high within Jersey's basin areas (Megan Newstead, pers. comm.).

It is, however, recognised that accurate SAR data is desirable and that obtaining field measurements in relation to this should be a requirement for the development of future Blue Carbon modelling.

2.4 – CAR Calculations

To estimate the weight of carbon buried annually in individual habitats with permanent sediment cover, this report adopted the methodology of Burrows *et al.* (2017) which assesses the top 10 cm of sediment and from this provides estimates for the carbon accumulation rate (CAR), total carbon stock and annual carbon accumulation for a given area of substrate. These calculations were performed on data relating to each of the 250 x 250 metre (0.0625 km^2) polygons that constitute the Jersey benthic biotope map.

A total of 37,055 such polygons were assessed with the calculations being performed twice to accommodate the different sediment biomass figures from the regional studies of Retière and Le Hir *et al.* (see Section 2.2). Although each polygon has an assigned biotope, some of the parameters used in the calculations (such as sediment properties, carbonate content, SAR) were measured or estimated independently from this. The calculation for each square should therefore produce a result that reflects its circumstance and conditions, even if its assigned biotope is the same as neighbouring polygons. Performing 37,055 such calculations for Jersey's territorial waters allows the distribution of the Blue Carbon resource to be modelled in detail, highlighting the role, contribution and importance of individual areas to the overall Blue Carbon budget.

With the CAR calculations complete, the weight of carbon relating to standing stock, stocks, production and burial were summarised collectively for Jersey's territorial seas and then by biotope. These results are described in section 3.0.

Assessment Period	Resource	AVG Carbon (t)	MIN Carbon (t)	MAX Carbon (t)
Any given moment	OC Standing Stock: Fauna	15746	10497	20994
	OC Standing Stock: Plants	87827	87827	87827
	OC Standing Stock: All	103573	97461	109684
	IC Standing Stock	12795944	12795944	12795944
Annual	Production: Fauna	8838	6408	11267
	Production: Plant	82327	82327	82327
	Production: All	91165	88171	94159
	OC Accumulation Rate	1605	855	2355
	OC Burial Rate	1284	684	1884
	Carbon Accumulation: Total	12811	12811	12812
	Carbon Burial: Total	10249	10249	10250

Table 3.1 – A summary of the estimated weight of CO_2 in Jersey's offshore waters. Figures are rounded and expressed in tonnes (t). SS = standing stock. OC = organic carbon. IC = inorganic carbon.

3.0 – Blue Carbon Budgets

An assessment of key Blue Carbon resources was performed for the whole of Jersey's offshore area of 2,313 km² using a grid of 37,055 individual grid polygons with a dimension of 250 x 250 metres (=0.0625 km²). The assessment was performed using the methodology outlined in Section 2.0 on individual grid squares so that the results could be modelled and analysed at a high spatial resolution.

Separate calculations for faunal derived organic carbon were made using the benthic biomass figures from Retière (1979) and Le Hir *et al.* (1986). The difference between these biomass measurements was small with the figures from Le Hir *et al.* usually being higher than those of Retière (Tables 4, 6, 7). For the purposes of further analysis and mapping, the higher biomass measurements by Le Hir *et al.* have been used. The estimated weight of carbon was obtained for the following resource categories:

1 - Organic carbon standing stock (faunal) associated with benthic habitats.

2 - Organic carbon standing stock (algae/plants) associated with benthic habitats.

3 - Inorganic carbon stock (carbonate) associated with benthic habitats.

4 - Annual production of organic carbon (faunal) associated with benthic habitats.

5 - Annual production of organic carbon (algae/plants) associated with benthic habitats.

6 - Annual accumulation and burial (sequestration) of organic carbon associated with benthic habitats.

7 - Annual permanent accumulation of inorganic carbon associated with benthic habitats.

The summary results for the Blue Carbon assessment are given in Tables 3.1 and 3.2 and displayed in Figures 10 and 11. These figures represent the maximum carbon budget for Jersey's offshore territorial waters.

In summary, Jersey's Blue Carbon budget is dominated by the estimated 12.8 Mt standing stock of inorganic carbon. Average production (0.08 Mt) and organic carbon standing stock for algae/plants (0.08 Mt) far exceeds that of benthic fauna (0.009 Mt; 0.01 Mt). The annual weight of buried organic carbon derived from benthic fauna is 0.001 Mt and from inorganic carbon 0.01 Mt. These results are displayed in Figures 10 and 11 and discussed in Sections 3.1 to 3.4 below.

Resource	AVG CO2 (t)	MIN CO2 (t)	MAX CO2 (t)
OC Standing Stock: Fauna	57786	38523	77049
OC Standing Stock: Plants	322326	322326	322326
OC Standing Stock: All	380112	357681	402542
IC Standing Stock	46961114	46961114	46961114
Production: Fauna	32434	23518	41350
Production: Plant	302141	302141	302141
Production: All	334575	323587	345564
OC Accumulation Rate	5889	3137	8641
OC Burial Rate	4711	2510	6913
Carbon Accumulation: Total	47018	47015	47020
Carbon Burial: Total	37614	37612	37616

Table 3.2 – The estimated equivalent CO_2 *in Jersey's offshore waters based on the weight of carbon. Figures are expressed in tonnes (t).* CO_2 *equivalent conversion factor: one tonne carbon = 3.667 tonnes* CO_2*.*

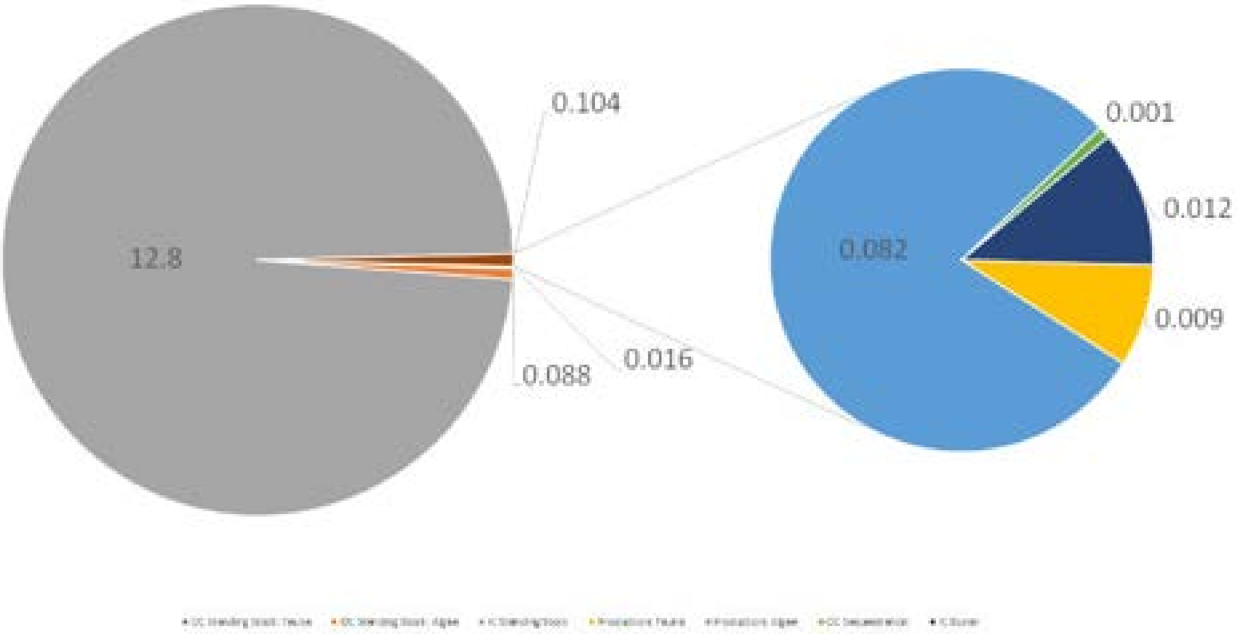


Figure 10 – The Blue Carbon budget (weight: Mt) for Jersey's subtidal territorial seas. This illustrates the dominance of inorganic carbon standing stock in comparison to other resources. The total weight of inorganic carbon stock (12.8 Mt) is more than the combined weight of all other resources.

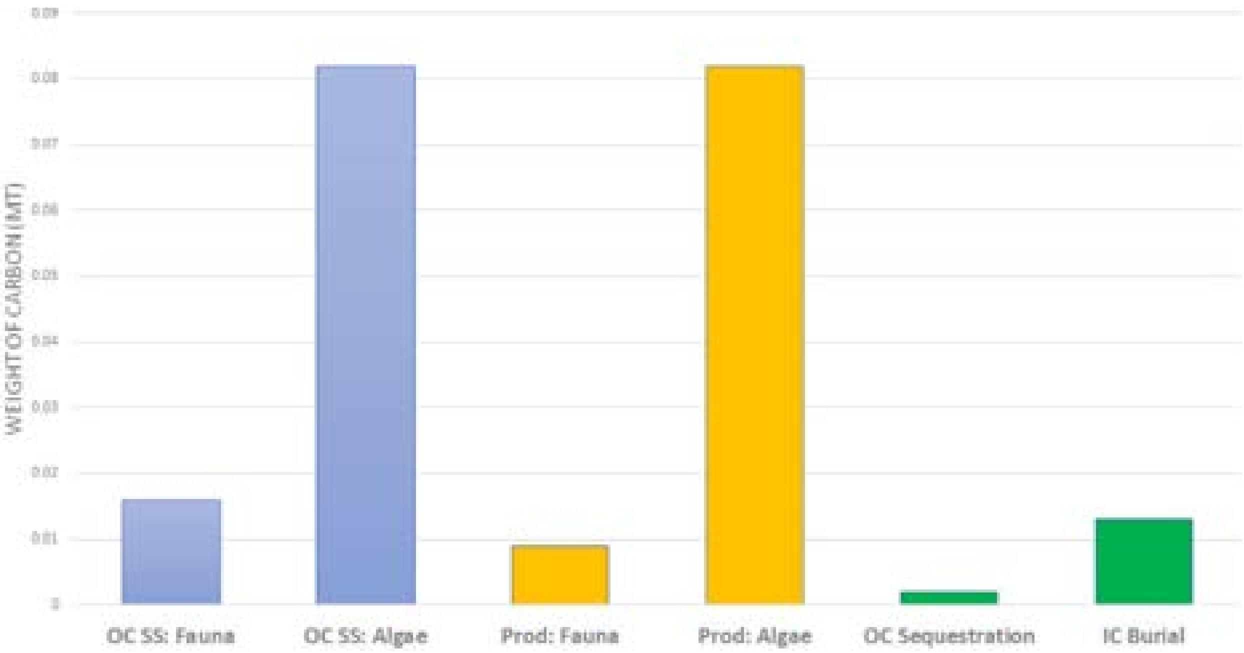


Figure 11 – The weight of carbon (Mt) for standing stock (SS; organic carbon only), production (Prod) and accumulation (Seq). (Due to its large size, the figure for inorganic carbon standing stock is omitted to allow a visual comparison of the other resources.)

3.1 – Organic Carbon Standing Stock

The standing stock of organic carbon represents the weight of carbon stored in the flesh of living plants and animals at any given point in time. The average total standing stock of organic carbon for Jersey's waters is estimated to be 103,574 tonnes (0.104 Mt). Of this, around 80% (87,827 t; 0.088 Mt) derives from living algae (primarily seaweeds but also seagrass) as these may grow rapidly to a large size, occur in dense stands and occupy large geographic areas (e.g. kelp forests). Habitats dominated by kelp (*Laminaria* spp.; IR.MIR.KR.Lhyp and IR.MIR.KR.Lhyp.Pk) are particularly important and account for 53% of the total plant carbon standing stock. The non-plant derived organic carbon standing stock is small by comparison (average: 15,747 t; 0.016 Mt) and stored in the flesh of invertebrates (e.g. worms, molluscs, crustaceans, etc.) and other creatures living in or on the seabed.

The distribution of the standing stock for inorganic carbon in in Jersey's territorial seas is shown in Figure 12 and the weight for each JNCC biotope is given in Table 4. The lowest organic carbon standing stock is found in deeper water (>25 metres) biotopes with little or no permanent sediment (e.g. CR.HCR.Xfa). In these biotopes organic carbon is mostly stored in encrusting organisms (such as corals, bryozoans, sponges, etc.) or in beds of sessile species such as brittlestars. Conversely, biotopes that hold the highest standing stock of organic carbon tend to be within the photic zone with key factors being suitability for dense kelp growth (or other seaweeds) or, to a lesser extent, the accretion of stable sediment promoting a diversity of infauna such as worms, bivalves, burrowing crustaceans, etc. (Figure 10).

JNCC Biotope	Area (Km2)	SS: benthic Fauna (t)			SS: Plants (t)
		Minimum	Maximum	Average	
IR.HIR.Ksed	89.1	126	220	173	1966
IR.HIR.KSed.XKScrR	185.5	284	497	291	33397
IR.MIR.KR.Lhyp	74.3	272	–	–	33444
IR.MIR.KR.Lhyp.Pk	54.1	198	–	–	13783
CR.HCR.Xfa	414.9	1202	1517	1359	0
SS.SCS.ICS.MoeVen	53.2	367	1095	731	1278
SS.SCS.ICS.Glap	284.1	1606	5840	3723	0
SS.SCS.ICS.Slan	14.4	287	–	–	0
SS.SCS.CCS.PomB	463.2	1693	1758	1726	0
SS.SCS.CCS.MedLumVen	90.1	838	1853	1346	0
SS.SCS.CCS.Blan	275.9	1559	5672	3616	0
SS.SSa.IFiSa	4.0	6	21	14	0
SS.SSa.IFiSa.IMoSa	196.6	302	527	415	0
SS.SSa.IMuSa	0.3	0	4	2	0
SS.SMx.IMx.CreAsAn	18.2	42	–	–	0
SS.SMx.OMx.PoVen	42.6	294	876	585	384
SS.SMp.Mrl	56.4	536	1111	824	3382
SS.SMp.SSgr.Zmar	3.2	22	66	44	193
Total	**2313**	**10496**	**20994**	**15747**	**87827**

Table 4 – The estimated weight of organic carbon (tonnes) held as standing stock (SS) for benthic fauna and plants within JNCC benthic habitats. Estimates for the minimum, maximum and average benthic fauna estimated weights reflect the different biomass measurements found in Le Hir et al. (1986) and Retière (1979). Other figures are totals derived from single biomass measurements.

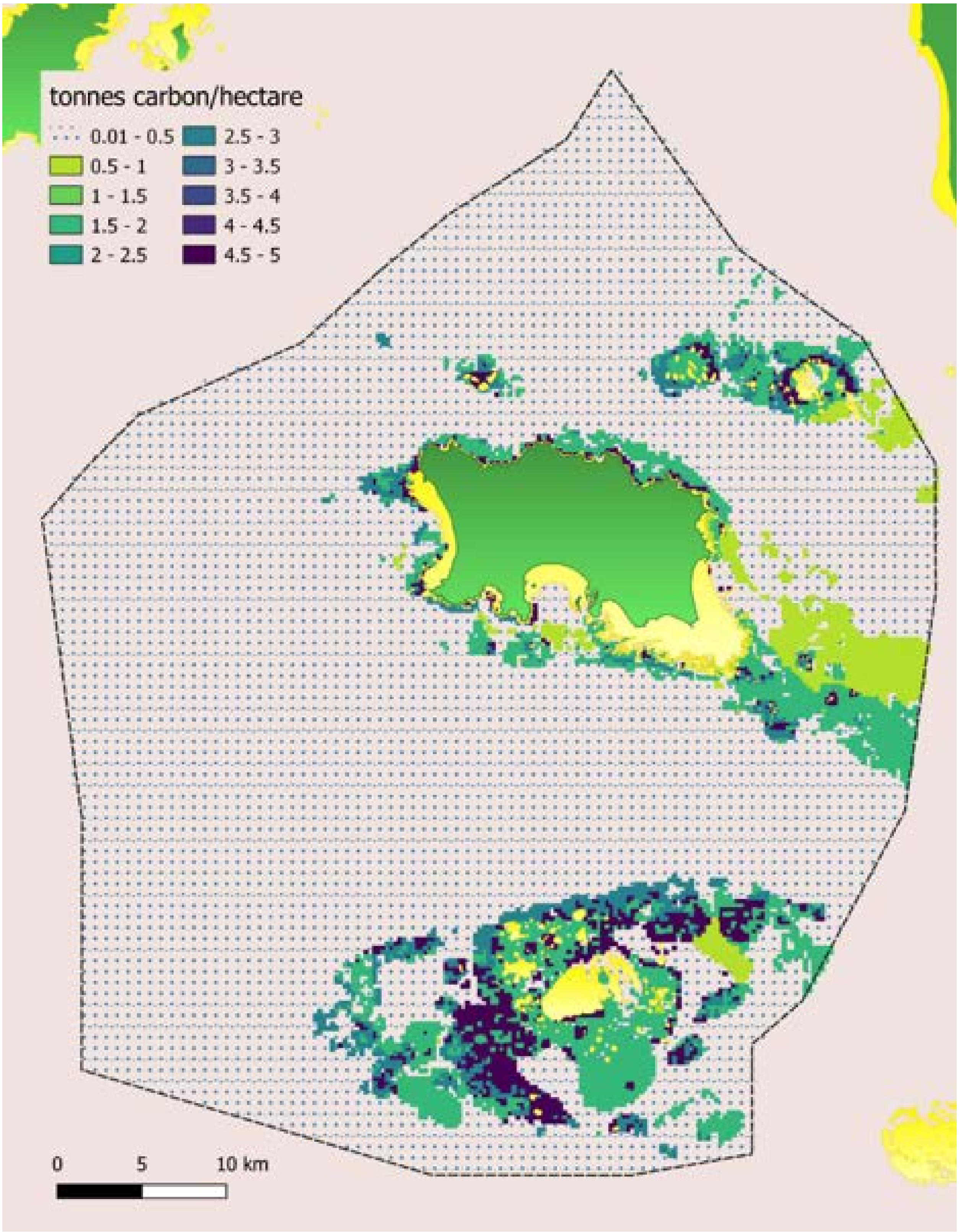


*Figure 12 – Distribution of the organic carbon standing stock (tonnes/ha) in Jersey's territorial waters using averaged biomass figures (see Table 3). The greatest concentration of stock is around the coast of Jersey and on the shallow water rocky areas of Les Minquiers, Les Écréhous and other offshore reefs. This reflects the weight of carbon held in seaweeds, especially kelp (*Laminaria *spp.) which form dense forests in shallow marine rocky habitats. By comparison to plants, the weight of carbon held in living animals is small.*

3.2 – Inorganic Carbon Standing Stock

The total standing stock of inorganic carbon represent the weight of carbon held in the carbonate that forms shells, tests and other organically derived debris. In Jersey's territorial seas this stock is estimated at 12.8 Mt which is over a hundred times greater than the estimated standing stock of organic carbon. The high weight of inorganic carbon reflects the high carbonate content of local sediments which, in turn, reflects a high rate of biological productivity in Jersey's seas and strong tidal currents which may transport shell material and debris considerable distances.

Inorganic stock contains carbon that is held within the carbonate of shells, tests, corals, etc., and whereas the organic carbon in living organisms will readily degrade and disperse, more durable carbonate material may remain intact for years or even decades. For example, empty native oyster (*Ostrea edulis*) shells caught during the early nineteenth century may still be found on Jersey's seashore even though the beds they came from were fished out in the 1860s.

The distribution of the standing stock for inorganic carbon in in Jersey's territorial seas is shown in Figure 13 and the weight for each JNCC biotope is given in Table 5. Of the total weight of inorganic carbon, 73% (9.3 Mt) derives from three biotopes (SS.SCS.ICS.Glap, SS.SCS.CCS.Blan, SS.SSa.IFiSa.IMoSa). These are dominated by coarse sediment, often in high energy settings. Considerable quantities of loose carbonate material may be swept in to accumulate in these areas producing deposits that are rich in shell and other debris (See Section 4.2; Hommeril, 1967). Another notably rich source of inorganic carbon is maerl beds, some of which are composed of nearly 100% calcareous algae. Maerl is important both from a Blue Carbon and is internationally recognised for its beneficial ecosystem services and natural capital value (Blampied, 2015). For example, maerl occupies just 2.4% of Jersey's seabed area but contribute 5.4% (0.7 Mt) to the total standing stock of inorganic carbon.

Other notable biotopes are those with a high bivalve content such as IR.HIR.KSed.XKScrR and SS.SCS.CCS.MedLumVen (0.5 Mt each). The least rich biotopes are those dominated by hard substrates (including kelp forest) or fine-grained sediments which, through mobility or low energy, receive relatively little extraneous shell debris.

JNCC Biotope	Area (Km^2)	SS: Inorganic Carbon (t)
IR.HIR.Ksed	81.9	115921
IR.HIR.KSed.XKScrR	185.5	507516
IR.MIR.KR.Lhyp	74.3	113
IR.MIR.KR.Lhyp.Pk	54.1	0
CR.HCR.Xfa	414.9	0
SS.SCS.ICS.MoeVen	53.2	618422
SS.SCS.ICS.Glap	284.1	3188484
SS.SCS.ICS.Slan	14.4	81778
SS.SCS.CCS.PomB	463.2	0
SS.SCS.CCS.MedLumVen	90.1	532978
SS.SCS.CCS.Blan	275.9	3980700
SS.SSa.IFiSa	4.0	17932
SS.SSa.IFiSa.IMoSa	196.6	2170761
SS.SSa.IMuSa	0.3	1596
SS.SMx.IMx.CreAsAn	18.2	210020
SS.SMx.OMx.PoVen	42.6	628821
SS.SMp.Mrl	56.4	708765
SS.SMp.SSgr.Zmar	3.2	32136
Total	**2313**	**12795943**

Table 5 – The estimated weight of inorganic carbon (tonnes) present as standing stock in Jersey's offshore JNCC benthic habitats.

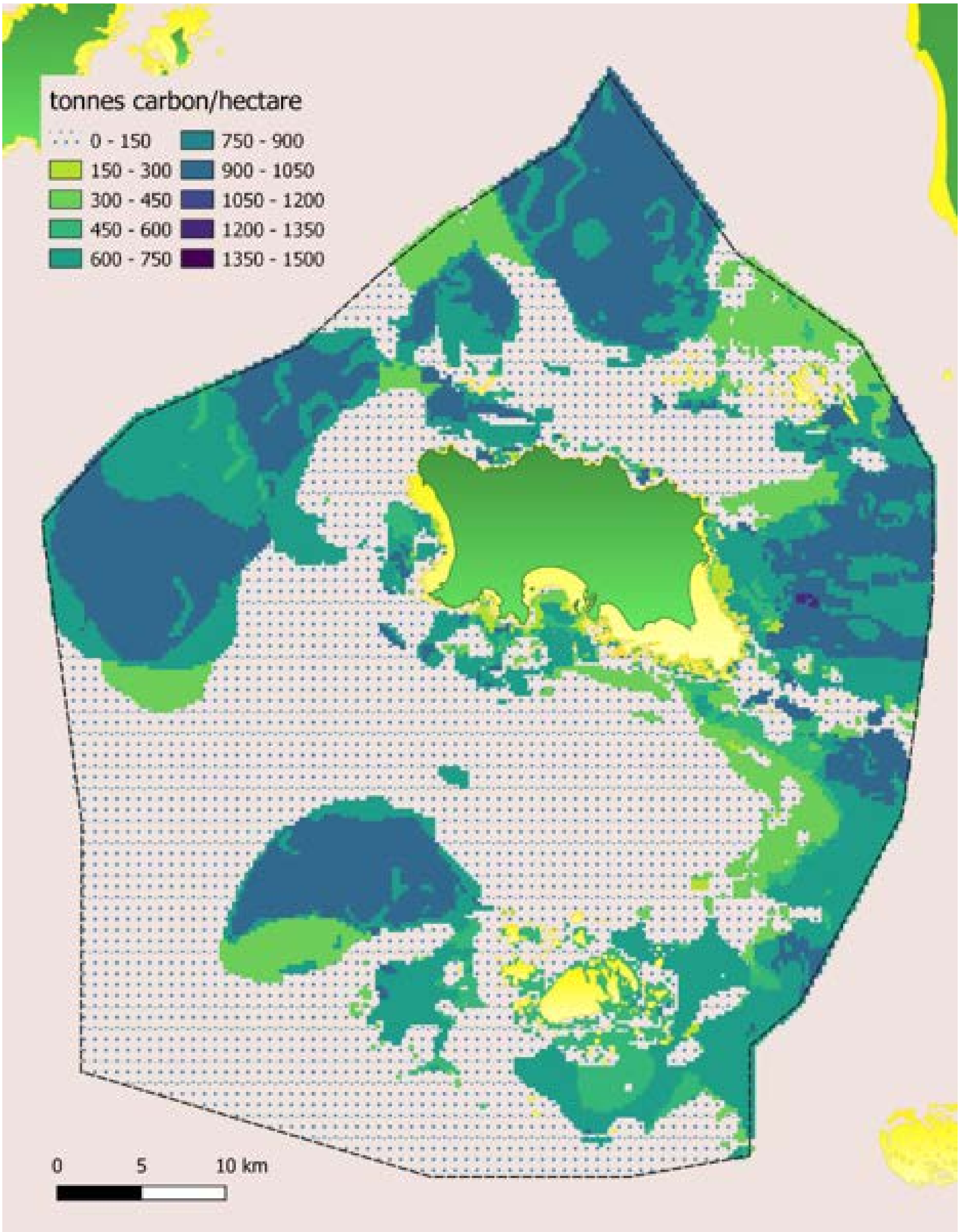


Figure 13 –The distribution of inorganic carbon stock (tonnes/ha) in Jersey's territorial waters. A majority of inorganic carbon will be stored as calcium carbonate in the shells, tests and skeletons of animals as well as in some species of calcareous seaweed, such as maerl. After death the hard parts of animals may survive on the seabed for many years or decades which means that much of the carbon stored in shells, etc., may have been generated historically. Both contemporary and historical inorganic carbon are associated with sedimentary areas where carbonate will accumulate with sands and gravels (see Figure 6)

3.3 – Annual Production

The annual production of carbon represents the weight of new carbon that is created each year through biological reproduction and the growth of plants and animals. This is an important process as the growth of plants and animals incorporates carbon into body tissues and shells. This process mineralises atmospheric-derived carbon making it potentially available for later burial although, in practice, most will not be buried but recycled through attrition, consumption and decomposition. The estimated weight of annual production organic carbon (plant and faunal) for Jersey's territorial seas is 91,164 tonnes (0.091 Mt).

The geographic distribution of this resource is shown in Figure 14 and the weight is broken down by biotope in Table 6. The reproduction and growth of marine plants (seaweeds and seagrass) are responsible 87% (82,327 t; 0.08 Mt) of total annual production. This weight reflects the high growth rate of plants, their large size/weight and their high density. The important biotopes are associated with shallow water fringes of rocky reefs and especially those with a high density of kelp (IR.MIR.KR.Lhyp; IR.MIR.KR.Lhyp.Pk) or other brown seaweeds (IR.HIR.KSed.XKScrR). Maerl (SS.SMp.Mrl), which is dense and widespread, is also a notably productive benthic biotope.

The weight of carbon related to animal growth is considerably lower than plants at around 8,837 tonnes (0.008 Mt). This reflects a slower growth rate in animals (relative to plants), their generally smaller size (e.g. most marine animals are invertebrates) and their density which may be constrained by factors such as food supply, substrate, habitat capacity, etc. Important habitats are generally sedimentary in nature where animals can live on and inside sand, gravel and other loose substrates. Some harder substrates, such as CR.HCR.Xfa, have a high annual production total but low levels of growth because of the large areas of seabed they occupy (Figure 14).

JNCC Biotope	Area (Km^2)	Production: benthic Fauna (t)			Production: plants (t)
		Minimum	Maximum	Average	
IR.HIR.Ksed	81.9	73	128	101	983
IR.HIR.KSed.XKScrR	185.5	166	291	228	50096
IR.MIR.KR.Lhyp	74.3	133	134	134	21738
IR.MIR.KR.Lhyp.Pk	54.1	97	–	–	6892
CR.HCR.Xfa	414.9	1033	1304	1169	0
SS.SCS.ICS.MoeVen	53.2	224	667	445	639
SS.SCS.ICS.Glap	284.1	734	2669	1701	0
SS.SCS.ICS.Slan	14.4	202	–	–	0
SS.SCS.CCS.PomB	463.2	1456	1512	1484	0
SS.SCS.CCS.MedLumVen	90.1	383	847	615	0
SS.SCS.CCS.Blan	275.9	713	2592	1652	0
SS.SSa.IFiSa	4.0	4;	16	10	0
SS.SSa.IFiSa.IMoSa	196.6	138	241	189	0
SS.SSa.IMuSa	0.3	0	3	1	0
SS.SMx.IMx.CreAsAn	18.2	13	–	–	0
SS.SMx.OMx.PoVen	42.6	134	400	267	192
SS.SMp.Mrl	56.4	326	677	502	1691
SS.SMp.SSgr.Zmar	3.2	13;	40	27	96
Total	**2313**	6404	11267	8837	82327

Table 6 – The estimated weight of organic carbon (tonnes) produced annually in Jersey offshore waters for fauna and algae/plants in JNCC benthic habitats.Estimates for the minimum, maximum and average benthic fauna estimated weights reflect the different biomass measurements found in Le Hir et al. *(1986) and Retière (1979). Other figures are totals derived from single biomass measurements.*

3.4 – Annual Carbon Accumulation and Burial

The annual weight of carbon that can accumulate in sedimentary habitats is of particular interest to climate scientists as the eventual burial of carbon derived from the natural environment prevents it from being recycled back into the atmosphere. Measuring and conserving the carbon accumulation/ burial potential of natural environments is therefore a key process in the reduction atmospheric greenhouse gases. It is this potential that underpins the documentation and accreditation of natural habitats and ecosystems for carbon offsetting purposes.

Conversely, the destruction or disruption of habitats with a high accumulation potential (e.g. mangrove forests, maerl beds and seagrass) will not only reduce the potential for greenhouse gas reduction but possibly reactivate buried carbon allowing it to return to the atmosphere (Atwood *et al.* 2020).

The average weight of organic carbon that accumulates annually in Jersey's seas is estimated at 1,604 tonnes (0.0016 Mt). However, carbon that accumulates within surface sediment layers can be reactivated by disturbance from storms, tidal currents, fishing gear, etc. The loss of accumulated carbon in sediment due to degradation is expressed as the percentage of superficial organic carbon that becomes permanently buried (sequestered). This percentage is called burial efficiency and for this study a figure of 20% was applied to the OCAR based on the study by Smeaton, Yang and Austin (2021).

JNCC Biotope	Area (Km^2)	Burial: organic carbon (t)			Burial: inorganic carbon (t)
		Minimum	Maximum	Average	
IR.HIR.Ksed	81.9	5	9	7	116
IR.HIR.KSed.XKScrR	185.5	3	5	4	508
IR.MIR.KR.Lhyp	74.3	0	–	–	0
IR.MIR.KR.Lhyp.Pk	54.1	0	–	–	0
CR.HCR.Xfa	414.9	0	–	–	0
SS.SCS.ICS.MoeVen	53.2	87	260	174	618
SS.SCS.ICS.Glap	284.1	157	572	365	3188
SS.SCS.ICS.Slan	14.4	31	–	–	82
SS.SCS.CCS.PomB	463.2	0	–	–	0
SS.SCS.CCS.MedLumVen	90.1	199	320	320	533
SS.SCS.CCS.Blan	275.9	61	222	142	3981
SS.SSa.IFiSa	4.0	1	3	2	18
SS.SSa.IFiSa.IMoSa	196.6	13	23	18	2171
SS.SSa.IMuSa	0.3	1	–	–	2
SS.SMx.IMx.CreAsAn	18.2	5	–	–	210
SS.SMx.OMx.PoVen	42.6	64	190	127	629
SS.SMp.Mrl	56.4	55	115	86	709
SS.SMp.SSgr.Zmar	3.2	2	2	5	32
Total	**2313**	**683**	**1883**	**1284**	**12797**

Table 7 – The estimated weight of carbon (tonnes) sequestered annually in Jersey offshore waters in JNCC benthic habitats.Estimates for the minimum, maximum and average benthic fauna estimated weights reflect the different biomass measurements found in Le Hir et al. (1986) and Retière (1979). Other figures are totals derived from single biomass measurements Note: the organic carbon figures represent the burial of carbon derived directly from living fauna; organic carbon from particulate or dissolved sources (such as seaweed debris) are not included (see Section 5.2).

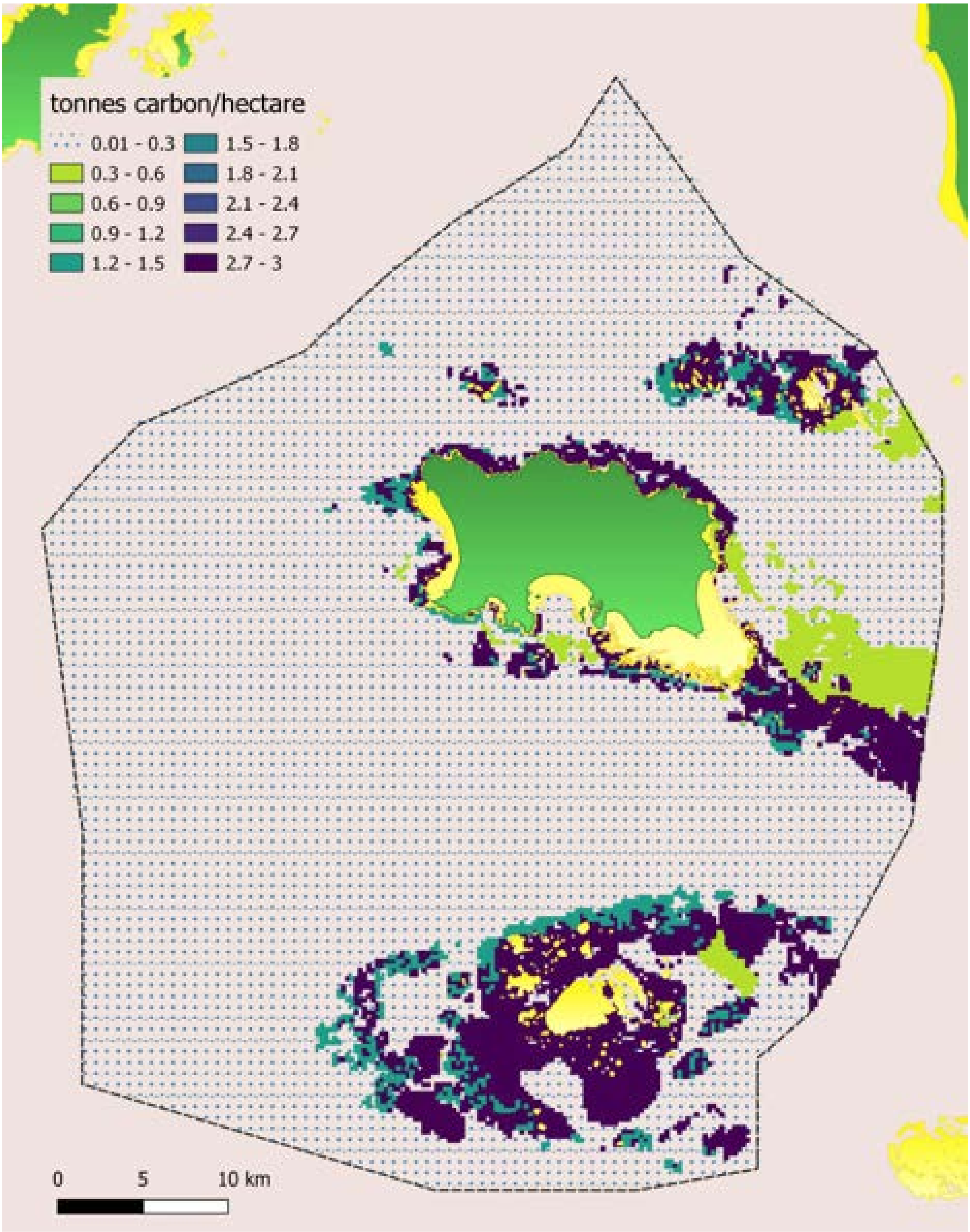


Figure 14 – Annual carbon production (tonnes/ha) in Jersey's territorial seas. The highest concentration of carbon production is in seabed areas with dense brown seaweeds such as kelp. This means that there is a high correlation between the weight of organic carbon held as standing stock (Figure 12) and the annual weight of carbon produced via new growth. Shallow water rocky areas such as Les Minquiers, Les Écréhous and other offshore reefs will produce a high annual weight of carbon via growth whereas the the weight of carbon produced in sedimentary and deeper water areas (where seaweeds are scarce or less dense) is comparatively small.

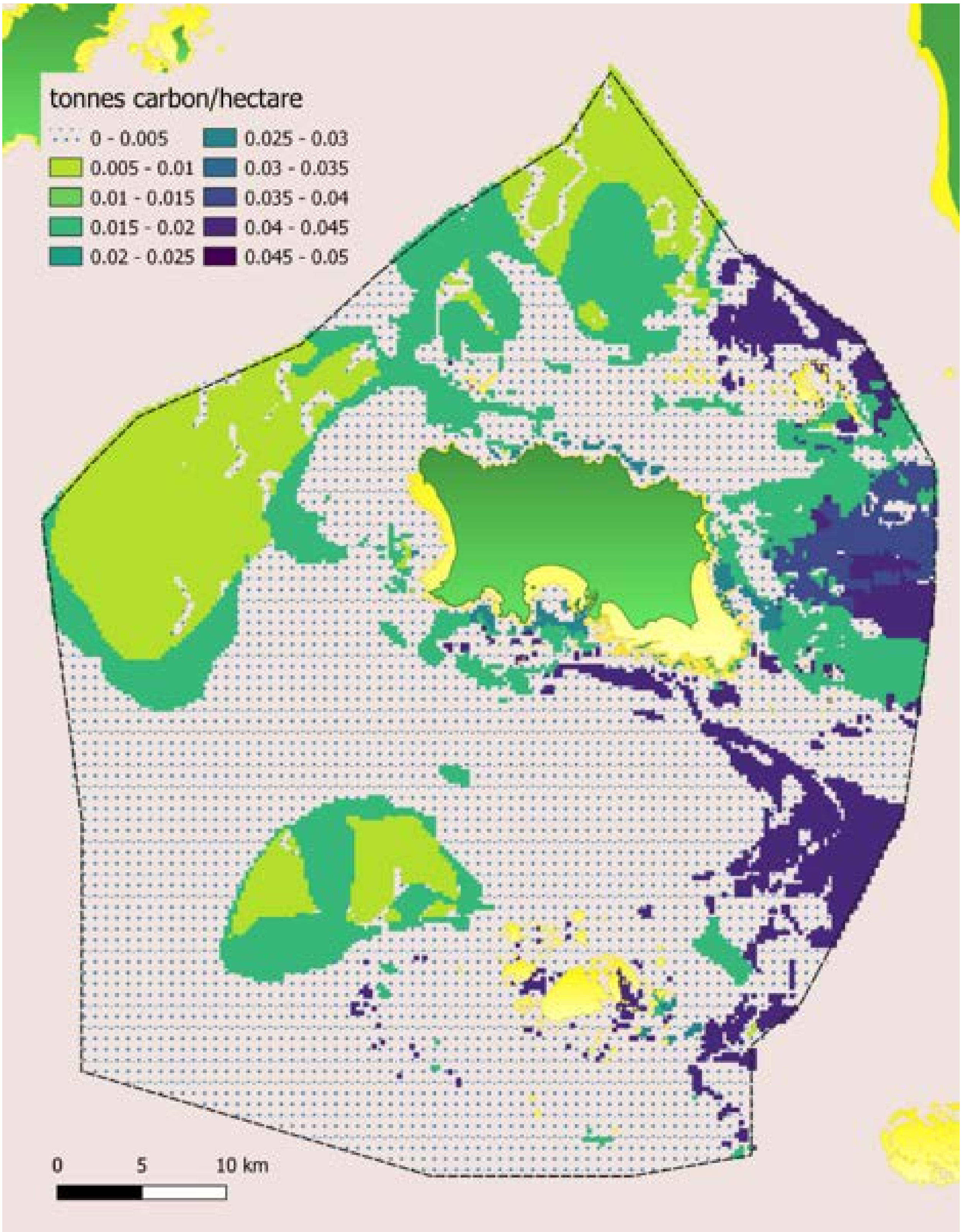


Figure 15 – Annual carbon accumulation (tonnes/ha) in Jersey's territorial seas. Accumulation potential reflects a combination of biodiversity, production and sedimentation with the highest rates being concentrated in the three sedimentary basins indicated in Figure 3. Lower rates of accumulation are associated with offshore areas of unstable sand and gravel where production and burial rates are lower.

Within Jersey waters it is only sedimentary habitats that can effectively accumulate carbon as areas of bedrock, boulders and cobble have little or no sediment cover to bury and preserve carbon. Even within sedimentary habitats, it is only those with a moderate to high accumulation rate (see Section 2.3) that will be effective at permanent burial as in mobile or semi-permanent sedimentary biotopes any accumulated carbon may be re-exposed and recycled back into the marine environment.

The total weight of carbon accumulated in Jersey's marine sediments is 12,811 tonnes (0.013 Mt). Of this, 12.5% (1,604 t) originates from the organic carbon and 97.5% (11,207 t) from inorganic carbon stored mainly as carbonate within shell material. With a burial efficiency of 20%, the weight of accumulated organic carbon that is permanently buried (sequestered) annually is between 683 and 1,182 tonnes (average = 1,284 t). [3]

The dominance of individual sedimentary habitats is reflected in the weight of buried carbon given in Table 7 and geographic distribution of accumulated carbon in Figure 15. It is those habitats with a combination of high biodiversity (and therefore production) and a high sediment accumulation rate that have the greatest potential for carbon accumulation and burial. This includes offshore clam beds (e.g. SS.SCS.ICS.MoeVen and SS.SCS.CCS.MedLumVen) and biodiverse sedimentary habitats that occupy large areas of seabed (e.g. SS.SCS.ICS.Glap and SS.SCS.CCS.Blan).

Some of the marine habitats in Jersey, such as seagrass, have been recognised elsewhere for their high sequestration potential. However, they occupy a relatively small area (3 km^2 for offshore seagrass) and so, while effective, their ability to sequester carbon relative to the territorial sea area is small. Other key habitats, such a maerl, are suspected to have a high potential for carbon burial (much of it inorganic) and can cover larger areas of seabed but are not presently recognised for the purposes of international carbon budgeting (see Section 5.2.4).

Additional to *in situ* organic carbon within a biotope may be an accumulated weight of organic carbon derived from detritus swept into the biotope from elsewhere. The weight contribution of detritus may be significant but is not considered here as no data are available. This is recognised as an area that requires further research (see Sections 4.2 and 5.2).

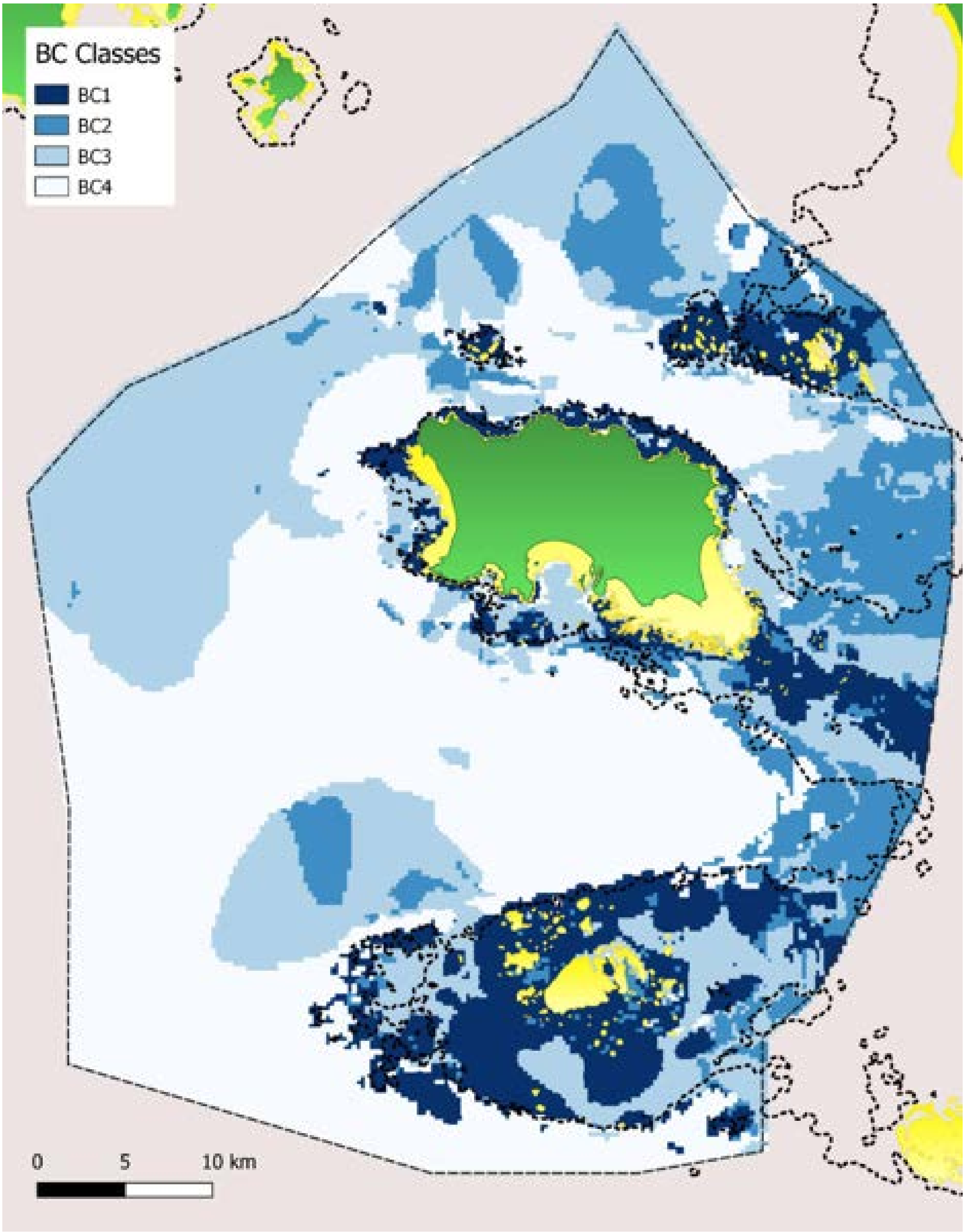


Figure 16: The geographic distribution of the four Blue Carbon classes (BC1 to BC4) identified through cluster analysis (see Table 8). The dashed line represents the 15 metre isobath. See Figure 17 for maps of the individual BC classes.

4.0 – Blue Carbon Resources

Marine biotopes/habitats are defined largely by their geotechnical attributes and by associated key species. This means that the distribution of Blue Carbon resources (which are formed from a combination of biological and geological/geotechnical processes) in Jersey waters is also reflective of the distribution of biotopes.

This close association between Blue Carbon and biotopes is not an artefact of the assessment process but a reflection of the high degree of control that individual biotopes have over their production, standing stock and storage. For example, dense seaweed habitats, such as kelp forests, will be a major source of carbon production and standing stock through high plant density and growth rates. However, due to a lack of accumulating sediment, kelp forests are unable to bury much of the organic carbon they produce. Conversely, productive accumulating sedimentary habitats such as maerl beds and basin sands have more potential to produce and bury organic and inorganic carbon derived both from within the habitat but also washed in from elsewhere (e.g. kelp forests).

The link between defined terrestrial habitats and their carbon potential is already well-documented and the same is true for selected coastal fringe habitats such as seagrass meadows, mangrove swamps and saltmarsh. Obtaining similar recognition for Blue Carbon resources in other shallow marine and offshore habitats has become a priority for marine science communities working in climate change sectors. Recognition of a link between benthic habitats and Blue Carbon resources is important when interpreting the results from assessments such as this one but also when it comes to the future management of carbon for offsetting and capitalisation purposes (IUCN, 2021).

The importance of biotopes/habitats in Blue Carbon budgeting has emerged from multiple desktop and physical studies across the globe (Barnes *et al.*, 2019; Barnes and Sands, 2017; Burrows *et al.*, 2021). Being able to link Blue Carbon resources to a habitat type provides a means by which the distribution of and potential for such resources may be estimated and evaluated. This can assist with the design of field studies plus the rapid identification of and mitigation of potential threats to key Blue Carbon habitats.

As well attempting to understand Jersey's Blue Carbon potential, this assessment set out to examine the geographic distribution of these resources and to identify patterns and areas of notable importance. The results as described in Section 3.0 suggest that there is considerable potential for Jersey's Blue Carbon resources and that these are formed from a complex network of biotopes each with differing Blue Carbon properties. Making sense of such a complex network is not simple and so the Blue Carbon resources from Section 3.0 were statistically grouped so that the key functions of individual geographic areas can be more easily identified and assessed.

4.1 – The Distribution of Blue Carbon Resources in Jersey Waters

The results outlined in Section 3.0 were classified into groups with similar Blue Carbon properties to create a simplified spatial model that can assist with the identification, interpretation and assessment of Jersey's Blue Carbon resources including against potential threats.

The results were analysed using a k-means cluster analysis, based on individual polygon figures for: total organic carbon production; organic carbon accumulation; and inorganic carbon accumulation. Results for the total standing stock and productivity were highly correlated and so the former was omitted from the analysis. The total within-cluster sum of squares suggested the optimal number of clusters (k) to be four.

The four clusters identified from the analysis have been labelled Class BC1 to Class BC4. The cluster analysis centroid values in Table 8 indicate whether the average value for organic carbon production, organic carbon accumulation and inorganic carbon accumulation for each BC class is above or below the overall mean. This means the centroid values may be used to indicate the relative influence of each of these three parameters within the four classes. A description of each cluster's characteristics is given below with their distribution being shown in Figures 16 and 17.

4.1.1 – Class BC1: High production; low accumulation

Class BC1 represents biotopes with high productivity/standing stock for organic carbon but a low productivity /standing stock for inorganic carbon plus a low accumulation potential.

Class BC1 is dominated by biotopes that are rich in large, fast-growing seaweed species such as kelps and wracks and therefore also have a high production rate and a high standing stock of organic carbon. These seaweed species attach to hard substrates, such as bedrock or boulders, and need to have access to sunlight which restricts BC1 habitats to shallow water (generally <15 metres below chart datum) rock and rock fringe areas. Notably important BC1 areas are Jersey's coastal rock fringe (especially the north and west of the island) and the offshore reefs (Figures16, 17A). These areas generally lack sediment cover.

High annual production and low accumulation in Class BC1 suggests that much of the organic carbon standing stock within living seaweeds will be exported into other areas in the form of detritus and particulates (i.e. dissolved organic and particulate organic carbon). This suggests that much of the organic carbon generated in BC1 areas may be being swept elsewhere to be recycled or accumulated (e.g. see Krause-Jensen *et al.* 2018). Modelling the quantity, movement and destination of organic carbon within debris or particulates is complex and beyond the scope of this report but it is acknowledged that this is an area where further research would be highly beneficial (see Section 4.2).

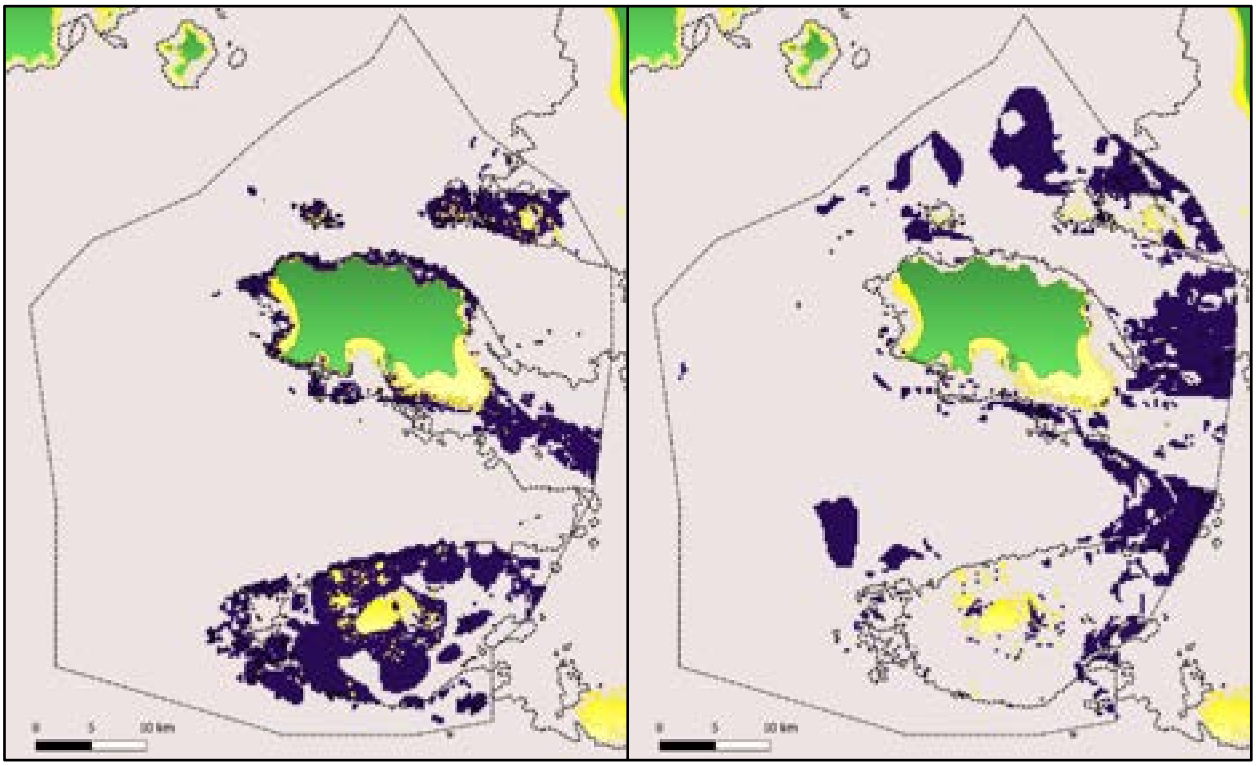
4.1.2 – Class BC2: High OC and moderate IC accumulation

Class BC2 represents sedimentary biotopes which have a high accumulation potential but usually only moderate productivity and a low organic carbon standing stock. Class BC2 areas are geographically well-defined and dominated by stable sedimentary habitats with moderate to high carbonate content, SAR and productivity (Figures16, 17B). These areas may be notably biodiverse and include important biogenic biotopes such as maerl and clam beds.

The effective long-term sequestration of carbon requires the burial of organic carbon to a depth or position where it may be permanently trapped and cannot re-enter the marine environment. This usually requires habitats that are actively accumulating sediment, or which have associated processes (such as the growth of seagrass) that can lock away carbon. In Jersey these conditions are met only inside the island's sedimentary basins where tectonics, tidal currents and a rising sea level combine to raise the erosion base slowly over time.

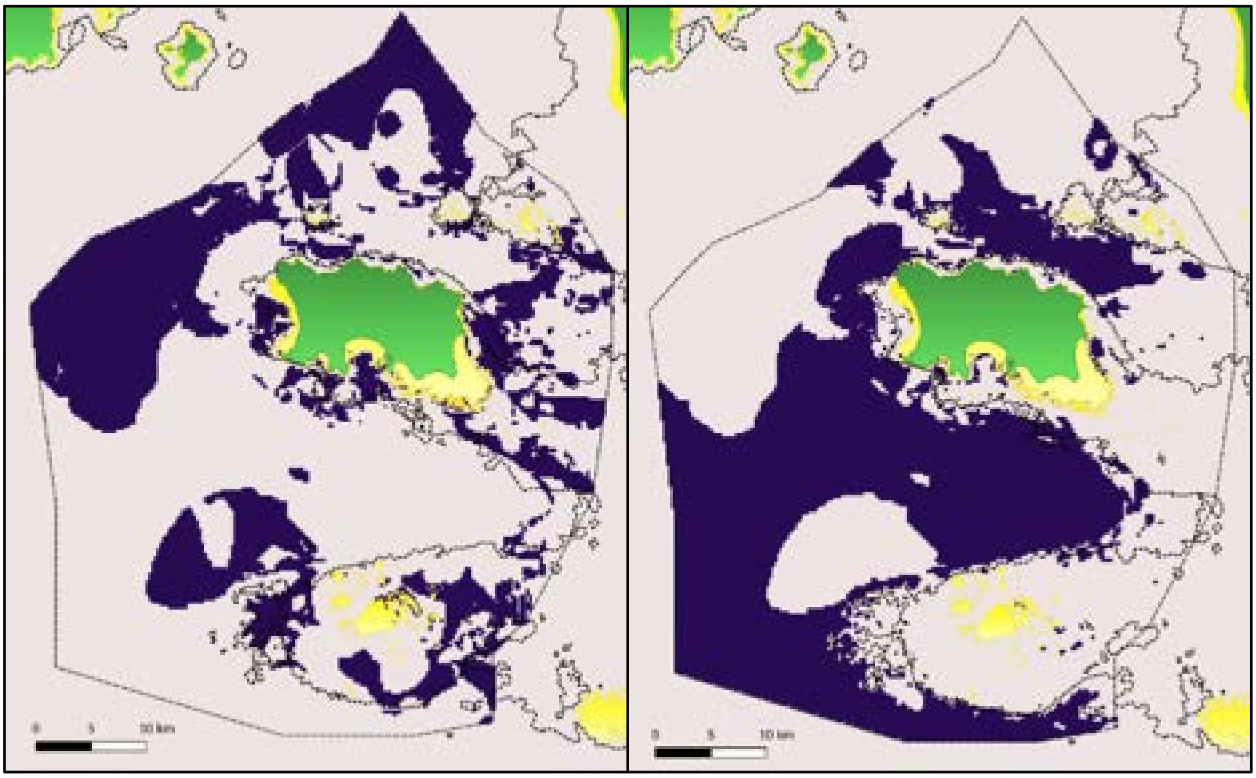
Class	Production/SS: OC	Burial: OC	Burial: IC	No. Polygons
Class BC1	2.8	-0.6	-0.6	5,047 (13.6%)
Class BC2	-0.4	2.1	1	4,773 (12.9%)
Class BC3	-0.4	0.3	1.1	11,773 (31.8%)
Class BC4	-0.5	-0.7	-0.9	15,462 (41.7%)

Table 8 - Coordinate values obtained from a k means cluster analysis for OC production, OC burial and IC accumulation. The standing OC stock value has a high correlation with OC production and was omitted from the analysis. The values are z-score standardised and are relative to the overall mean. The four clusters (classes) are labelled as Classes BC1 to BC4 with the right column displaying the number of polygons within each class.



Map A - Class BC1: high production

Map B - Class BC2: high OC accumulation



Map C - Class BC3: high IC accumulation

Map D - Class BC4: low production

Figure 17 - Four charts showing the geographic extent for each of the BC classes in Figure 16.

The accumulation rate is to a large degree controlled by undersea topography and Class BC2 areas are largely restricted to Jersey's sedimentary basins and the stable sedimentary areas to the north of Les Écréhous and Dirouilles (Figure 16). Of these, it is three sedimentary basins that are notably important for their ability to accumulate carbon. From north to south, these are: (1) Les Écréhous Basin; (2) Canger Basin; and (3) Sauvages Basin. All three basins contain a mix of high energy sands and gravels which may have a high carbonate content due to shell debris. Some of these basins also contain seagrass, clam beds and biogenic sediments such as maerl.

Class BC2 areas contain notable Blue Carbon resources (accumulated carbon and, in maerl and seagrass areas, significant organic and inorganic carbon standing stocks) and are associated with a wide range of beneficial biological, physical and socioeconomic ecosystem services (Blampied, 2015; Chambers *et al.* 2016). This will afford Class BC2 areas a high natural capital value and, while all Jersey's marine biotopes will have a beneficial value, it is suspected that those in the basin areas probably represent the most important in terms of overall ecosystem service provisioning (Marine Resources pers. comm.).

4.1.3 – Class BC3: High IC accumulation

Class BC3 represents habitats with a low production/standing stock for organic carbon, a low accumulation potential but with a high standing stock for inorganic carbon. BC3 sedimentary habitats contain the greatest standing stock of carbon (by weight) in Jersey waters, almost all of which is inorganic in nature and mostly derived from legacy and/or reworked carbonate material.

Organic carbon stored within the flesh of living plants and animals can be readily mobilised, broken down and recycled/accumulated in the marine environment. However, inorganic carbon occurs as the carbonate which forms shells, bones, tests, etc., and is more stable and durable. Inorganic carbon will often outlive the death of the animal or plant which generated it and may survive in the marine environment for years or even decades. As such (and in general contrast to organic carbon) the standing stock of inorganic carbon in Jersey waters may represent a legacy from historical biological growth with only a small fraction being attributable to contemporary production.

JNCC Biotope	Total	Class BC1	Class BC2	Class BC3	Class BC4
IR.HIR.Ksed	3.54	0	0	0.29	3.25
IR.HIR.KSed.XKScrR	8.03	8.02	0	0	0
IR.MIR.KR.Lhyp	3.26	3.26	0	0	0
IR.MIR.KR.Lhyp.Pk	2.34	2.34	0	0	0
CR.HCR.Xfa	17.92	0	0	0	17.92
SS.SCS.ICS.MoeVen	2.3	0	2.3	0	0
SS.SCS.ICS.Glap	12.27	0	4.02	8.24	0
SS.SCS.ICS.Slan	0.64	0	0	0.29	0.35
SS.SCS.CCS.PomB	20	0	0	0	20
SS.SCS.CCS.MedLumVen	3.89	0	3.89	0	0
SS.SCS.CCS.Blan	11.91	0	0	11.91	0
SS.SSa.IFiSa	0.19	0	0	0.11	0.08
SS.SSa.IFiSa.IMoSa	8.5	0	0	8.39	0.11
SS.SSa.IMuSa	0.02	0	0	0	0.02
SS.SMx.IMx.CreAsAn	0.79	0	0	0.79	0
SS.SMx.OMx.PoVen	1.84	0	1,84	0	0
SS.SMp.Mrl	2.43	0	0.79	1.65	0
SS.SMp.SSgr.Zmar	0.15	0	0.04	0.11	0

Table 9 – The area of seabed (% of whole seabed) occupied by each of the Blue Carbon classes for each biotope. Most biotopes are dominated by a single class with the notable exception of SS.SCS.ICS.Glap and SS.SMp.Mrl which are split across BC2 and BC3.

Within Jersey waters high levels of inorganic carbon are associated with sedimentary environments but especially the accumulating shallow sedimentary basins along the eastern part of the territorial seas. These areas contain coarse sands and gravels within which is carbonate debris that derives from living and dead organisms with the latter sometimes having been swept in from other areas by tidal currents (Figures16, 17C).

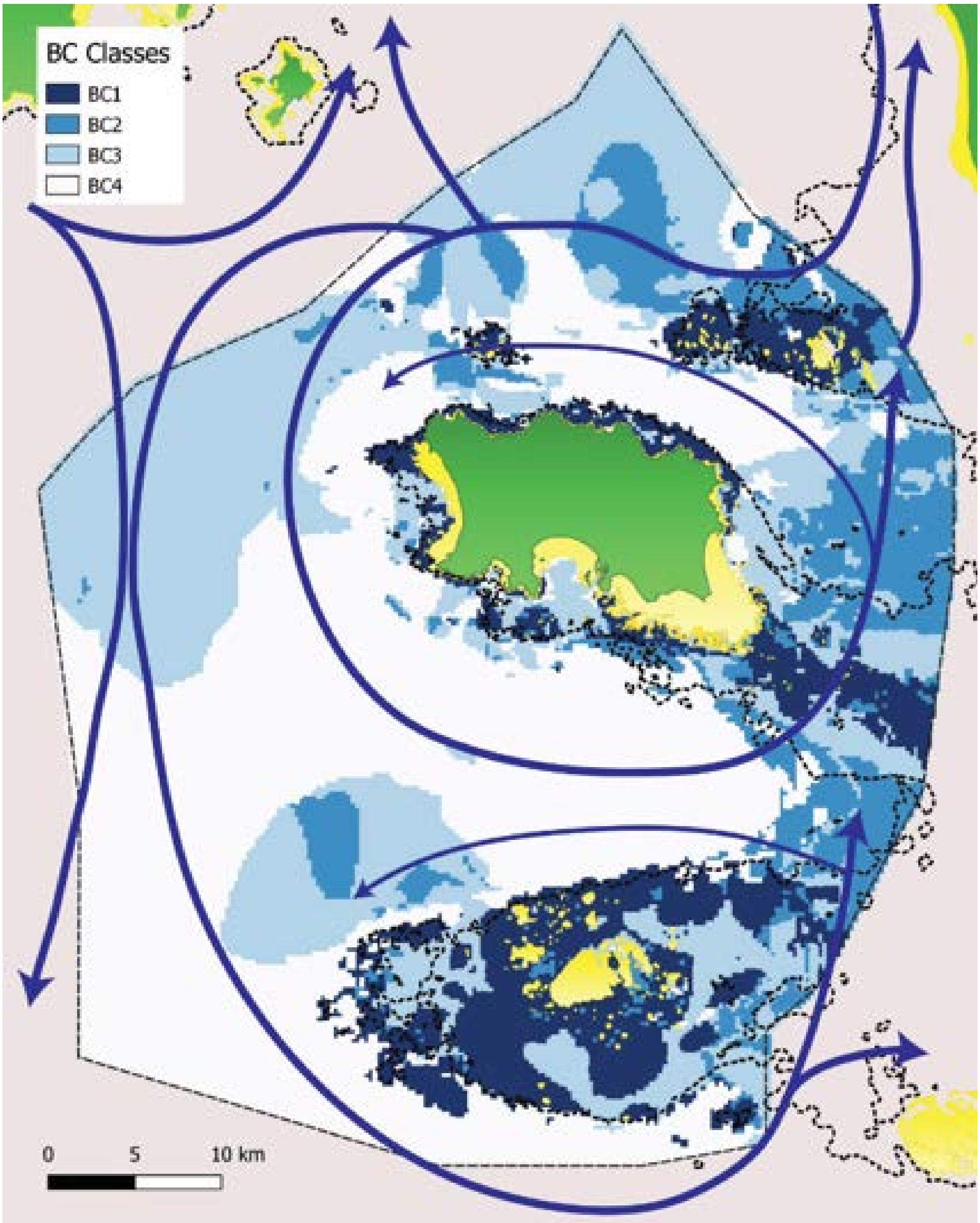


Figure 18 – A map of the four BC classes identified in Section 4.1 with residual tidal current patterns superimposed (Greenaway, 2001 and refs therein). This illustrates the long-term direction travel of seawater within the region (i.e. net movement across multiple tidal cycles); this needs to be considered in relation to the local and regional transport of organic and inorganic matter (see also Figure 19).

Outside of the basin areas, primarily to the west of the island at a depth of >25 metres, are mobile sand and gravel features which also have a moderate carbonate content that is mostly broken shells and other debris. These areas of mobile sediment are tidal features which will form downstream (in terms of the dominant tidal current direction) of major obstructions such as offshore reefs and the even the other Channel Islands. These areas will have accumulated autochthonous shell material but work by Hommeril (1967) suggests that much of the carbonate debris offshore has been swept there from neighbouring shallow water areas (i.e. it is allochthonous).

In terms of Jersey's overall carbon budget, the Class BC3 areas represent a major repository (temporary and permanent) of inorganic carbon. These areas need to be managed to maintain their standing stock of carbon and to their functioning to ensure that historic inorganic carbon is not released back into the atmosphere.

4.1.4 – Class BC4: Low productivity, low accumulation

Class BC4 represents biotopes have the lowest overall Blue Carbon resources but cover the widest geographic area. They are generally deeper water (>25 metres) hard seabed areas which have few plants and little or no stable sediment cover. Although not devoid of life, a lack of seaweed and a dominance of encrusting and mobile organisms (sponges, corals, fish, crabs, etc.) means there is a low standing stock and low annual production rates. The hard seafloor and a lack of permanent sediment accumulation restricts the potential for accumulation.

The geography of the Normano-Breton Gulf creates Class BC4 seabed areas through the strong tidal currents that enter from the western English Channel transporting sediment away from BC4 biotopes towards the coast of France where it may be deposited in the sedimentary basins (Figure 5). This leaves the seafloor to the south, west and south-west of Jersey largely devoid of sediment or covered in shallow thicknesses of mobile sands and gravels (Figures 16, 17D).

4.1.5 - BC classification: a Summary

the results from Jersey's Blue Carbon assessment were classified into one of four groups based on a cluster analysis of their potential to produce and accumulate organic and inorganic carbon. These four classes display a broad coherence in terms of the biotopes they contain and their geographic distribution. Defining resources by these classes assists with identifying the distribution of resources, the spatial recognition of potential value and in identifying probable movement of carbon on a localised and regional scale. This will assist with resource management and any plans to research and establish accredited Blue Carbon offsetting projects.

4.2 – Local and Regional Blue Carbon Flux

The identification of four BC classes may assist with summarising potential *in situ* resources and their distribution but it does not consider the movement of carbon within food chains or any exchange that may occur with neighbouring geographic areas. For example, key Class BC1 habitats, such as kelp forests, have high production rates and a large standing stock of organic carbon but little potential for its accumulation and burial. With a limited opportunity for local burial, much of the organic carbon generated in Class BC1 areas will, through the death of plants, seasonal die back and attrition, be exported in the form of detritus (for simplicity, this term is taken to cover particulate and dissolved organic carbon) into other BC areas or outside of Jersey's territorial seas altogether. Here it may be subject to decomposition, consumption, burial or re-mobilisation. If the exported carbon enters Class BC2 and BC3 biotopes and is buried, then it has the potential to be buried and sequestered. If it enters Class BC4 areas, then burial is unlikely.

The movement of carbon resources between biotopes/areas has not been included in this model and yet it has the potential to substantially alter some of the Blue Carbon results presented in Section 3.0. This may be particularly true for accumulation/burial estimates as organic detritus imported from other areas could add significantly to overall weight of carbon removed from the environment. The role of macroalgal carbon in Blue Carbon modelling is a recognised issue as is the need for more research in this area both internationally and locally (e.g. Krause-Jensen *et al.*, 2018).

Figure 19 - NASA satellite images of the Normano-Breton Gulf taken 24 March 2020 around one hour after low water (at St Helier) on a large spring tide. The top image shows sediment re-suspended by the large tidal movement. The bottom image shows the concentration of chlorophyll-a at the sea surface. Both images illustrate a differentiation between the sea waters of the Bay of Granville and the wider English Channel (dashed red line). Residual tidal currents(indicated) mean that watering entering the Bay of Granville may be trapped there for weeks or months before reentering the English Channel (Greenaway, 2001; see also Figure 18). This long residency has a marked effect on the oceanographic process operating in the Normano-Breton Gulf and therefore also the properties of sea water (such as temperature, turbidity, etc.). It may also affect the region's

For example, Jersey's offshore algae has an estimated annual production of 82,000 tonnes of carbon, much of which will eventually become detached detritus. (Kerambrun (1984) estimated that up to 66% of marine algae become detached annually.) Some of this detritus may be buried locally and some will be transported elsewhere. Modelling where detritus originates, how it is transported, the quantities involved and where it accumulates will be important if the potential of Jersey's Blue Carbon resources are to be fully documented.

Similarly, modelling the movement of carbon through localised food webs will offer insights into the flow of carbon within ecosystems and the relative importance of different parts of the food web. Carbon flux models have been for created for ecosystems within the Normano-Breton Gulf region using the simulation model of Pace *et al.* (1984). These suggest that dissolved and particulate detritus derived from plants (including phytoplankton) form an important role in the movement and exchange of carbon between trophic groups (Le Hir *et al.* 1986; Chardy, 1987; Chardy and Dauvin, 1992).

The creation of carbon flux models for key Jersey ecosystems/biotopes is desirable in terms of a greater understanding of the role that elements of food webs play in the consumption, excretion and transfer of carbon. Modelling carbon flux across food webs could also allow the testing of various hypotheses in relation to changing environmental parameters (e.g. sea temperature) and management scenarios.

The process of carbon flux modelling may be complicated by Jersey's location and oceanographic processes which result in one of the world's largest tidal ranges (>12 metres), strong tidal currents (>5 knots) and a water circulation regime that may serve to partially isolate the south-eastern part of the Normano-Breton Gulf from the English Channel. This complex and localised oceanographic regime could interact with the flow of organic and inorganic carbon resources, redistributing them within Jersey waters and permitting the import and export of material with the rest of the Normano-Breton Gulf and English Channel.

Localised tidal current models have been created for the Normano-Breton Gulf some of which have modelled the transport and settlement of sediments including biogenic carbonate material (Le Hir *et al.* 1986; Salomon, 1990; Greenaway, 2001). These suggest that there is a general gradation from coarser to finer grain sizes along a general west to east trend. The movement of inorganic carbonate material is thought to conform with this and is transported by currents from shallower water areas (such as coasts and offshore reefs) into deeper water sedimentary basin areas or sandbank features (Hommeril, 1967; Le Hir *et al.* 1986).

The results from this study also suggest that there is a gradient from coarser to finer sediments along the path of dominant tidal currents and that unstable (mobile) sandbanks form where tidal current flow is disrupted by physical obstacles, such as reefs, or other tidal currents. Biogenic habitats, such as maerl and seagrass beds, tend to form at the end of this fining sequence, often accumulating against or up or downstream (in terms of dominant current) from topographic features such as reefs.

Based on current knowledge, it seems probable that high organic-inorganic production within Jersey's shallower water Class BC1 areas (such as reefs and inshore plateaus) does not accumulate in situ but is (in the form of detritus) exported elsewhere. Detrital material that is imported into Class BC2 areas has a higher chance of burial than in Class BC3 areas which are generally less stable with lower accumulation rates. Material which ends up in Class BC4 will either be consumed, oxidised or temporarily resident before being swept into other areas.

Although Class BC1 is probably the dominant exporter of carbon and Classes BC2 and BC3 the dominant sequesters of it, detrital and other organic and inorganic material will move within and between all areas in a complex manner. As well as modelling carbon flux within Jersey waters, there is a need to model interactions between different Blue Carbon areas and between the habitats they contain (e.g. Wijnbladh *et al.* 2006; Bauer *et al.* 2013). Marine ecosystem modelling has an important part to play in the assessment and management of Blue Carbon resources and increased awareness around environmental conservation and the commercial potential for Blue Carbon has made this the subject of research both locally and internationally (see Section 5.2.3).

4.3 – Jersey’s Blue Carbon Resources and Offsetting

During 2019 the island of Jersey is produced an estimated 0.4 megatonnes of CO_2 emissions. This figure is low for an administrative region with a resident population of at least 105,000 plus seasonal visitors and temporary residents. Use of French nuclear generated electricity and a lack of heavy industry have assisted with lowering the island’s carbon footprint with total emissions having fallen by 35.8% since 1990.

A breakdown of the 2019 emissions total (Figure 20) reveals that the biggest contributors are transport (44.4%), residential/domestic (20.9%), business (14.6%) and energy supply (11.6%) with remaining 8.5% being from sectors such as agriculture (5.8%) and waste management (2.88%). As with most European countries, there remains considerable scope to reduce emissions through standard and innovative measures from government, businesses and the private/public sector. The options and associated timescales available to the island have been presented in the Government of Jersey’s Carbon Neutral Strategy and Carbon Neutral Roadmap reports (Government of Jersey, 2019, 2021).

Jersey’s greenhouse gas emissions will be likely be reduced through initiatives centred on energy efficiency, technological change and a move away from fossil fuel dependency. It is, however, recognised that a reduction pathway is unlikely to achieve full carbon neutrality and that any residual emissions will eventually need to be offset with carbon credits.

Carbon credits are a tradable commodity in which ‘credits’ generated by greenhouse gas emissions reductions made by one party may be purchased by other parties seeking to reduce their carbon footprint. For example, an airline seeking to reduce its overall greenhouse gas emissions might purchase credits from a project that has reduced its emissions through energy efficiency initiatives. A single credit is worth a tonne of CO_2 (or equivalent for other greenhouse gases) and the trade in carbon credits operates on an open market is the same way as other commodities. This means that their price fluctuates over time in response to supply, demand and other commercial factors.

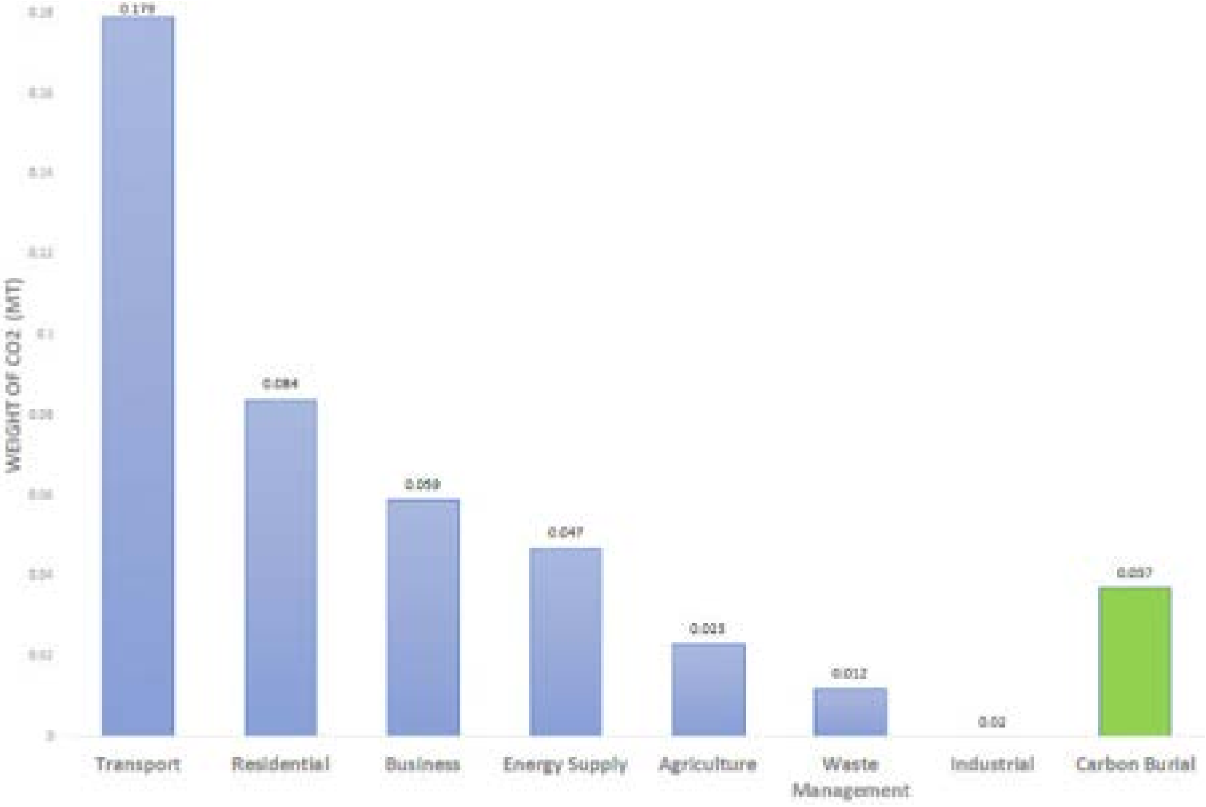


Figure 20 – Jersey’s CO_2 emissions by weight (Mt) for 2019 (blue columns) with the CO_2 equivalent weight of sequestered Blue Carbon from this study (green column). The weight of carbon sequestered annually approximates to the combined CO_2 emissions from the island’s energy supply and waste management sectors. [SOURCE: Government of Jersey]

However, while credit schemes can avoid the release of additional greenhouse gases into the atmosphere, they do not reduce overall emissions and so cannot count towards a net-zero target. For net-zero purposes, the use of offset carbon credits is required as these must be derived from projects that permanently remove greenhouse gases from the atmosphere.

In practice this means if residual emissions in Jersey are to be neutralised then they must be offset using credits from projects which permanently sequester (capture) atmospheric carbon. Sequestration may be achieved through both artificial and natural means and, as with carbon credits, the measurement unit is equivalent tonnes of CO_2. Examples of offset credit projects include reforestation, soil management and habitat restoration all of which will increase the carbon sequestration capacity of an area. This results in an increased weight of carbon being removed from the atmosphere and it is this tonnage of carbon that is used to create the offset credit. There are many guidelines and regulations around the accreditation and valuation of carbon offsetting projects and the role of IPCC being in this area is particularly important (see Brindoff *et al.* 2019; IUCN, 2021).

As an island of just 120 km^2, the scope for terrestrial restoration on Jersey is limited and could not make a significant reduction on its residual emissions. However, 95% of the Bailiwick of Jersey consists of sea and this assessment has identified areas of sedimentary seabed which may be able to sequester important weights of carbon annually. These habitats could, with time and investment, be accredited for use in projects that generate Blue Carbon credits either for use locally (e.g. to offset Jersey's residual emissions) or for commercial trading perhaps to raise funding for other climate change mitigation projects such as enhanced sea defences.

The recent interest in Blue Carbon resources (locally and internationally) has in part been driven by their potential financial value as offset credits. With current offset prices ranging anywhere between £15 and £40 for a tonne of carbon, the estimated average of 10,249 tonnes of permanently buried Blue Carbon identified in this report could have a monetary value of between £500,000 and £1.2 million annually or it could be used to offset 8% of Jersey's greenhouse gas emissions. Inclusion of other habitats with Blue Carbon potential, such as kelp forests (see Section 4.2), could raise this figure to several million pounds annually or perhaps offset up to 20% of current greenhouse gas emissions. Additionally, the cost of carbon offset credits is expected to rise above inflation potentially adding further value to these deposits. [4]

Although simple in principle, the creation, accreditation and use of Blue Carbon in offsetting projects is complex and currently not possible for many marine areas within the IPCC guidelines (Brindoff *et al.* 2019). Pressure is growing for the IPCC to widen its list of recognised Blue Carbon habitats so that resources associated with key habitats such as maerl beds, coral reefs and seaweed forests may be included. [5]

If the IPCC framework does expand to allow some of Jersey's offshore habitats to qualify for offsetting, then the areas of seabed concerned will need to be assessed, defined and encapsulated in projects that have well-defined strategic management principles. Only then can such projects be put forward for accreditation which means that from start to finish, the process of creating a Blue Carbon project may take several years.

Somewhat ironically, a higher Blue Carbon value may potentially be derived from seabed areas that have the potential for restoration (i.e. where burial/sequestration potential has been degraded, usually anthropogenically) rather than healthy areas where burial potential is already at or close to its natural capacity. In all instances, areas used for Blue Carbon offsetting must be closely managed to ensure that the principles under which the resource was accredited remain valid (IUCN, 2021).

The complexities and uncertainties that exist around local and international Blue Carbon offsetting do not affect the weight of carbon sequestered annually in Jersey's offshore marine habitats. This, and the Government of Jersey's continued research in this area and its participation in UK and international initiatives to develop and expand Blue Carbon accreditation, could eventually allow much of this potential to be offset against residual greenhouse gas emissions or they could be capitalised through international carbon credit trading. Jersey's offshore Blue Carbon could therefore be an untapped asset whose correct management and marketing has the potential to provide environmental and economic benefits on a local, regional and international scale.

4.4 – Preliminary Assessment of Pressures and Threats

The world’s coastal seas are under threat from a range of environmental pressures which have the potential to disrupt the physical, chemical and biological functioning of habitats and species. These pressures range from the cumulative effects of climate change and introduced invasive species to sudden impacts from mineral extraction and intensive fishing. Most of these pressures are recent in origin (post-1800) and are linked to anthropogenic activity.

The integral link between Blue Carbon resources, biodiversity and habitat functionality suggests that any threat to the marine environment will have the potential to impact Blue Carbon functionality to a greater or lesser degree. Coastal marine habitats, such as those found in Jersey’s territorial seas, may be especially vulnerable to a wide range of pressures due to their shallow depth, proximity to densely populated coasts and their association with human/economic activity.

A list of the probable pressures operating within Jersey waters is given in Table 10 (adapted from Tyler-Walter *et al.* 2018). The potential impact of these pressures on the functionality and servicing provision (including Blue Carbon resources) of the biotopes identified in this report is being undertaken by the Government of Jersey with the results expected in 2022. Rather than attempting to presage these results, this report will offer only an outline of the key pressures liable to affect Jersey’s offshore Blue Carbon resources.

The principal threats to carbon resources in Jersey’s waters derive from pressures that can cause seabed disruption, threaten habitat integrity and/or cause changes in biodiversity. Threats to the production and standing stock of carbon may derive from climate related factors which have the potential to change the sea’s acidity, salinity, temperature or increase wind and wave exposure (Tyler-Walter *et al.* 2018). Jersey is not immune from the effects of climate change and its potential impact on marine habitats is currently being assessed. Other reports have documented some of the measured and likely effects from climate change and their possible impact on the island (AECOM, 2020).

Changes in temperature, acidity (pH) and salinity have the potential to alter the sea’s chemistry which may in turn affect biological processes such as the formation and stability of calcium carbonate. Similarly, pollution derived from land runoff, transport and other sources has the potential to disrupt key ecosystem or biological functions potentially leading to reduced biodiversity, eutrophication or smothering.

The arrival and proliferation of non-native species (especially those classed as invasive) may also disrupt habitats and species. For example, at least two non-native species may have had an impact on Blue Carbon resources; these are the American slipper limpet (*Crepidula fornicata*; first recorded 1962) and wireweed (*Sargassum muticum*; first recorded 1980) both of which have moderated existing habitats to the extent that they have had to be reclassified to reflect the domination of the new species (States of Jersey, 2017).

The link between carbon burial and accumulating sedimentary habitats could render seabed areas vulnerable to physical disruption. The rapid burial of carbon plays a crucial role in sequestration as it will remove organic and inorganic material away from oxygenated seabed waters (where it will be rapidly recycled) into sediments with anoxic pore waters where the rate of recycling is far slower. In stable sedimentary areas, such as the basins off Jersey’s coast, anoxic sediment may lie just a few millimetres or centimetres below the seabed surface. Disruption to the anoxic layer risks bringing buried carbon material into contact with oxygenated waters where it will be consumed by organisms and released as carbon dioxide.

Sediment disturbance may result from many activities and may vary in scale with a legacy that ranges from a few hours to permanent. The mining of minerals (in the form of aggregate extraction) has not occurred in Jersey waters since the 1980s and regular commercial dredging is not required in association with the maintenance of shipping lanes, etc. There may be some impact on sediment re-suspension/mixing from the effects of climate change (e.g. increased storm intensity/regularity and rising sea level) but this has yet to be assessed. The disruption of sediment through the burial of infrastructure, such as electricity cables, is episodic and, from the study of seagrass beds via aerial photography, recovery will occur within two to three years. The effect of moorings for boats and navigation buoys will be localised to a radius of a few metres but may nonetheless have an impact on sensitive habitats such as seagrass meadows. For example, individual boat moorings in Jersey's shallow marine seagrass areas have removed all plants within a diameter of 10 to 19 metres which, in St Catherine's Bay, has removed seagrass from an area of around 6,000 m^2 (0.6 ha; figures estimated from aerial photography).

However, in Jersey's territorial seas the largest commercial activity is fishing which does require fishing vessels engaging with the seabed. In general terms Jersey's fisheries may be divided into two broad types: (1) vessels that operate static fishing gear, such as pots and nets; and (2) vessels that operate mobile fishing gear, principally dredges and trawls.

Both fishing gear types require contact with the seabed and so have the potential to disrupt sediments and habitats. Scientific investigations into the impact of fishing gear on benthic habitats began in the 1860s and continues to this day as does an associated debate on the need to balance socioeconomic requirements against the conservation/restoration of ecosystem services. Local research is being undertaken into the socioeconomic and environmental framework of Jersey's commercial fisheries, the results from which are expected soon. In the meantime, this report will offer an overview of the key issues and potential interactions that may exist between commercial fisheries and Blue Carbon resources.

Theme	Pressure
Hydrological Change	Salinity Change Temperature Change Tidal Current Change Wave Exposure
Physical Damage	Seabed Change Water Clarity (Turbidty) Habitat Structure Seabed Disturbance/Abrasion Seabed Deep Disturbance Seabed Smothering/Silting
Pollution	Hydrocarbons/PAH Radionuclids Synthetic Compunds Other Substances De-oxygenation Nutrient Enrichment Organic Enrichment Acidification
Biological	Genetic Modification Microbial Pathogens Non-native Species
Fisheries	Static Fishing Gear Mobile Fishing Gear
Other	Barrier to movement Electromagnetic change Collision Light/Shading Litter Noise/Sound Vibration Visual Disturbance

Table 10 – A list of threats/pressures that have the potential to impact on Jersey's Blue Carbon resources. (Adapted from Tyler-Walter et al. *2018)*

4.4.1 – Fisheries: Static Gear

Research into the impact of static gear (such as pots and nets) on fisheries and the marine environment has tended to focus on bycatch, mortality, pollution and ghost fishing rather than seabed disruption (Uhlmann and Broadhurst, 2015; Shester and Micheli, 2011). The few studies that have looked at interaction between static gear and the seabed have found a localised (e.g. 1 to 2 metres) impact on sedimentary and dense seaweed (but not rocky) habitats. This is caused by tidal or weather generated sweeping movements associated with the fishing gear or mooring equipment such as ropes and chains (Eno *et al.* 2001; Coleman *et al.* 2013).

In Jersey the fishing effort associated with potting is high and tends to be concentrated within inshore rocky areas and reefs (for lobster and crab) and coarse basin sediments (for whelk). Benthic gillnets ('tangle nets') are extensively used by French vessels (but not Jersey ones) to target spider crab in the south-west of the Bailiwick although issues around data sharing means that little is known about the scale of this industry.

A study within the Lyme Bay marine protected area, Dorset, suggests that an increased density of pots can impact seabed habitats especially when levels exceed 15 to 20 pots per 0.25 km². The Lyme Bay study focused on damage to reef-building epibenthic species, such as sea fans and sea squirts, rather than sediment integrity but an impact on burrowing species, such parchment worms, was also noted (Rees *et al.* 2021). Similarly, studies on benthic gillnets suggest that their movement through current action and weather will have a localised effect on seabed habitats (Savina *et al.* 2018).

The Government of Jersey has data relating to potting and benthic netting fishing activity modelled from landing, VMS and patrol data averaged between 2015 and 2019. These models mapped fishing effort and retained catches onto a 1 km² grid covering Jersey's territorial seas. The datasets were created for general marine management purposes and, while the underlying dataset for potting activity was sufficiently detailed to capture fishing effort, the data available for benthic netting was poor and reliant on VMS positions. Consequently, this dataset could only model where a net had been deployed/collected and not the area of seabed it occupied nor the catch weight. For this reason, only the potting activity dataset was used in this report (Marine Resources, pers. comm.).

The potting activity offers an insight into the concentration of fishing effort within Jersey's seas and suggests that the highest activity levels are around the island's coast and on the offshore reefs (e.g. Les Écréhous, Les Minquiers and Les Dirouilles). In these areas most potting activity targets large crustaceans such as lobsters, brown crab and spider crab. Potting activity also occurs on sedimentary and mixed seabed areas where vessels target whelk and crustaceans. Fishing for whelks is particularly concentrated within the Les Écréhous, Canger and Sauvages basins and in an area to the north of Les Dirouilles (Figure 21).

A simple presence/absence analysis of potting activity against the 37,055 Blue Carbon assessment polygons offers an insight into the association of potting activity with the four BC classes identified in Section 4.1. The result is expressed as a percentage of the seabed area within each BC class that does and does not have potting activity associated with it. The different spatial resolution between the two datasets (1 km² for potting against 0.065 km² for the BC classes) is accounted for but means the result should be viewed as indicative, rather than absolute. Nonetheless, this suggests that potting activity is high in Classes BC1 and BC2 and lower in Classes BC3 and BC4 (Figure 22).

Class BC1 is dominated by hard seabed with dense seaweed (such as kelp forests) and it is probable that potting activity in these areas is associated with crustaceans. Class BC2 areas are mostly stable coarse sediments within basin areas suggesting that potting activity here will primarily target whelks although some crustacean potting will also occur. Class BC3 has less activity associated with it but potting in coastal areas probably reflects a mixture crustacean and whelks while offshore it is more likely to be focused on whelks. Class BC4 is generally hard seabed located offshore and so potting in these areas will be for crustaceans.

In terms of potential damage to the Blue Carbon resource, the localised impact of potting activity and its concentration on Class BC1 areas, which have a low sequestration potential, suggests that any impact is liable to be relatively low. In other BC classes potting activity is widespread but a low level suggesting there will be minimal impact on stable sedimentary areas in Classes BC2 and BC3 with perhaps less still in Class BC4 areas.

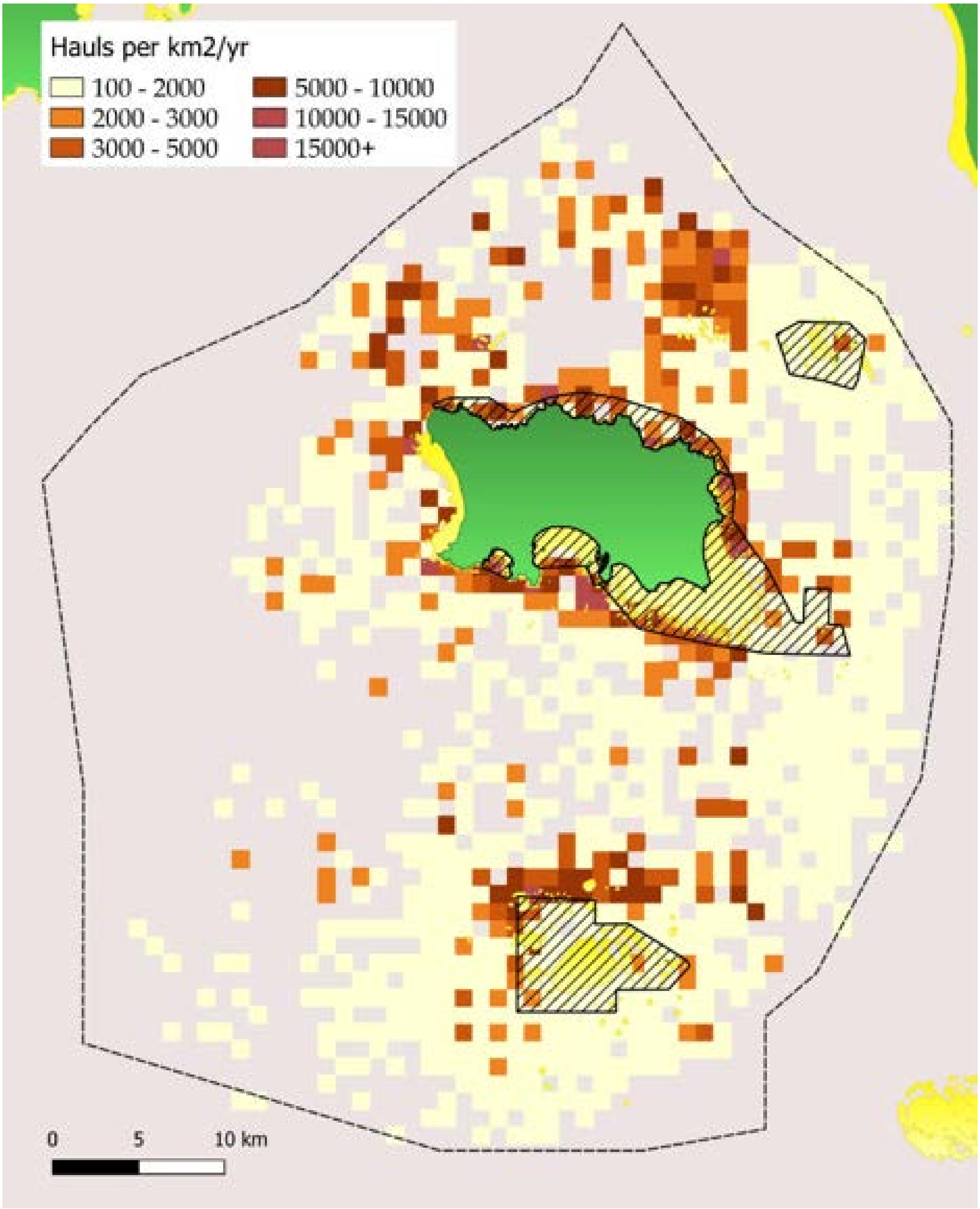


Figure 21 – The concentration of fishing effort (pot hauls/yr per 1 km²) for static gear (lobster and whelk potting) commercial vessels. Areas of high activity are concentrated on inshore rocky seabed areas and the offshore reefs; this represents potting for crustaceans. Lower levels of activity are found offshore including in sedimentary areas; this represents a mix of whelk and crustacean potting. The hatched areas are MPAs where static fishing gear can still be used. [SOURCE: Government of Jersey]

The overall threat to Blue Carbon resources by potting is probably low although this study should only be taken as indicative as there are potential threats which have not been assessed, such as loss of seaweed and other sessile organisms through gear and mooring rope movement. Similarly, the impact of benthic nets has not been assessed and so a more detailed study into the impact of static gear on local carbon resources should be undertaken before definite conclusions can be drawn.

4.4.2 – Fisheries: Mobile Gear

Studies into the impact of mobile fishing gear (principally trawling and dredging) on the seabed are numerous and the results more conclusive than for static gear. With only minor exceptions, the results of these studies report that mobile gear does have an impact on seabed habitats and sediment integrity with the scale of disruption depending on gear type, fishing effort and the habitat concerned (e.g. see Duplisea *et al.* 2001; De Borger *et al.* 2021)

The impact on benthic ecosystems by fishing activity is consistently reported as being higher from mobile gear than other methods. For example, Enos *et al.* (2013) summarised the results of studies into 14 types of fishing activity relating to 31 marine habitats across the UK. The results suggests that most seabed habitats are adversely impacted by trawling and dredging while static gear was thought to impact three habitats and only when used at intensive levels. A similar project covering the USA reached a near identical conclusion (Grabowski *et al.* 2014).

The use of mobile fishing gear in Jersey waters is widespread and occurs at varying levels of intensity across all depths and over a broad geographic area (Figure 23). Species commonly targeted by dredging are scallops (*Pecten maximus*) and burrowing clams (*Venus* and *Glycymeris*) while benthic trawls (primarily otter trawls with some beam trawling) are used to target various fish species. Scallop dredges and trawls will affect epifauna such as molluscs, sponges, hydroids, anemones, etc.,

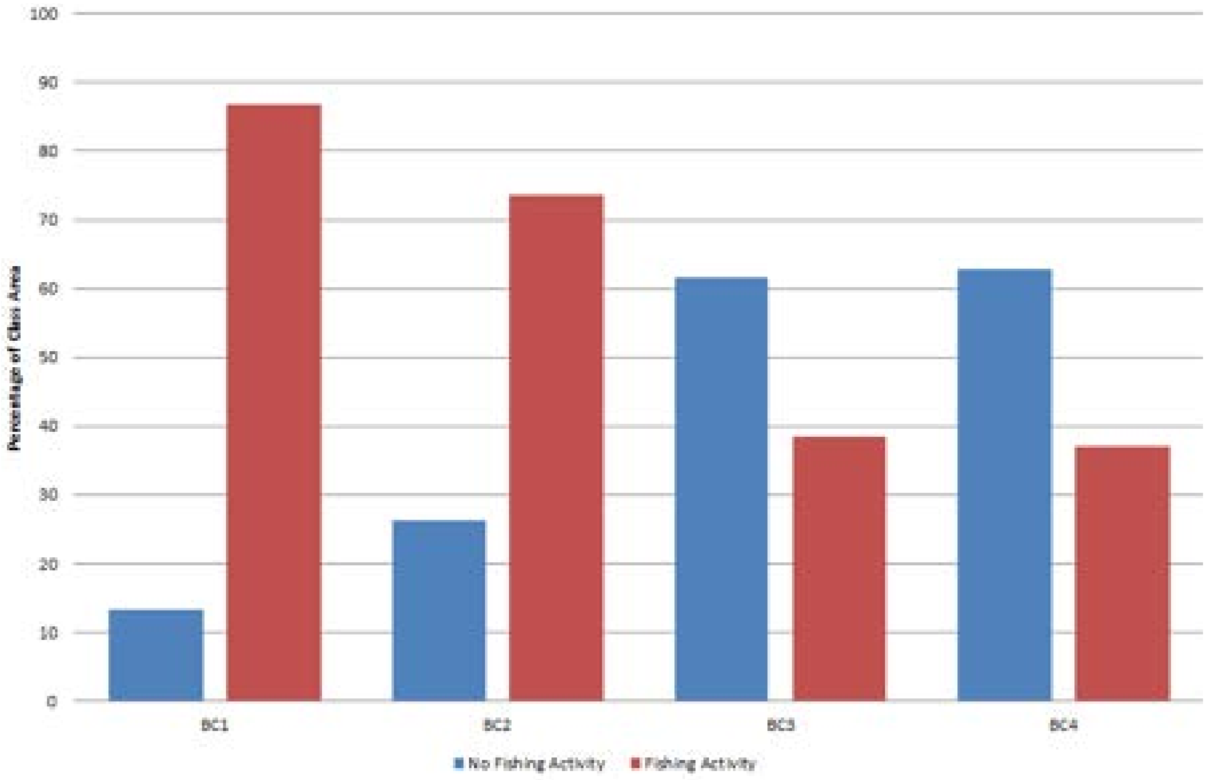


Figure 22 – A presence/absence analysis of potting activity within the BC class areas identified in Section 4.1 expressed as a percentage of class area with/without fishing activity. This suggests that potting activity occupies a higher area percentage of classes BC1 and BC2 than BC3 and BC4.

and, depending on substrate properties, may penetrate the top few layers of sediment where burrowing organisms (infauna) inhabit. Burrowing clams such as praire (*Venus verrucosa*) are targeted using the box-like 'praire dredge' which may penetrate sediment to a depth of 30 centimetres and so has potential to cause severe disruption for benthic sediments.

Impact by mobile gear on key habitats identified in Jersey waters has been documented through diver surveys, towed video and aerial photography (Blampied, 2015; Chambers *et al.* 2016). The need to protect maerl and seagrass areas from mobile gear led to the creation of three MPAs covering 6.5% of Jersey's territorial seas where dredging and trawling are prohibited (Chambers *et al.* 2019). Other data include an unpublished study grain-size distribution in sediment cores taken off the coast of Jersey which suggests that parts of Les Écréhous Basin may be being severely disrupted by dredging (Société Jersiaise, pers. comm.).

This report has compared the distribution of the four Blue Carbon classes (outlined in Section 4.1) with a Government of Jersey model for distribution of average mobile gear fishing effort from 2015 to 2019. As with the potting activity dataset referred to in Section 4.4.1, the mobile gear models operate at a 1 km^2 resolution and is based on data from VMS, fisheries patrol and landing records. [6]

A chart showing the concentration of mobile gear fishing effort in Jersey waters is displayed in Figure 23. This suggests that most seabed areas have some mobile fishing activity associated with them but usually at a low level of between one and two hours annually (i.e. that seabed area may expect to be dredged/trawled once or twice a year).

There are, however, several hotspots within Jersey's waters where fishing effort rises above 10 hours a year and a smaller number of areas where fishing effort is more than 80 hours a year. These are dominated by Classes BC2 and BC3 both of which have higher a Blue Carbon value because of their productivity and sequestration potential. Areas with no recorded mobile gear activity are generally topographically complex rocky reefs where dredges/trawls cannot operate (dominated by Classes B1 and BC4) plus within MPAs (generally BC1 and intertidal) where mobile gear use is prohibited (Figure 23).

Figure 24 compares the presence/absence of mobile gear activity in the BC classes identified in Section 4.1. This analysis operates to the same methodology as for the potting study in Figure 22 and has the same constraint in its interpretation (see Section 4.4.1). The results suggest that mobile gear activity is lowest in Class BC1, highest in BC2 and BC3 and moderate in BC4.

Class BC1 areas contain rocky offshore reefs while BC4 is predominantly hard seabed of bedrock or cobble which difficult to access by trawlers/dredgers or do not contain the species they target. Classes BC2 and BC3, on the other hand, are generally high productivity/sequestration sedimentary habitats in basin or offshore areas. These areas are easily accessible to mobile gear and contain target species such as scallops and high value demersal fish so an increased concentration of fishing effort is to be expected.

There is a concentration of fishing effort within the Les Écréhous and Les Sauvages sedimentary basins located to the east and south-east of Jersey's territorial sea area. These basins are dominated by Class BC2 habitats that include maerl, seagrass and clam beds. Any disruption to sediments in these areas has the potential to impact Blue Carbon resources through the remobilisation of buried carbon and any decline in productivity associated with biodiversity loss. High fishing effort across Class BC2 habitats occurs to the south of St Helier and in the eastern part of Canger Basin. These areas are principally targeted by dredging for scallops and burrowing clams and any impact from these activities should be quantified in relation to Jersey's Blue Carbon resources.

An additional concentration of fishing effort occurs along a NE-SW line offshore to the west of Jersey. This is generated by a mix of trawling and scallop dredging along a series of sandbanks and gravel patches that form downstream from the islands of Guernsey and Sark. These sediments are mostly in Class BC3 and are subject to strong tidal currents and are mostly mobile and semi-mobile with high concentrations of shell material. It is suspected that their instability and lower biodiversity (than BC2 areas) may create more resilience to impacts from mobile gear than inshore areas although this has yet to be assessed formally through fieldwork.

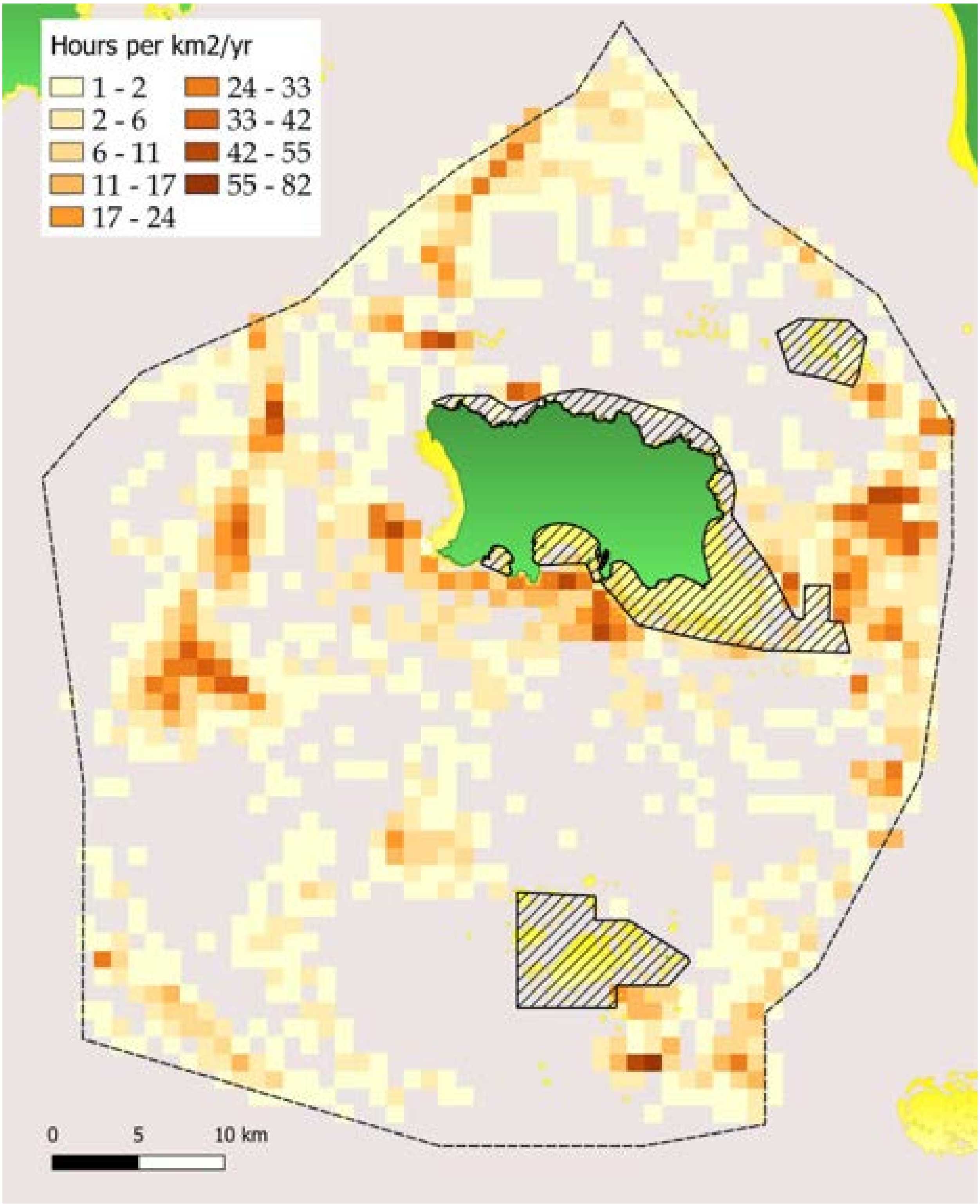


Figure 23 – The concentration of fishing effort (hours/yr per 1 km²) for mobile fishing gear (dredging and trawling) for commercial vessels. Areas of high activity are concentrated along the eastern part of the territorial seas, along Jersey's south coast and to the west of the island. The hatched areas are MPAs where static fishing gear can still be used. [SOURCE: Government of Jersey]

The relationship between anthropogenic activity and the marine environment is complex with economic and political considerations sometimes being at odds with recommended conservation and resource management measures. If Jersey's Blue Carbon resources are to be meaningfully conserved/managed for capitalisation/offsetting purposes, then all potential benefits and conflicts will need to be evaluated so that appropriate and proportional management measures may be recommended.

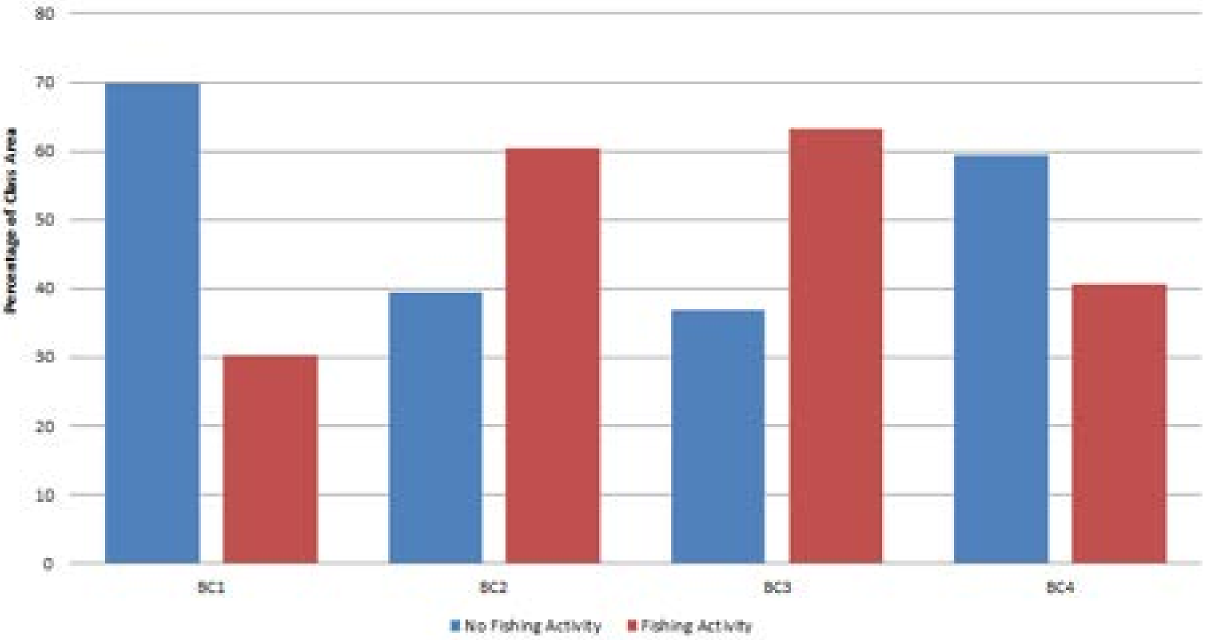


Figure 24 – A presence/absence analysis of mobile gear fishing activity within the BC class areas identified in Section 4.1, expressed as a percentage of class area with/without fishing activity. This is based on the datasets used to generate Figures 16 and 23. This suggests that dredging and trawling activity is more spatially widespread in classes BC2 and BC3 than for classes BC1 and BC4.

5.0 – Conclusions

This report has used biological, ecological, geotechnical and oceanographic data to estimate the Blue Carbon resources within the Bailiwick of Jersey's subtidal area (survey area: 2,315 km^2). This is the first such study of Blue Carbon resources within the Channel Islands region.

The average production of carbon in organic material is estimated to be 8,837 t OC yr-^{1} for fauna and 82,327 t OC yr-^{1} for plants. The standing stock is estimated to be 15,745 t OC yr-^{1} for animals and 87,827 t OC yr-^{1} for plants. The standing stock for inorganic (principally carbonate) material is 12,795,943 t IC yr-^{1}. Burial (sequestration) is estimated to be 1,283 t OC yr-^{1} for organic carbon, and 8,961 t IC yr-^{1} for inorganic carbon. The average carbon burial potential is 10,249 t C yr-^{1} which equates to 8.6% of Jersey's annual CO$_2$ emissions (based on 2019 figures).

The distribution of these resources is linked to benthic habitat type (classified as JNCC biotopes). A cluster analysis of production, organic and inorganic burial potential suggests that seabed areas may be placed into one of four different classes (labelled BC1 to BC4) that can be used to define their Blue Carbon properties. These classes show a coherent geographic distribution and suggest that Jersey's offshore reefs are areas of high organic production (Class BC1) while the sedimentary basins are areas of high organic/inorganic production and burial (Classes BC2 and BC3). Hard seabed areas have generally low Blue Carbon resources (Class BC4).

The geographic distribution of the four Blue Carbon classes suggests that Jersey's territorial waters possess a coherent and integrated Blue Carbon framework. Within this, the offshore reefs and sedimentary basins play a particularly important role in terms of production and burial. Although not modelled, it is suspected that there is a considerable movement of carbon (especially dissolved and particulate) between sea areas and habitats. This, and the flux of carbon through localised food webs, is an area that needs to be researched further.

A list of potential threats and pressures to Blue Carbon resources was identified. An assessment of habitats/classes against these threats was not undertaken except in relation to static and mobile gear fishing. This suggests that static fishing using pots is localised with a probable minimal impact on some sedimentary habitats. Mobile gear fishing activity is more widespread and offers a higher possibility of seabed disruption including in some potentially valuable Blue Carbon areas.

This report concludes that Jersey's offshore marine habitats are productive, complex and biodiverse with a potential for the development of accredited Blue Carbon projects. Further work will be required to ground-truth the results, identify project sites and obtain a better understanding of the generation, stock and storage of carbon in Jersey's territorial seas plus any potential threats.

5.1 –Confidence and Uncertainty

In this report estimated weights for carbon associated with benthic production, standing stock and burial were derived from a desktop-based assessment. This required the acquisition, standardisation, analysis and adaptation of data from a variety of sources. This, together with the large number of data sources used, will introduce a degree of uncertainty into the results. In the interests of confidence, it is important to highlight areas where more or better data are required or where improvements could be made.

The processing, analysis and synthesis of a variety of datasets (modern and historic) produced a habitat map/model which has been subject to ground-truthing and peer review. Therefore, it is felt that the habitat extent modelling in this report represents an accurate reflection of the biotopes and environmental properties within its area of coverage. It is, however, recommended that the habitat model should be further developed through surveys using side-scan sonar, grab sampling, towed video and other sampling techniques. This is particularly true in the western parts of Jersey territorial seas where little recent surveying work has been undertaken.

Obtaining accurate data for carbon stocks and production for sedimentary habitats in the Jersey region was problematic. Datasets exist but these are based on sampling and laboratory analyses that were undertaken between the 1960s and 1980s. While it would be hoped that the biological situation hasn't changed significantly over the past forty years, it is expected that warming sea temperatures, the spread of non-native species and intensive fishing in some areas, may have affected the biodiversity, productivity and physical properties of some habitats. Obtaining modern and accurate biomass data for Jersey sedimentary areas should be a priority for any future offshore Blue Carbon assessments. The algae biomass and production data of Kerambrun (1984) probably remains relevant to the modern marine environment around Jersey but that confirmation of this is desirable.

The physical properties of benthic sediments were obtained from professional geotechnical studies undertaken just over a decade ago and which probably remain relevant. This dataset was, however, derived from samples taken off Jersey's east coast and, while other sampling and remote geophysical work offers a good insight into sediments elsewhere, additional data on grain-size, porosity and bulk density from Jersey waters should be obtained.

In this report the sediment accumulation rate (SAR) was estimated by looking at the burial depth for a non-native species (*Crepidula fornicata*; American slipper limpet) whose date of arrival and rate of spread in the region is known. This is, however, a crude method of determining SARs as it assumes that the deepest slipper limpets are all of the same age and that there are no other factors, such as the use of deep penetration dredges, that could be responsible for the burial of specimens. Accurate SARs are needed to calculate the carbon accumulation rate in sedimentary areas and the use of estimated SAR figures will add uncertainty to any result. It is therefore important that any future assessment has access to measured figures for the accumulation/burial potential of local sediments or for the SAR in key seabed areas.

Overall, it is the authors' view that while there may be uncertainty associated with aspects of this assessment, this is not of sufficient severity to invalidate the results. As with all desktop studies, it is recommended that results are treated as indicative of the situation in relation to Blue Carbon resources rather than an absolute quantification of them. The next step in measuring and developing a further understanding of Jersey's Blue Carbon position should be to undertake field and laboratory work to ground-truth and develop the conclusions from this assessment.

5.2 – Future Research

Notwithstanding the recommendations already made in Section 5.1, below is a summary of knowledge gaps and areas identified during this study where future research might be beneficial.

5.2.1 - Ground-truth the Assessment

This report describes an assessment that is based largely on pre-existing datasets and statistical modelling. Nonetheless, the results will be representative of the quantity and distribution of Blue Carbon resources in Jersey's territorial seas. However, if Jersey's Blue Carbon resources are to be used in commercial or other offsetting, then more accurate data will be needed much of which will need to be derived from field studies.

Of particular importance will be obtaining accurate information on sediment geotechnical properties (especially grain-size distribution), biodiversity, biomass, carbonate content and burial/accumulation rates. The role of CO_2 release during carbonate formation in Jersey waters should also be investigated to see if this could impact on the burial/sequestration value of key habitats (see Saderne *et al.* 2019). On hard ground a better understanding of seaweed distribution, density and cover is desirable although some of this information should be obtainable from aerial photography. It should be noted that fieldwork to ground-truth the results from this report began in the summer of 2021 with results being expected in 2023.

5.2.2 – Assess Habitat Health and Potential Threats

The ability of habitats to function successfully as a Blue Carbon resource will be proportionate to their ecological health and integrity. Disturbed and degraded habitats are less able to deliver beneficial functions and services than healthy ones. This applies not just to Blue Carbon but other ecosystem services some of which play a role in the maintenance of fisheries, tourism/leisure and act as buffers against pollution and weather/climate change.

The ecological health of Jersey's offshore seabed habitats remains largely undocumented. Shallow water areas, especially those in association with reefs, have been subject to diver assessments which suggest that habitats associated with topographically complex features, such as reefs, are generally in good health as are sediments located within the island's MPAs (Chambers *et al*. 2019). However, seabed damage has been reported to some sedimentary habitats including high value ones such as maerl beds, seagrass, kelp forests and clam-rich sedimentary areas (Blampied, 2015). For example, an unpublished study of vibrocores taken along an electricity cable route between east Jersey and France has found evidence suggestive of recent disruption to the top 5 to 30 cm sediment. (Société Jersiaise, pers. comm.).

Utilising Jersey's Blue Carbon resources will require an assessment of Jersey's seabed habitats in relation to their resilience and resistance to identified pressures and threats. Of particular importance is documenting the health of habitats with an important biogenic component such as maerl, kelp forests and seagrass. This is not just for Blue Carbon accreditation but will be valuable for general marine management purposes. Aspects of this assessment work already form part of ongoing government and NGO research and an assessment of all Jersey's marine habitats is underway.

5.2.3 - Carbon Flux

This report identifies four classes of Blue Carbon resource which can be used to summarise the collective potential of an area's production/standing stock and burial potential. Understanding connectivity between these classes and/or between the marine areas inside and outside of Jersey's territorial sea is important as is the modelling/documentation of carbon flux in local food webs.

Of particular importance is understanding the rate of seaweed attrition and the degree to which dead plant material is recycled through decay/consumption or sequestered into sediment. Modelling the origin, destination and fate of organic carbon detritus (particulate and dissolved) is important so that the contribution that such material makes to Blue Carbon may be fully accounted for.

Such a study could also examine any impact from the removal of organic and inorganic biomass from the marine environment in the form of fisheries retention and (to a much lesser extent) seaweed harvesting. For example, in Jersey's territorial seas at least 5,700 tonnes of fish and shellfish (live weight) are caught and retained annually. [7] The anthropogenic removal of biomass from the oceans should be accounted for when carbon flux modelling and any influence on Blue Carbon budgeting should be explored. This seems to be area that has been little researched to date.

5.2.4 – Offsetting

The Government of Jersey Carbon Neutral Roadmap recommends the evaluation and, if feasible, development of local sequestration projects prior to purchasing of off-Island offset credits to reduce residual emissions. This includes Blue Carbon resources with a suggestion that their potential should be explored with regard to the establishment of accredited projects within the next decade. It is recognised that Blue Carbon projects will require management measures 'to protect, enhance and expand marine sequestration and biodiversity in the Island's territorial waters'. It is also an ambition that Jersey should become 'a centre of excellence for Blue Carbon research and industries' (Government of Jersey, 2021). However, to achieve globally recognised accreditation will require a wider acceptance of Blue Carbon for inventory reporting purposes by international environmental organisations.

IPCC guidelines currently recognise a limited number of coastal fringe habitats in relation to emissions offsetting just one of which, seagrass, is native to Jersey waters. Given the potential for Blue Carbon resources in other seabed areas, obtaining budgetary recognition for key offshore habitats, such as maerl and high biodiversity sedimentary habitats, is important. This issue is the subject of attention from several research groups and NGOs including ones where Jersey is an active member. Jersey's participation in this field of research is desirable to ensure that key habitats are being managed to maximise their natural capital and that their Blue Carbon resources can contribute to the island's Carbon Neutral Strategy.

Endnotes

1 - Although not formally defined, the Normano-Breton Gulf is usually depicted as the sea area south-east of an imaginary line drawn between the tip of the Cherbourg Peninsula and Île-de-Bréhat in Brittany.

2 - The weight of carbon from the dry weight biomass of animal flesh is approximately 40% while from inorganic carbon (carbonate) it is 12%. The percentage of carbon in algae species was taken from Kerambrun (1984) although for most species is *circa* 33%. The results from a laboratory analysis of Jersey seaweeds is expected during 2022.

3 - The production of calcium carbonate ($CaCO_3$) emits CO_2 which has led to questions about whether carbonate formation may offset the value of sequestered organic carbon in some Blue Carbon habitats (Saderne *et al.* 2019; Van Dam *et al.* 2021; see also Section 5.2).

4 - These figures are from Government of Jersey (2021). The valuations given should be treated with extreme caution as it is unlikely that all the island's Blue Carbon resources will be usable for offsetting and because of the volatility and complexity of offsetting projects and their capitalisation. Kelp forests as a Blue Carbon offsetting resource is complex as most of the biomass is exported (see Section 4.2)

5 - The Government of Jersey is assisting in moves to widen the IPCC habitat lists through its participation with the British-Irish Council and partnership with the Blue Marine Foundation and local NGOs.

6 - In line with UK government recommendations, VMS enabled vessels with recorded speeds of more than six knots were deemed to be on passage and not fishing. Sightings data is derived from enforcement patrols (and other marine work) by Government of Jersey during which all vessel sightings and encounters are recorded (Marine Resources, 2020). Vessel metier is determined from landings data, fishing permits and local intelligence work.

7 - These figures are 2018, the latest year for which both official Jersey and French data are available to the Jersey authorities. French landing figures are from Foucher *et al.* (2020) and are derived from the apportionment of fishing activity within ICES sub-rectangles based on the percentage of sea area occupied by Jersey's territorial waters. Jersey data are from Marine Resources (2020) and represent declared landings from vessel daily logsheet returns.

References

AECOM, 2020. *Jersey Shoreline Management Plan*. Government of Jersey Report.

Atwood TB, Witt A, Mayorga J, Hammill E and Sala E, 2020. Global Patterns in Marine Sediment Carbon Stocks. Front. Marine Sci.ence. Vol. 7: 165

Barnes, DKA and Sands C.J, 2017. Functional group diversity is key to Southern Ocean benthic carbon pathways. *PLoS ONE*. Vol. 12(6): e0179735.

Barnes, DKA, Sands, CJ, and Smith, N, 2019. *Valuation of carbon storage, sequestration and social cost by benthos in Ascension Island's EEZ*. Report for the South Atlantic Overseas Territories Natural Capital Assessment.

Bauer, J, Cai, W-J, Raymond, PA, Bianchi, TS, Hopkinson, CS and Regnier, PA, 2013. The changing carbon cycle of the coastal ocean. *Nature*. Vol. 504: 61-70.

Bindoff, NL, Cheung, WWL, Kairo, JG *et al.*, 2019. Changing ocean, marine ecosystems, and dependent communities, in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Pörtner, H-O *et al.* (eds), IPPC.

Bishop, AC and Bisson, G, 1989. *Classical areas of British geology: Jersey*. HMSO.

Blampied, S, 2015. *Do species assemblage, richness and abundance change between Rock, Sediment and Maerl at Les Écréhous off Jersey?* Unpublished BSc dissertation, University of Plymouth.

Blanchard, M, 1995. Origine et état de la population de *Crepidula fornicata* (Gastropoda, Prosobranchia) sur le littoral Français. *Haliotis*. Vol. 24, 75-86.

Bréhaut, RN, 1975. The Mollusca of Guernsey. *Reports and Transactions of La Société Guernesiaise*. Vol. 19(5), 503-533.

Burdige, DJ, 2007. Preservation of organic matter in marine sediments: Controls, mechanisms, and an imbalance in sediment organic carbon budgets? *Chemical Reviews*. Vol. 107: 467-485.

Burrows, MT, Kamenos, NA, Hughes, DJ, Stahl, H, Howe, JA, Tett, P 2014. *Assessment of carbon budgets and potential Blue Carbon stores in Scotland's coastal and marine environment*. Scottish Natural Heritage Report (No. 761).

Burrows, MT, Hughes, DJ, Austin, WEN, Smeaton, C, Hicks, N, Howe, JA, Allen, C, Taylor, P, Vare, LL 2017. *Assessment of Blue Carbon resources in Scotland's inshore marine protected area network*. Scottish Natural Heritage Report No. 957.

Burrows, MT, Moore, P, Sugden, H, Fitzsimmons, C, Smeaton, C, Austin, W, Parker, R, Kröger, S, Powell, C, Gregory, L, Procter, W, Brook, T, 2021. *Assessment of carbon capture and storage in natural systems within the English North Sea (including within Marine Protected Areas)*. Report for the North Sea Wildlife Trusts, Blue Marine Foundation, WWF and RSPB.

Chardy, P, 1987. Modèle de simulation du système benthique des sediments grossiers du golfe normnand-breton (Manche). *Oceanologica Acta*. Vol. 10(4): 421-434.

Chardy, P and Dauvin, J-P, 1992. Carbon flows in a subtidal sand community from the western English Channel: a simulation analysis. *Marine Ecology Progress Series*. Vol. 81: 147-161.

Chambers, P, 2008. *Marine molluscs of the Channel Islands*. Charonia Media.

Chambers, P, Binney, F and Jeffreys, G, 2016. *Les Minquiers: a natural history*. Charonia Media.

Chambers, P, de Gruchy, C, Morel, G, Binney, F, Jeffreys, G and McIlwee, K, 2019. Crossing jurisdictions: the implementation of offshore marine protected areas in an international fishery. In: *Marine Protected Areas: Science, Policy and Management*, Humphreys, J. (Ed.). pp. 411-436. Elsevier.

Chambers, P and Nichols, R, 2014. The Jersey Electricity cores project: an interim progress report. *Annual Bulletin of the Société Jersiaise*. Vol. 31: 292-297.

Coleman RA, Hoskin MG, von Carlshausen E, Davis CM, 2013. Using a no-take zone to assess the impacts of fishing: Sessile epifauna appear insensitive to environmental disturbances from commercial potting. *Journal of Experiential Marine Biology and Ecolology*. Vol. 440: 100–107.

Connor, DW, Allen, JH, Golding, N, Howell, KL, Lieberknecht, LM, Northen, KO and Reker, JB, 2004. *The Marine Habitat Classification for Britain and Ireland: Version 04.05*. JNCC, Peterborough.

De Borger, E, Tiano, J, Braeckman, U, Rijnsdorp, AD and Soetaert, K, 2021. Impact of bottom trawling on sediment biogeochemistry: A modelling approach. *Biogeosciences.* Vol. 18: 2539-2557.

Duplisea, DE, Jennings, S, Malcolm, SJ, Parker, R and Sivyer, DB, 2001. Modelling potential impacts of bottom trawl fisheries on soft sediment biogeochemistry in the North Sea. *Geochemical Transactions*. Vol. 2: 112-117.

Elliott, SAM, Milligan, RJ, Heath, MR, Turrell, WR and Bailey, DM, 2016. Disentangling habitat concepts for demersal marine fish management. *Oceanography and Marine Biology: An Annual Review.* Vol. 54: 173-191.

Eno NC, Frid CLJ, Hall K, Ramsay K, Sharp RAM, Brazier DP, *et al.*, 2013. Assessing the sensitivity of habitats to fishing: From seabed maps to sensitivity maps. *Journal of Fish Biology*. Vol. 83: 826–846.

Eno NC, MacDonald DS, Kinnear JAM, Amos SC, Chapman CJ, Clark RA, *et al.*, 2001. Effects of crustacean traps on benthic fauna. *ICES Journal of Marine Science*. Vol. 58: 11–20.

Folk, RL, 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology*. 62, 344–359.

Foucher, E, Laurans, M, Leblond, E, Le Grand, C and Le Blond, S, 2020. *Réponse à la saisine de la Direction des Pêches Maritimes et de l'Aquaculture relative à l'activité des navires français en baie de Granville*. Report commissioned by Ifremer.

Fugro, 2009. *Normandy 3 cable route: geotechnical investigation*. Fugro Report 0912515-2, UK.

Government of Jersey, 2019. *Carbon Neutral Strategy*. 100 pp. Government of Jersey Report.

Government of Jersey, 2021. *Carbon neutral roadmap: preferred strategy*. Government of Jersey Report.

Grabowski JH, Bachman M, Demarest C, Eayrs S, Harris BP, Malkoski V, *et al.*, 2014. Assessing the Vulnerability of Marine Benthos to Fishing Gear Impacts. *Reviews in Fisheries Science and Aquaculture*.

Greenaway, E, 2001. *Beach and oceanographic process surrounding Jersey, Channel Islands*. Unpublished MPhil thesis, University of Southampton.

Hampshire, K, Raoult, J, 2020. *Guide to the Greenhouse Gas Inventories of Jersey and Guernsey*. Aether Ltd.

Hommeril, P, 1967. *Étude de géologie marine concernant le littoral bas-normand et la zone prélittoral de l'archipel anglo-normand*. Unpublished PhD thesis, Université de Caen, France.

IUCN, 2021. *Manual of the creation of Blue Carbon projects in Europe and the Mediterranean*. IUCN.

Kerambrun, L, 1984. *Contribution à l'étude de la fertilité des fonds rocheux côtiers de Bretagne*. Unpublished PhD thesis, Université de Bretagne Occidentale, France.

Krause-Jensen, D, and Duarte, CM, 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience*. Vol.9: 737–742.

Krause-Jensen D, Lavery P, Serrano O, Marba, N, Masque P, Duarte CM., 2018 Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology Letters*. Vol. 14.

Le Hir, P, Bassoullet, P, Erard, E, Michel, H, Jegou, A-M, 1986. *Golfe Normano-Breton- étude régionale intégrée*. Ifremer, France.

Leloup, A, Desroy, N, Le Mao, P, Pauly, D, Le Pape, O, 2008. Interactions between a natural food web, shellfish farming and exotic species: The case of the Bay of Mont Saint Michel (France). *Estuarine, Coastal and Shelf Science*. 76 (1), 111-120.

Lefort, J-P, Chambers, P, Danukalova, G, Monnier, J-L, Osipova, E, Renouf, J, Aoustin, D, Pustoc'h, F, 2020. Did an earthquake located off Jersey trigger a mudflow preserving the only loess outcrop actually known under the seas? *Journal of the Geological Society*. Vol. 177: 911-922.

Macreadie, P *et al.*, 2019. The future of Blue Carbon science. *Nature Communications*. Vol 10: 3998.

Marine Resources, 2020. *Marine Resources Annual Report: 2019*. Government of Jersey Report.

Nichols, R and Blampied, S, 2016. *Jersey's Geological Heritage: Sites of Special Interest*. Société Jersiaise.

Pace, ML, Glasser, JE and Pomeroy, LR, 194. A simulation of continental shelf food webs. *Marine Biology*. Vol. 82: 47-63.

Prime, T, 2018. *Jersey sea level and coastal conditions climate review*. National Oceanography Centre, Southampton.

Rees, A.,Sheehan, E. and Attrill, M., 2021. Optimal fishing effort benefits fisheries and conservation. Scientific Reports. *Nature Scientific Reports*. Vol. 11(11):3784.

Retière, C, 1979. *Contribution à la connaissance des peuplements benthiques du Golfe Normanno-Breton*. Unpublished PhD thesis, Université de Rennes.

Jegou, AM and Salomon, J, 1990. Hydrodynamique cotière: couplage imagerie thermique satellitaire modèles numeriques. Application à la Manche. *Oceanologica Acta*. Special Publication No. 11: 55-62.

Saderne, V, Geraldi, NR, Macreadie, PI *et al.*, 2019. Role of carbonate burial in Blue Carbon budgets. *Nature Communications*. Vol. 10: 1106.

Savina E, Krag LA, Madsen N., 2018. Developing and testing a computer vision method to quantify 3D movements of bottom-set gillnets on the seabed. *ICES Journal of Marine Science*. Vol. 75: 814–824.

Shester GG, Micheli F., 2011. Conservation challenges for small-scale fisheries: Bycatch and habitat impacts of traps and gillnets. *Biology Conservation*. Vol. 144: 1673–1681.

Smeaton, C, Austin, W, Turrell, WR, 2020. Re-Evaluating Scotland's sedimentary carbon stocks. *Scottish Marine and Freshwater Science*. 11(2), 16pp.

States of Jersey, 2017. *Non-native marine species in the Channel Islands*. Société Jersiaise, Jersey.

States of Jersey, 2021. *Achieving carbon neutrality: report of Jersey's Citizens' Assembly on Climate Change*. States Greffe.

Tyler-Walters, H, Tillin, HM, d'Avack, EAS, Perry, F, Stamp, T, 2018. *Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide*. Marine Biological Association of the UK, Plymouth

Uhlmann SS, Broadhurst MK., 2015. Mitigating unaccounted fishing mortality from gillnets and traps. *Fish and Fisheries*. Vol. 16: 183–229.

Van Dam, BR, Zeller, MA, Lopes, C *et al.* ,2021. Calcification-driven CO_2 emissions exceed "Blue Carbon" sequestration in a carbonate seagrass meadow. *Science Advances*. Vol. 7(51): 15 Dec 2021.

Wijnbladh, E, Jönsson and Kumblad, L, 2006. Marine ecosystem system modelling beyond the box: using GIS to study carbon fluxes in a coastal ecosystem. *Ambio*. Vol. 35(8): 484-495.

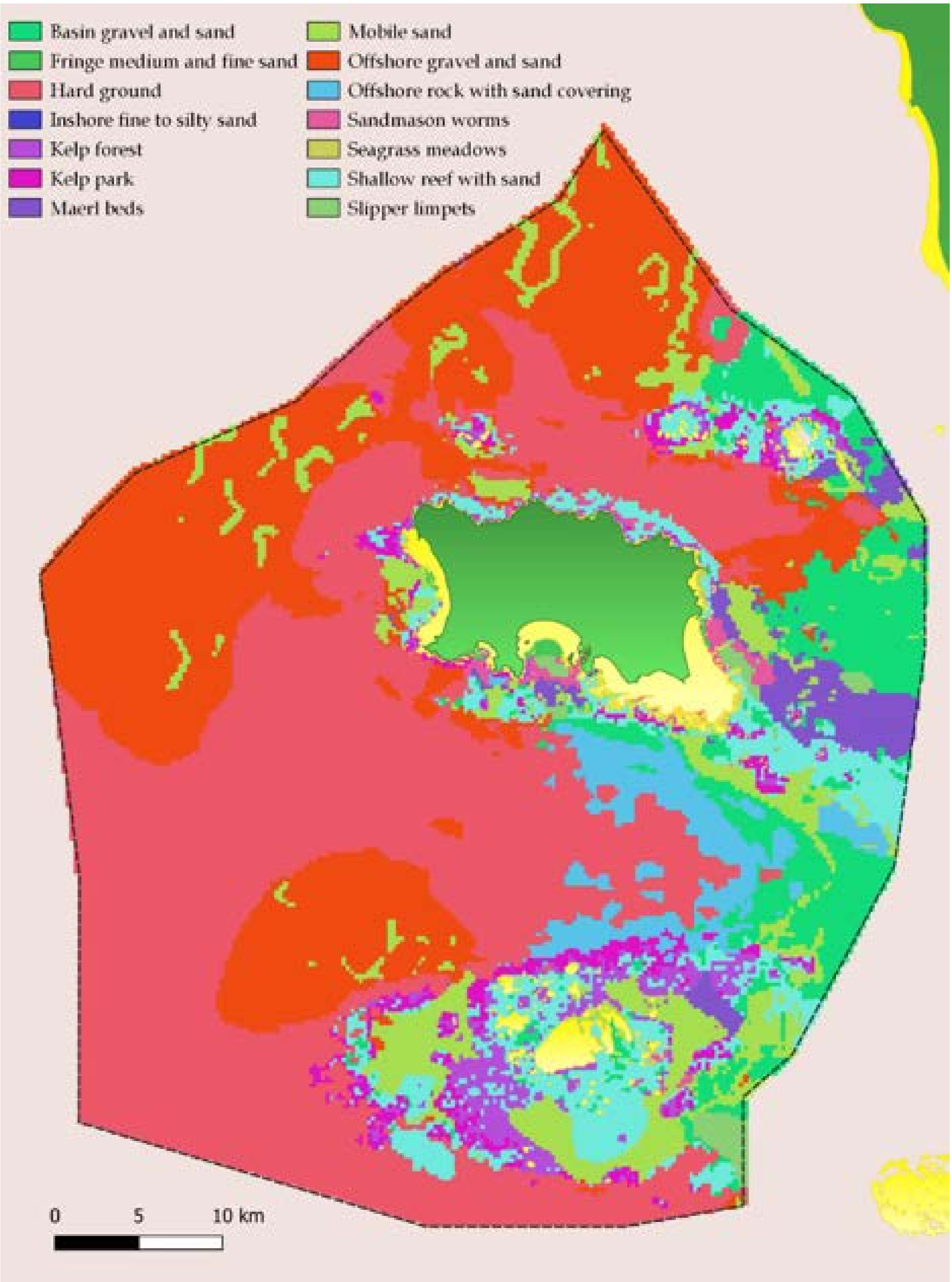


Figure 25 – A chart showing the extent of simplified benthic habitats identified for Jersey's offshore territorial seas. For an explanation of the habitats see Table 11 and Appendix I. For a more complex chart based on the JNCC biotope classification see Figure 7.

Appendix I – Habitats and Biotopes

The terms ‘habitat’, ‘biotope’ and ‘species’ are frequently used in many reports and papers concerning marine science and management including this one. Given the importance that has been afforded to these concepts by the authors, especially in relation to Blue Carbon and biodiversity, what is meant by the terms ‘habitat’, ‘biotope’ and ‘species’ is defined below. This is followed by a description (and accompanying map) for each of the 18 JNCC biotopes identified using the methodology from Section 2.1 (see Figure 7, and Table 12). Additionally, these 18 biotopes have been grouped into 14 habitats (Table 11; Figure 25) which represent a higher level overview of benthic ecology which may be more accessible to non-specialist readers.

In the context of this report the terms ‘habitat’, ‘biotope’ and ‘species’ are defined as follows.

‘Habitat’ is a general term that denotes either a single biotope (see below) or a collection of biotopes that share key characteristics which may include substrate, species (individually or communities) and parameters such as depth. Habitat names are often descriptive rather than purely scientific and so can be used in non-specialist literature or presentations. As an example, in this report the habitat ‘hard ground’ encompasses two similar biotopes (CR.HCR.Xfa and SS.SCS.CCS.PomB) which represent offshore rocky substrates with little or no sediment covering. A list of habitat terms used in this report are given in Table 11 and a map of benthic habitats is shown in Figure 25. For further information on the concept of defining habitats see Elliott *et al.* (2016).

‘Biotope’ is a specialist term that related to a habitat classification scheme developed by the Joint Nature Conservation Committee (JNCC). The scheme is hierarchical and classifies biotopes using several factors such as substrate, depth, exposure, features (such as ‘overhangs’, ‘caves’, etc.) and species (Connor *et al.* 2004).

Habitat Description	JNCC Biotopes	Extent km^2
Basin gravel/sand	SS.SCS.ICS.MoeVen; SS.SCS.CCS.MedLumVen; SS.SMx.OMx.PoVen	185.9
Fringe stable sand	SS.SCS.ICS.Slan; SS.SSa.IfiSa; SS.SSa.IMuSa	18.7
Hard ground	CR.HCR.Xfa; SS.SCS.CCS.PomB	878.1
Kelp forest	IR.MIR.KR.Lhyp	74.3
Kelp park	IR.MIR.KR.Lhyp.Pk	54.1
Maerl bed	SS.SMp.Mrl	56.4
Mobile gravel/sand	SS.SSa.IFiSa.IMoSa	196.6
Offshore gravel/sand	SS.SCS.ICS.Glap; SS.SCS.CCS.Blan	560
Offshore rock and sand	IR.HIR.Ksed	81.9
Seagrass meadows	SS.SMp.SSgr.Zmar	3.2
Shallow reef and sand	IR.HIR.KSed.XKScrR	185.5
Slipper limpet beds	SS.SMx.IMx.CreAsAn	18.2

Table 11 - A list of broad descriptive habitats used Figure 25) and listed in Appendix I.

Biotopes are labelled using a composite coding system that reflects the biotope's hierarchical position and complexity (in terms of descriptive components). The JNCC biotope classification also forms the basis of the European EUNIS habitat system which uses letters and numbers to denote a biotope's position and complexity. Although the JNCC classification labelling is preferentially in reference to individual biotopes in this report, these labels are directly interchangeable with the coding of EUNIS (e.g. SS.SMp.Mrl = A5.51). Table 12 contains a list of the JNCC biotope codes with their EUNIS equivalent; the description (JNCC name) is the same for both classification schemes.

'Species' is used in the taxonomic sense with a species being defined by its Latin binomial name (e.g. *Laminaria digitata*). Common (vulgar) species names are sometimes used in relation to defined species (e.g. American slipper limpet for Crepidula fornicata). The naming of species is in accordance with taxonomic rules but new research and advances in genetics, etc., means that species names may be liable to change. This means that species names used in any publication have the potential to change over time. The species names used in this report were, at the time of writing, recorded as valid by the WoRMs (World Register of Marine Species) database.

JNCC Code	JNCC Name	EUNIS Code	EUNIS Level
IR.HIR.Ksed	Sediment-affected or disturbed kelp and seaweed communities	A3.12	4
IR.HIR.KSed.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	A3.125	5
IR.MIR.KR.Lhyp	*Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock	A3.214	5
IR.MIR.KR.Lhyp.Pk	*Laminaria hyperborea* park and foliose red seaweeds on moderately exposed lower infralittoral rock	A3.2142	6
CR.HCR.Xfa	Mixed faunal turf communities	A4.13	4
SS.SCS.ICS.MoeVen	*Moerella* spp. with venerid bivalves in infralittoral gravelly sand	A5.133	5
SS.SCS.ICS.Glap	*Glycera lapidum* in impoverished infralittoral mobile gravel and sand	A5.135	5
SS.SCS.ICS.Slan	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand	A5.137	5
SS.SCS.CCS.PomB	*Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles	A5.141	5
SS.SCS.CCS.MedLumVen	*Mediomastus fragilis, Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel	A5.142	5
SS.SCS.CCS.Blan	*Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel	A5.145	5
SS.SSa.IFiSa	Infralittoral fine sand	A5.23	4
SS.SSa.IFiSa.IMoSa	Infralittoral mobile clean sand with sparse fauna	A5.231	5
SS.SSa.IMuSa	Infralittoral muddy sand	A5.24	4
SS.SMx.IMx.CreAsAn	*Crepidula fornicata* with ascidians and anenomes on infralittoral coarse mixed sediment	A5.431	5
SS.SMx.OMx.PoVen	Polychaete-rich deep Venus community in offshore gravelly muddy sand	A5.451	5
SS.SMp.Mrl	Maerl beds	A5.51	4
SS.SMp.SSgr.Zmar	*Zostera marina* beds on lower shore or infralittoral clean or muddy sand	A5.5331	6

Table 12 - A list of biotopes (using JNCC and EUNIS classification) used in the seabed habitat map (Figure 7) and described in Appendix I.

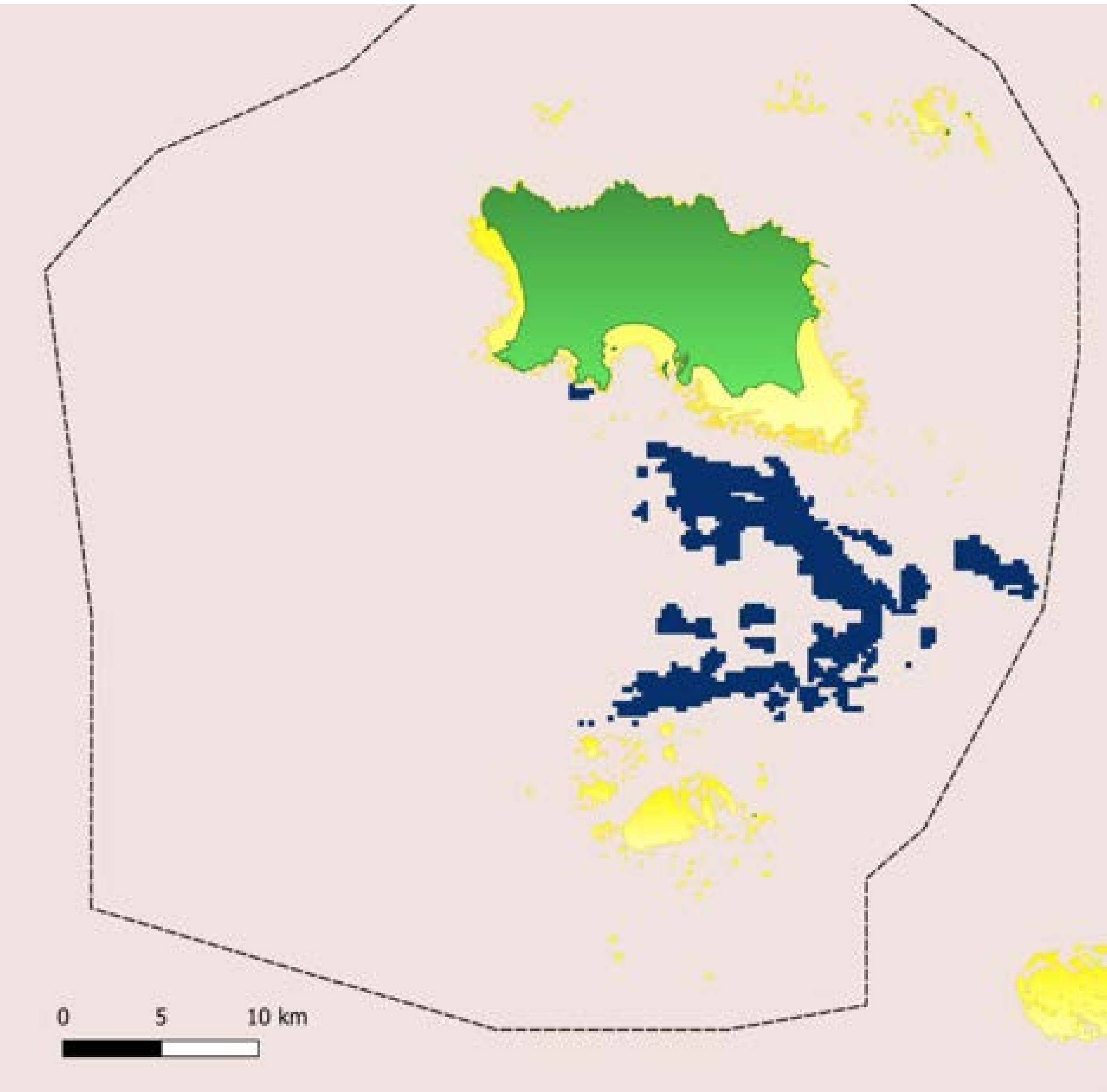
JNCC IR.HIR.KSed - EUNIS A3.12 - Description: Offshore Rock with Sand

Sediment-affected or disturbed kelp and seaweed communities.

This biotope occurs on offshore (>15 metres below chart datum), low gradient hard substrate (bedrock or boulders) in areas subject to strong tidal currents. The substrate is dominated by bedrock or boulders over which may lie patches of coarse sand, broken shell or gravel. This sediment is normally of shallow thickness, unstable and periodically mobile. Brown and red seaweeds may be present (often sparsely) on boulders or raised areas of bedrock. The biotope is generally of lower biodiversity but is often an important nursery area for fish such as wrasse, seabass, bream and other bentho-pelagic species.

Locally this biotope occurs on rocky seabed areas that are lower infralittoral (>15 metres below chart datum). Above this depth *Laminaria* generally forms denser stands and, on steeper rock areas, will be represented by the biotopes IR.MIR.KR.Lhyp and IR.MIR.KR.Lhyp.Pk. In shallower water there will often be more dense vegetation the classification of which will more probably be represented by IR.HIR.KSed.XKScrR.

Within Jersey waters this biotope generally occurs in two areas. (1) The shallow water and low gradient areas associated with the fringe of offshore rocky reefs (especially subtidal plateau areas) which are subject to strong tidal and sediment movement. (2) Exposed/high energy areas on the seaward edge of basin entrances or downstream from strong topographic features such as reefs.

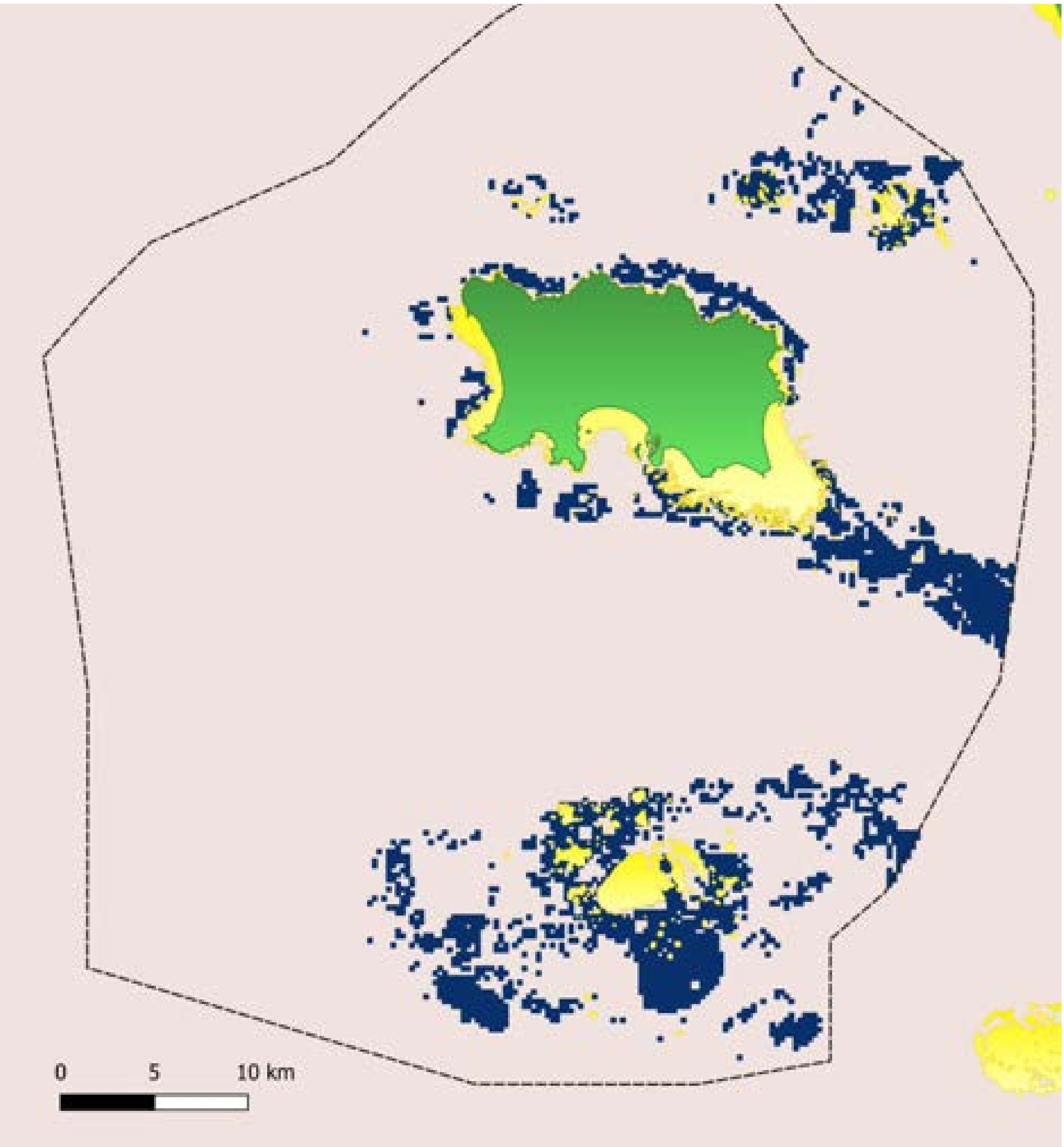


JNCC IR.HIR.KSed.XKScrR - EUNIS A3.125 – Description: Shallow reef with sand

Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock

This is a shallow water (<20 metres below chart datum) biotope associated with the fringe of rocky areas, gently sloping seabed and boulder fields where thin thicknesses of mobile sands overlie the bedrock. Movement of sand limits seaweed species tolerant of high energy conditions such as kelps (*Laminaria* spp.), sugar kelps (*Saccorhiza*) and *Desmarestia* together with tougher red species such as *Plocamium cartilagineum*. Fauna will be similar to IR.HIR.KSed being mostly encrusting 'turf' species such as sea squirts, anemones, tube worms, etc. Cracks and holes in rock may be home to larger animals such as lobsters and crabs, ormers and conger eels.

In Jersey waters this biotope is primarily associated with tide swept areas of reef, often downstream from obstacles such as rocks, rough ground, etc., where turbulent water causes sediment to be deposited, suspended and redeposited. Bedrock will often be just below the surface and although there can be some infauna (notably the bivalve *Glycymeris glycymeris*) most marine life is associated with areas of rocks and seaweed.



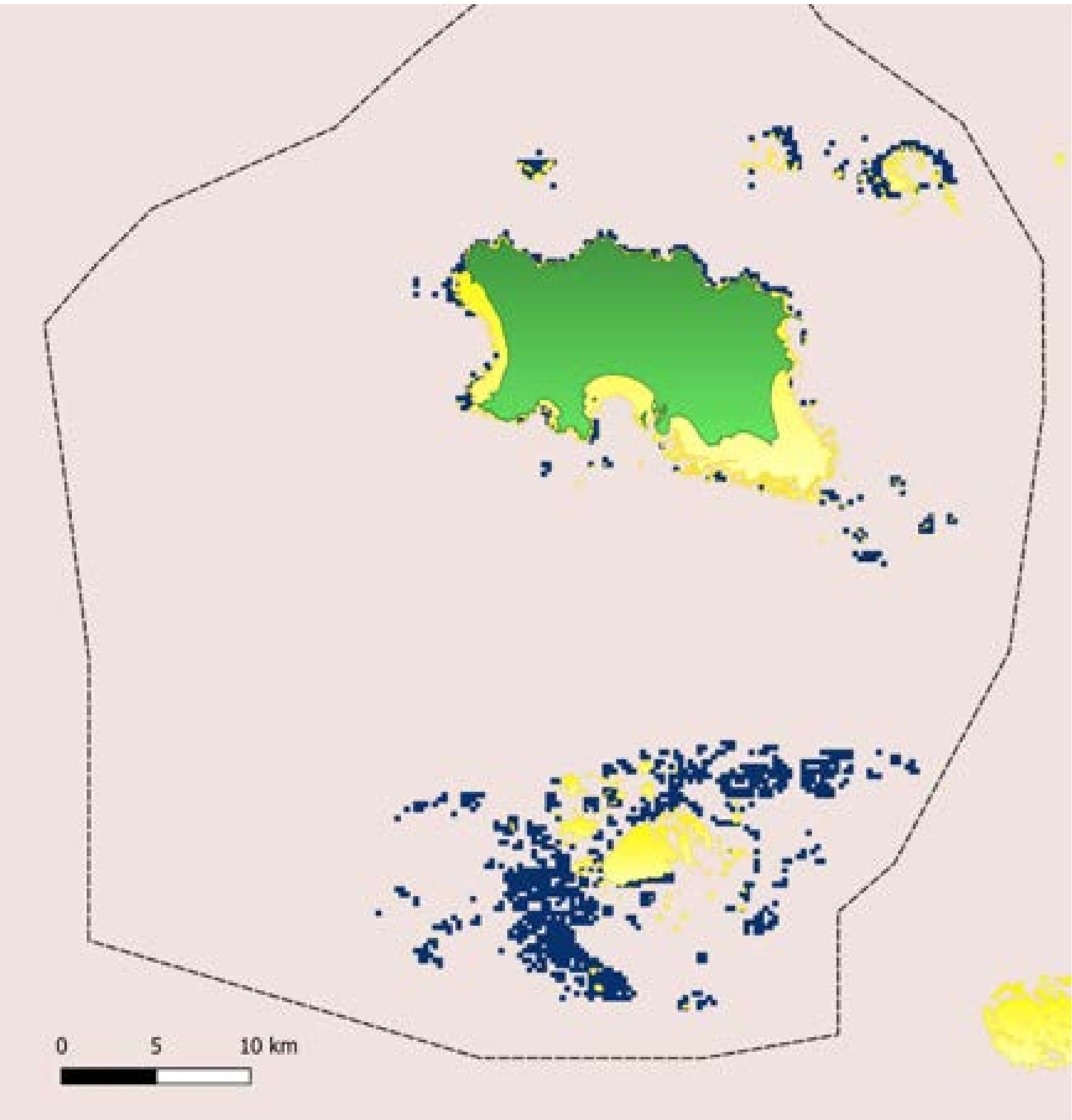
JNCC IR.MIR.KR.Lhyp - EUNIS A3.214 - Description: Kelp Forest

Laminaria hyperborea *and foliose red seaweeds on moderately exposed infralittoral rock.*

A shallow water (<20 metres below chart datum) biotope associated with moderate to steeply inclined bedrock and boulders. The biotope is defined by dense growths of the brown seaweed *Laminaria* (kelp) particularly *L. hyperborea* although the shallow subtidal (<3 metres) and in more sheltered areas may be populated with *L. digitata* and *L. ochrolucea*. Deeper than circa 12 to 15 metres this biotope will have a lower density of *Laminaria* and will be classified as kelp park (IR.MIR.KR.Lhyp.Pk).

Kelp forest is viewed as a key habitat because of its beneficial ecosystem services, especially in relation to biodiversity and nursery provision. The stipes of individual plants may support a variety of short red seaweeds and their holdfasts may be utilised by small crustaceans, worms and encrusting bryozoans. The rock to which kelp plants are attached is often scoured and shaded from sunlight making species poor for other seaweeds but more favourable for encrusting organisms such as sponges, bryozoans, hydroids and ascidians. The shelter and protection provided by kelp forests (including crevices, holes and overhangs in the bedrock/boulders) means that this biotope supports a wide variety of fish, crustaceans, molluscs and other species.

In Jersey waters kelp forests are associated with the shallow subtidal fringe and offshore rocky reefs. It may be the dominant shallow water habitat on the edge of the island's offshore reefs and immediately offshore from headlands and cliffs.



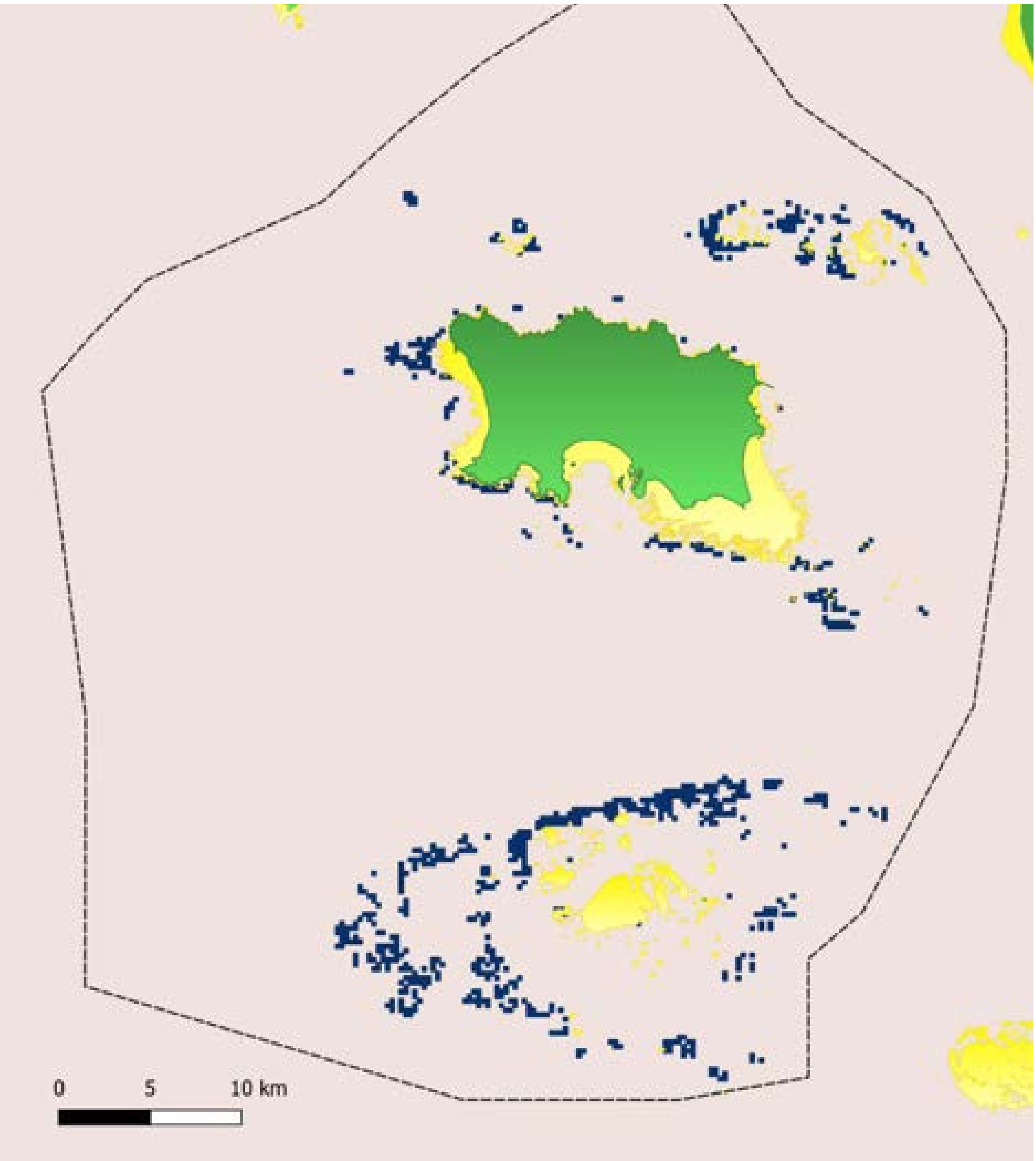
JNCC IR.MIR.KR.Lhyp.Pk - EUNIS A3.2142 - Description: Kelp park

Laminaria hyperborea *park and foliose red seaweeds on moderately exposed lower infralittoral rock*

Kelp park reflects a deeper water, less densely foliated, version of kelp forest with the boundary between the two often being gradational. Local and regional studies (e.g. Kerambrun, 1984) suggest that kelp park starts to form at around 12 to 15 metres below chart datum and that it ceases at around 20 metres depth where kelp plants will occur individually, rather in aggregations.

The principal kelp species is *Laminaria hyperborea* which may be accompanied by hardier species of red and brown seaweeds. As the density of kelp plants lessens with increasing depth, so the rocky substrate can become encrusted with barnacles, anemones, hydroids, ascidians, sponges and sometimes sea fans and cup corals.

The ecosystem service and other provisioning associated with kelp forests applied to kelp park as well with the biotope being considered as a key habitat. Kelp park is integrally associated with kelp forest and will occur in the same areas, where the water depth is deep enough.

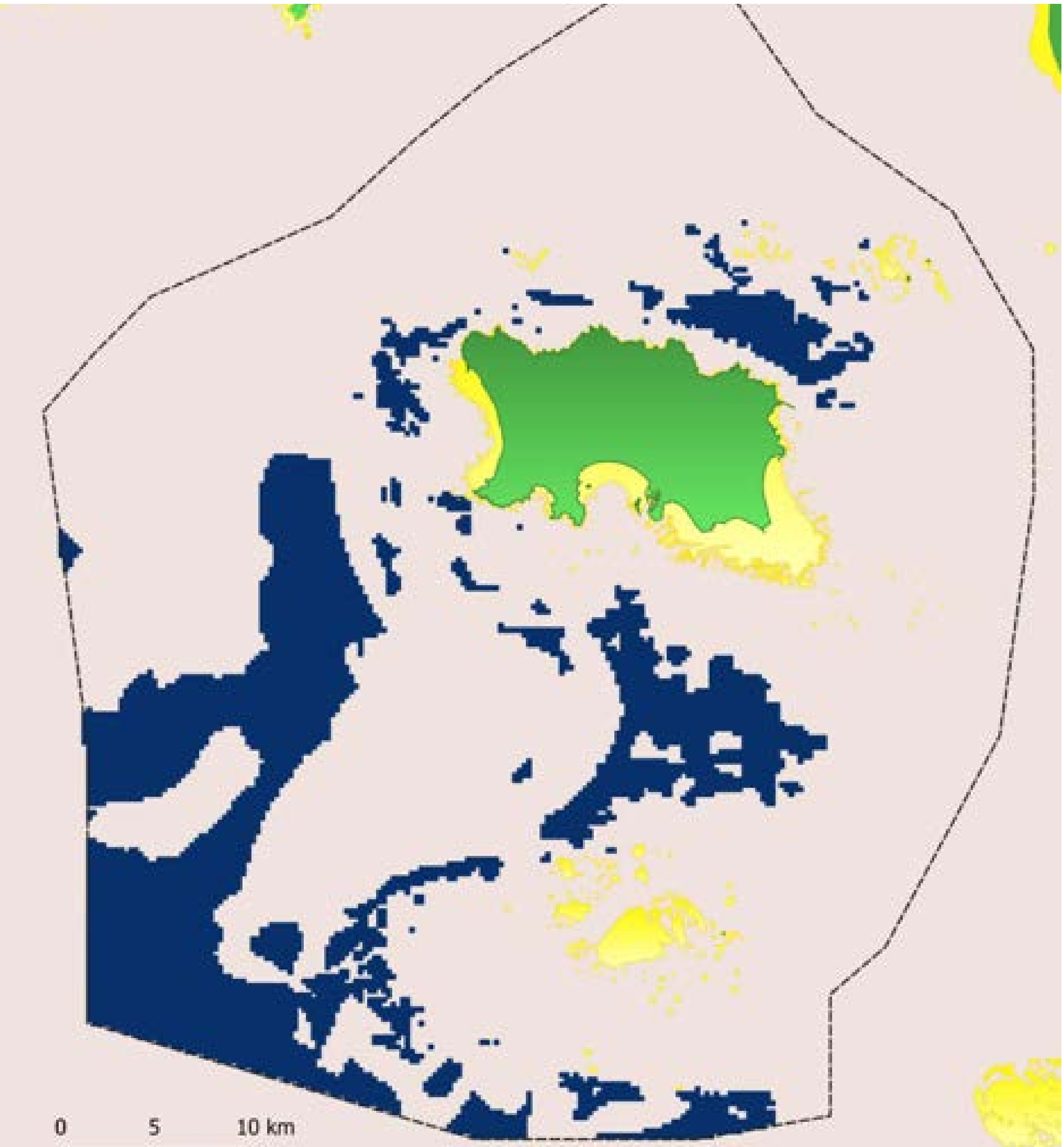


JNCC CR.HCR.XFa - EUNIS A4.13 - Description: Hard Ground

Mixed faunal turf communities

This is a deeper water (>20 metres below chart datum) biotope dominated by bedrock, boulders, cobble and other hard, immobile rock substrata. A combination of depth with moderate to strong tidal streams and periodic exposure to wave energy leads to a general absence of vegetation and sediment. There may be a restricted fauna of encrusting sponges, bryozoans, ascidians, barnacles, hydroids and other species. Other possible species could include crustaceans, echinoderms and benthic or semi-demersal fish, sometimes in quite large numbers. Dense aggregations of brittlestars may occur in some areas with some sediment cover and so could lead to a separate classification of SS.SMx.CMx.OphMx (brittlestar beds on sublittoral mixed sediment).

Within Jersey waters this biotope is associated with exposed seafloor areas that are subject to high tidal streams, especially at the entrance to the main sedimentary basins, off headlands and to the south-west of Jersey. The inaccessibility and depth of this habitat means it has not been widely studied or sampled.

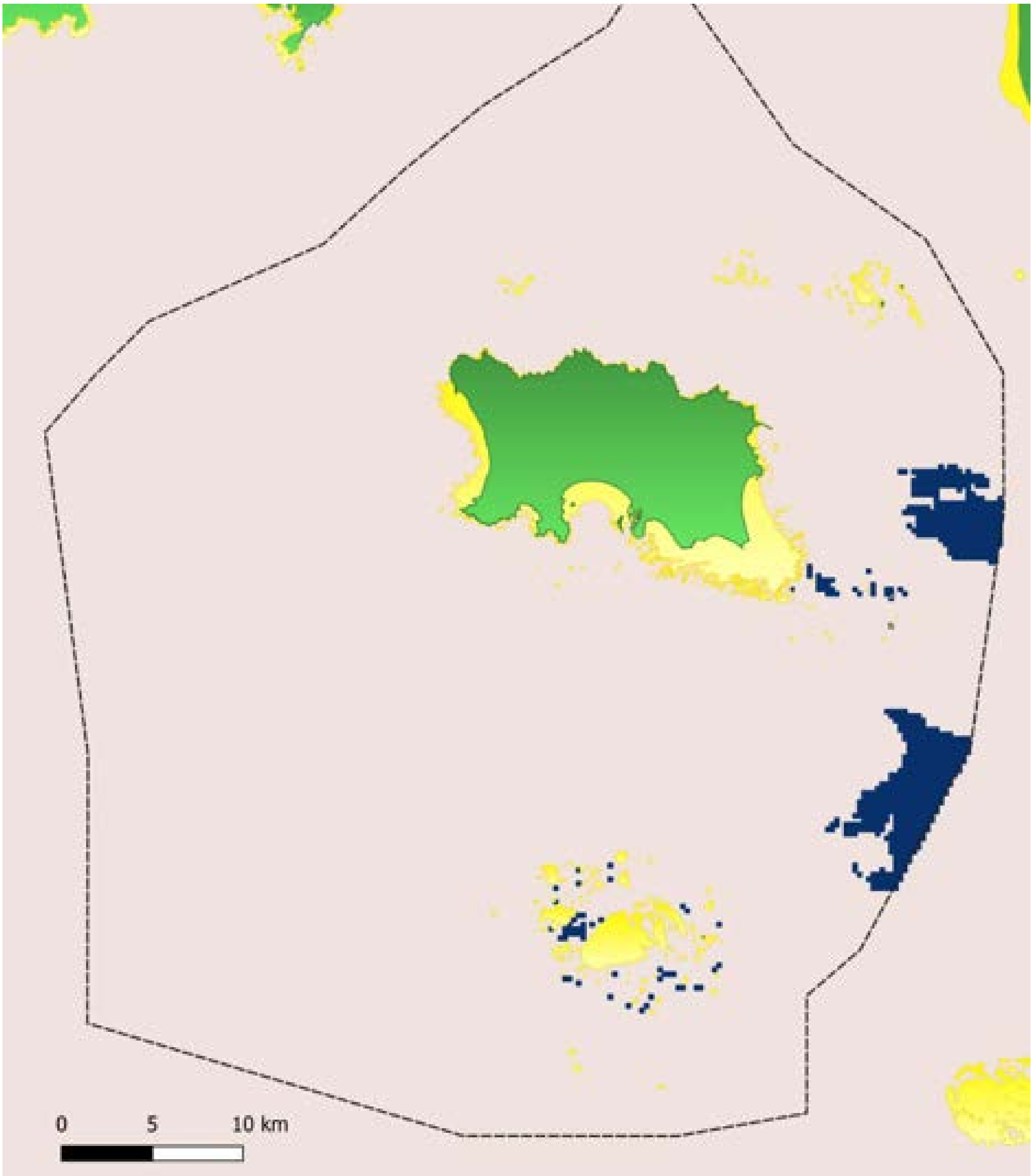


JNCC SS.SCS.ICS.MoeVen - EUNIS A5.133 - Description: Basin Gravel/Sand

Moerella *spp. with venerid bivalves in infralittoral gravelly sand*

This biotope is predominantly a mixed coarse substrate of sand, gravel, shell and, in places, fine sand, silt and maerl. It is typical of strong tidal regimes in shallow water areas (<15 metres below chart datum) but is relatively stable. This may be a diverse habitat with a dense burrowing fauna of bivalve molluscs, burrowing crustaceans, anemones, worms, echinoderms, etc. The epifauna may also be diverse with gastropod and bivalve molluscs, crabs, rays and demersal and semi-demersal fish species.

In Jersey waters the largest extents of this biotope form in offshore parts of sedimentary basins such as along the eastern sea border with France where the sediment can accumulate to a depth of several metres. Smaller patches form within the offshore reef complexes such off the south-east coast and Les Minquiers, often downstream from seabed obstacles such as rock ridges and sandbanks.

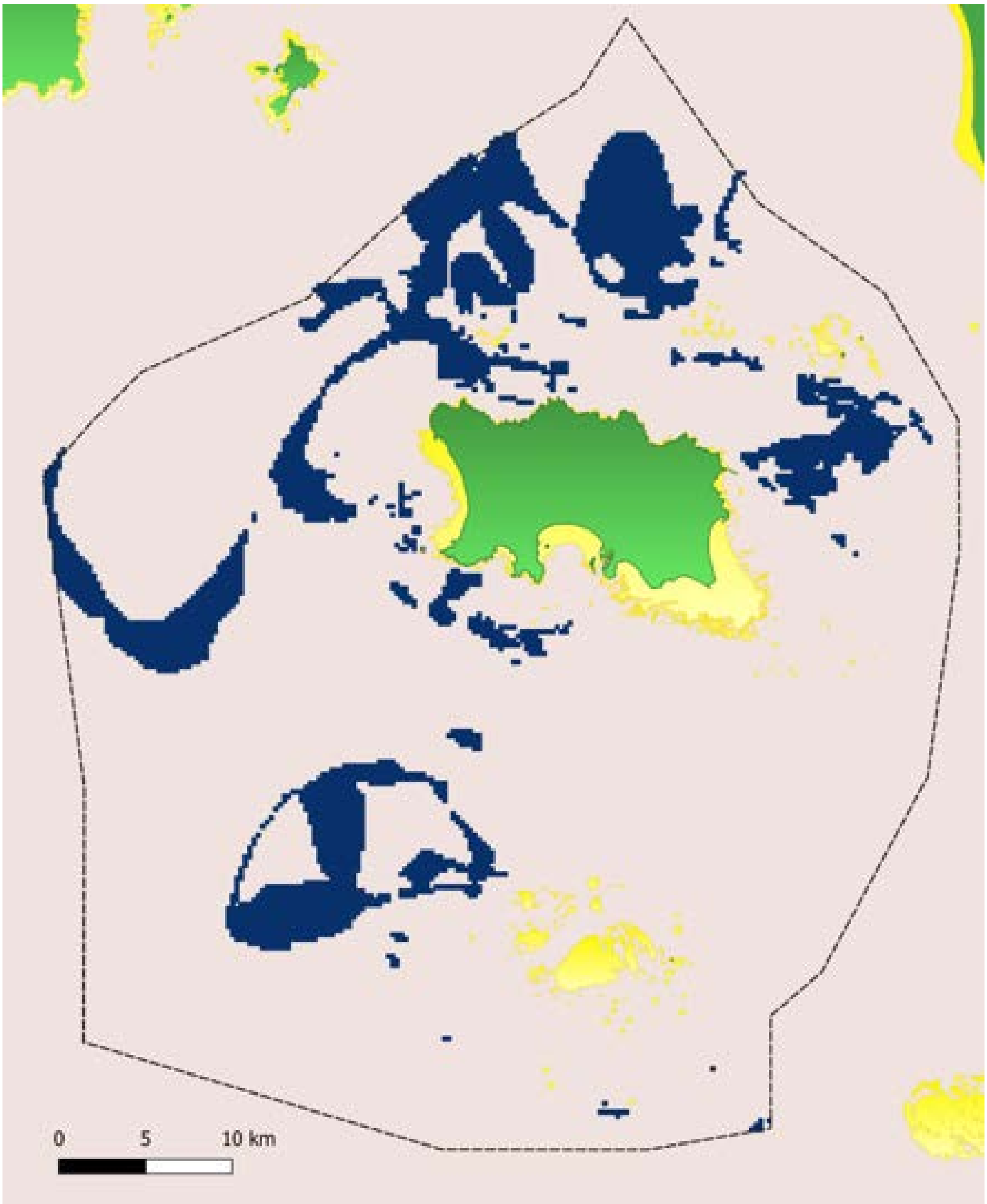


JNCC SS.SCS.ICS.Glap - EUNIS A5.135 - Description: Offshore Gravels/Sands

Glycera lapidum *in impoverished infralittoral mobile gravel and sand*

The identification and extent of this biotope in Jersey waters is based mostly on survey work undertaken during the 1970s. This biotope has many of the same characteristics as SS.SCS.CCS.Blan (see below) and forms in strong tidal current regimes shadow of seabed obstacles such as sandbanks and reefs. Its sediment is less stable and more subject to scour than that of SS.SCS.CCS.Blan leading to a more restricted fauna. There is a possible correlation between this biotope and the offshore oyster beds that once existed regionally but which were fished to extinction during the Victorian era (Société Jersiaise, pers. comm.).

In Jersey waters this biotope is closely associated with the fringes of offshore sandbanks and the margins of topographic features especially to the north and west of Jersey and north-west of Les Minquiers.

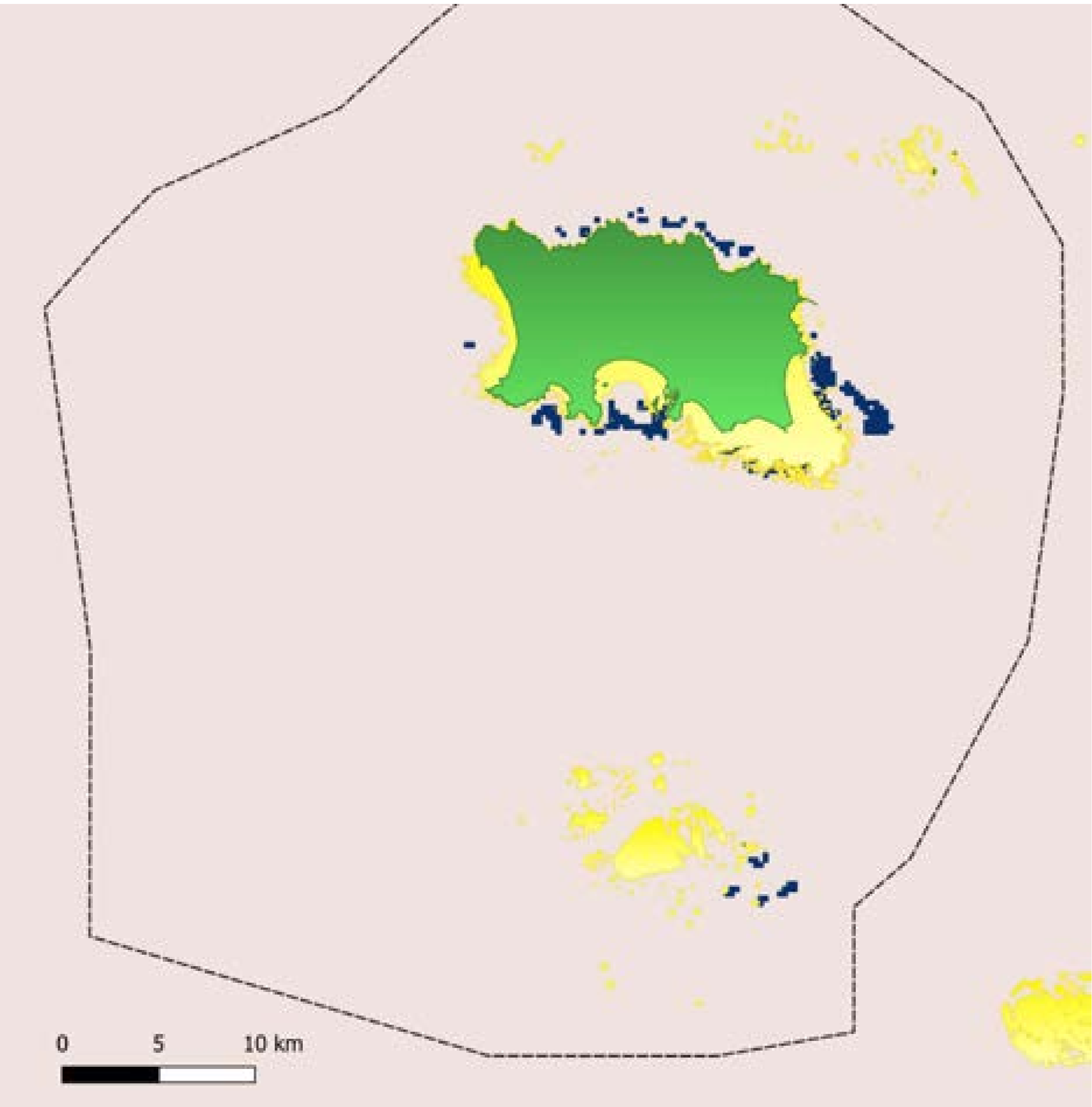


JNCC SS.SCS.ICS.Slan - EUNIS A5.137 - Description: Sandmason Worms/Fringe stable sand

Dense Lanice conchilega *and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand*

This biotope is mostly found on the sheltered fringes of basins and some shallow marine areas. It is characterised by a stable substrate of medium to coarse sand (plus low gravel/fine sand content) with a high density of the sandmason worm (*Lanice conchilega*) whose cemented tubes protrude above the sediment surface. The density of *L. conchilega* is around 50 to 100 ind./m^2 on the middle and lower shore but this may increase to more than 500 ind./m^2 offshore. Studies on Jersey and Chausey suggest that *L. conchilega* beds have burrowing species richness/abundance that is statistically similar to seagrass beds. It is probable that *L. conchilega* beds are undervalued as a key habitat and that their importance in provisioning ecosystem services to both natural and human activities has not been fully recognised (Godet *et al.* 2008; Société Jersiaise, pers. comm.).

In Jersey *L. conchilega* beds dominate the wide, sheltered bays and sandy areas along the south and east coasts from St Aubin's to St Catherine's Bays. These beds start on the middle and lower shore and continue into the subtidal where they may grade into other high value habitats such as maerl and seagrass. Offshore beds occur at St Brelade's Bay, in north coast bays (e.g. Bouley Bay) and the east coast where they are often associated with the edges of maerl beds (SS.Smp.Mrl see below).

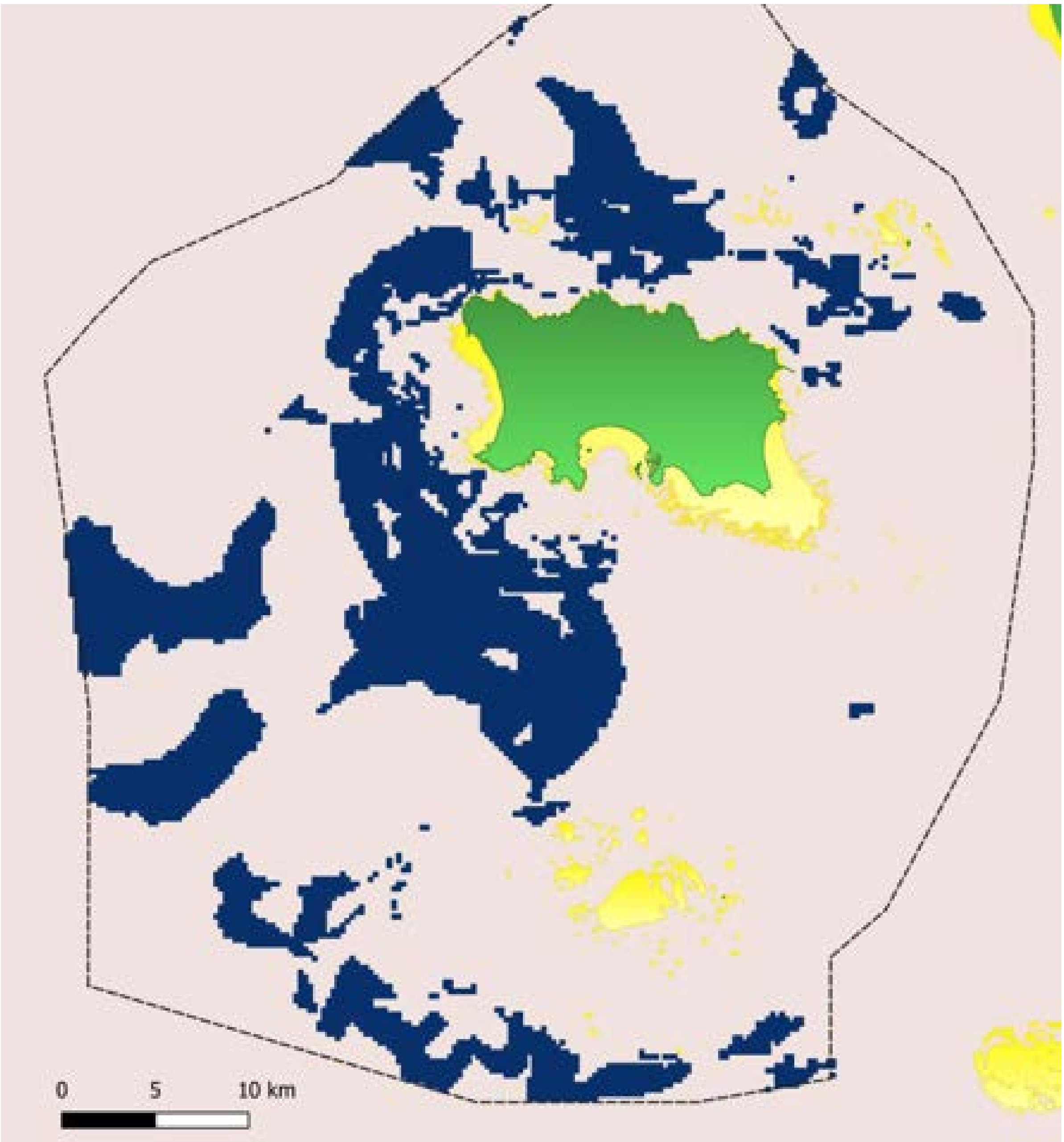


JNCC SS.SCS.CCS.PomB - EUNIS A5.141 - Description: Hard Ground

Pomatoceros triqueter *with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles*

This biotope forms in deeper water (>20 metres below chart datum) areas subject to strong tidal currents and wave exposure. It is subject to scouring leaving a seafloor that is dominated by cobble and pebble with a limited and often unstable coarse sediment cover of coarse sand or gravel. Being high energy, sediment poor and beyond the light depth of most seaweeds means that fauna will be either encrusting species (bryozoans, sponges, hydroids, tube worms, etc.) or mobile animals able to cling to the seabed or live in any interstitial gaps (crabs, anemones, starfish, gastropods, etc.). Larger fish species, such as rays, may be found here but in general this is a lower biodiversity habitat.

In Jersey waters this biotope covers large areas of low gradient exposed seabed areas immediately to the west and north of the island and to the west of Les Minquiers. As such it is typical of the open plain areas of seabed that fringe topographic features and have a limited and generally unstable sedimentation regime. To the west and north of this region this biotope merges into offshore sandbanks typified by SS.SCS.CCS.Blan and SS.SCS.ICS.Glap. Although it has some differences to exposed bedrock habitats such as CR.HCR.XFa, this biotope occurs in the same conditions and has many of the same processes and functions.

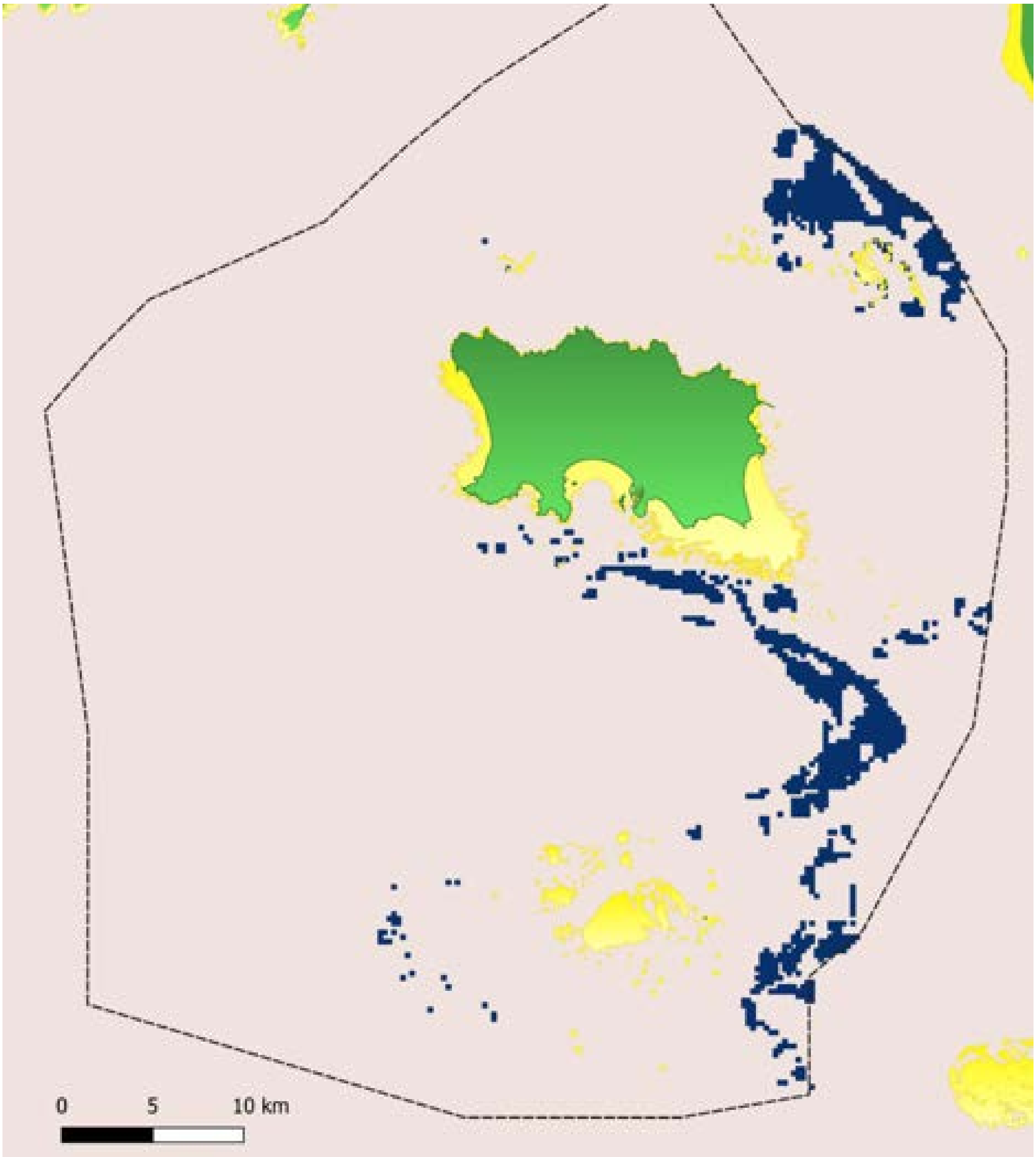


JNCC SS.SCS.CCS.MedLumVen - EUNIS A5.142 - Description: Basin Gravel/Sand

Mediomastus fragilis, Lumbrineris *spp. and venerid bivalves in circalittoral coarse sand or gravel*

This represents a sedimentary biotope found offshore (generally >15 metres below chart datum) which is dominated by coarse sand and gravel but with a variable contribution of shell material and finer sediment. This coarse mixed sediment substrate forms in areas that are subject to strong tidal currents, the combination of which can produce a diverse burrowing fauna of polychaetes, anemones, echinoderms and robust molluscs (especially bivalves) plus an epifauna of gastropod molluscs, crabs and fish.

In Jersey waters this biotope is associated with basin fringes where it is clustered around the 002°W line to the north of Les Écréhous, south of Jersey and east of Les Minquiers. As such it is indicative of deeper water exposed basin fringes where sediment starts to accumulate and stabilise. This biotope is often found between the similar but more stable SS.SCS.ICS.MoeVen (down current) and the less stable IR.HIR.Ksed (up current).

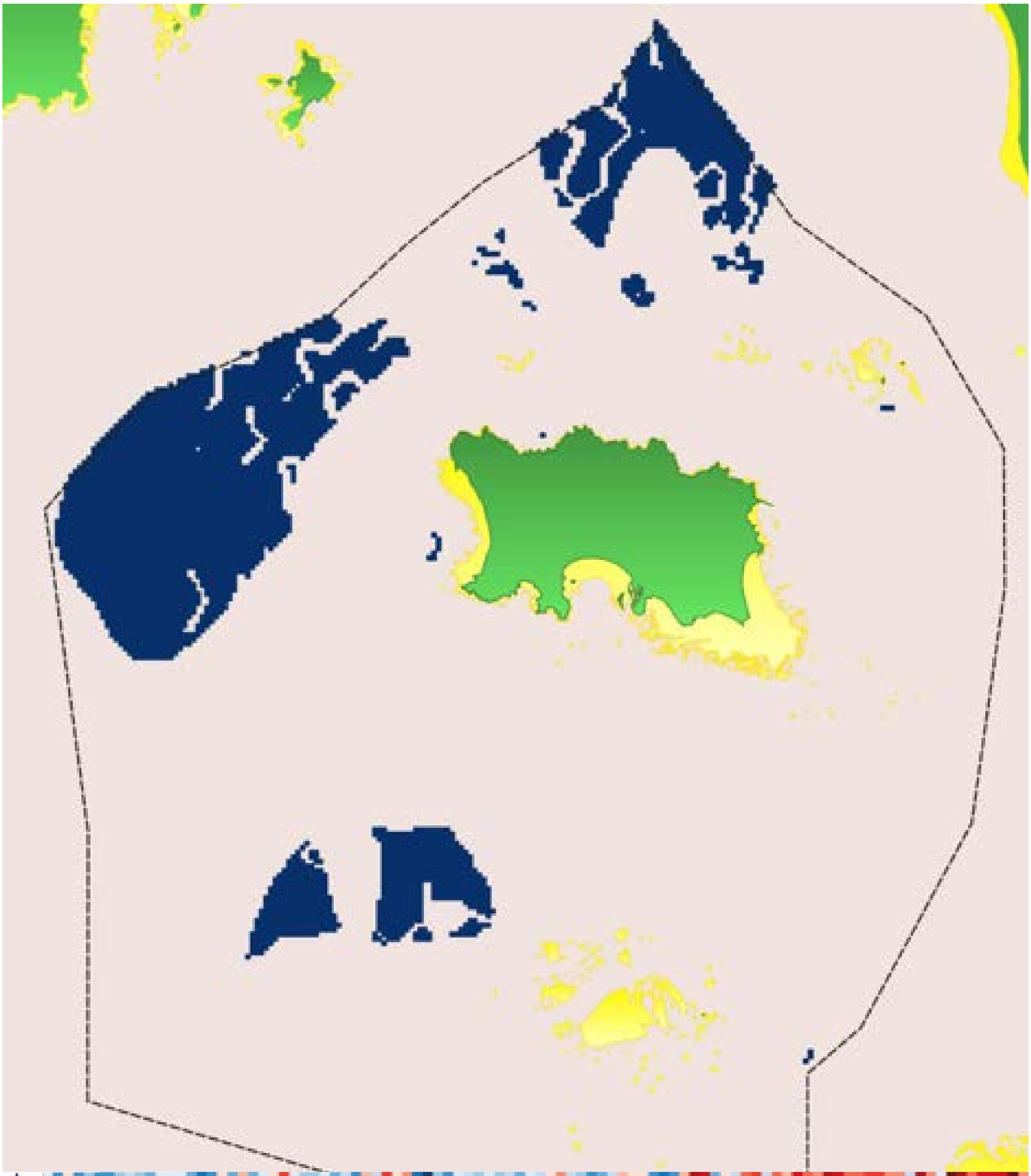


JNCC SS.SCS.CCS.Blan - EUNIS A5.145 - Description: Offshore Gravels/Sands

Branchiostoma lanceolatum *in circalittoral coarse sand with shell gravel*

This is an offshore biotope found deeper than about 20 metres in areas influenced by strong tidal currents. The substrate is dominated by mobile coarse sand and gravel which can have a moderately diverse burrowing fauna of molluscs (bivalves), polychaetes and echinoderms. The instability of the sediment tends to limit sessile epifauna but it can support benthic and semi-demersal fish species including commercial species such as rays and flatfish. There may be areas of more mobile sand that display high tidal energy bedforms such as sand waves, scour and streaks.

Within Jersey waters this biotope is indicative of offshore sand and gravel banks that will form in association with significant topographic features such as islands, offshore reefs and shoals. It will often grade into SS.SCS.ICS.Glap in the direction of the dominant tidal current. The offshore position of this biotope means that it has not been widely studied and much of what is known about this biotope comes from local studies from the 1970s and 1980s.



JNCC SS.SSa.IFiSa - EUNIS A5.23 - Description: Fringe medium and fine sand/Fringe Stable Sand

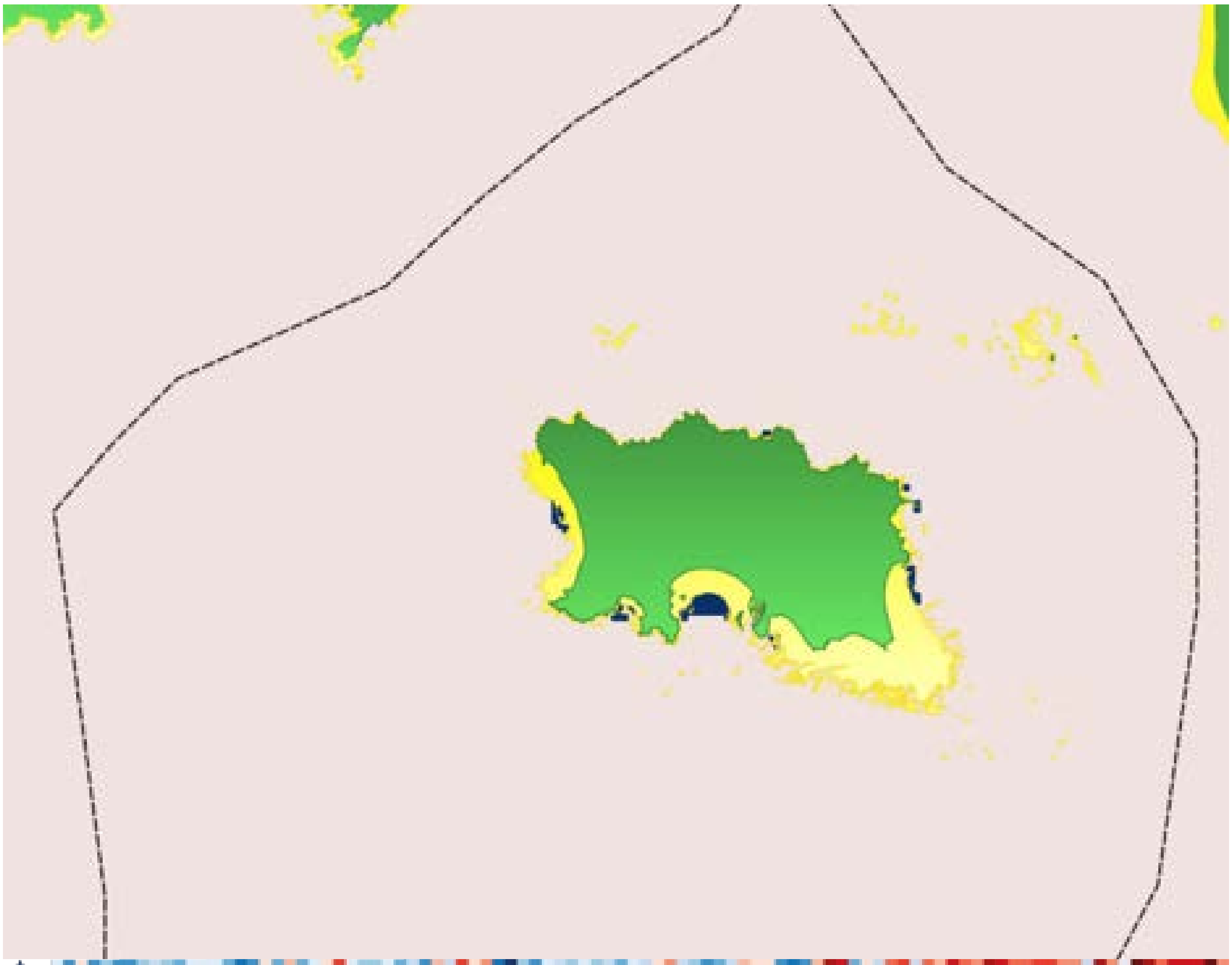
Infralittoral fine sand

A medium to low energy biotope characterised by medium and fine sand that has been moderately or well-sorted. It is primarily associated with more sheltered bays and near-shore shallow coastal areas where a combination of depth and coastline topography serve to lower the tidal current velocity. As such it is usually a fringe habitat, primarily associated with basin margins and wide bays. The substrate is generally stable with bedform features that may include sand ripples and small waves. The action of storms can create larger, usually temporary, features such as scour marks and larger sand waves.

The sedimentary stability of this biotope encourages a diverse burrowing fauna of annelids, burrowing crustaceans, molluscs, echinoderms, etc. In sheltered bays anoxia may be just a few centimetres below the surface, restricting the depth that some organisms can live. More exposed areas (such as St Ouen's Bay) may have no anoxic layer but a lower diversity of species due to increased sediment mobility.

Epifauna and bentho-pelagic species may include a variety of fish, gastropods, large to small crustaceans, burrowing anemones, etc. Algae is not common where suitable attachment points (generally loose rocks or bedrock) occur. Sheltered intertidal lower shore areas may have dwarf eelgrass (*Zostera noltii*).

Within Jersey waters this biotope is primarily associated with the island's coast where it dominates wide, horseshoe-shaped bays along the south and east coasts. The west and north-west of the island also has this biotope although it is more affected by waves and storms. Inshore this will grade into intertidal sand flats while offshore it may grade into a variety of higher energy coarse grained sedimentary habitats but especially SS.SCS.ICS.Slan (sandmason worms) on the east and south coasts it may grade into SS.SMp.SSgr.Zmar (seagrass beds).

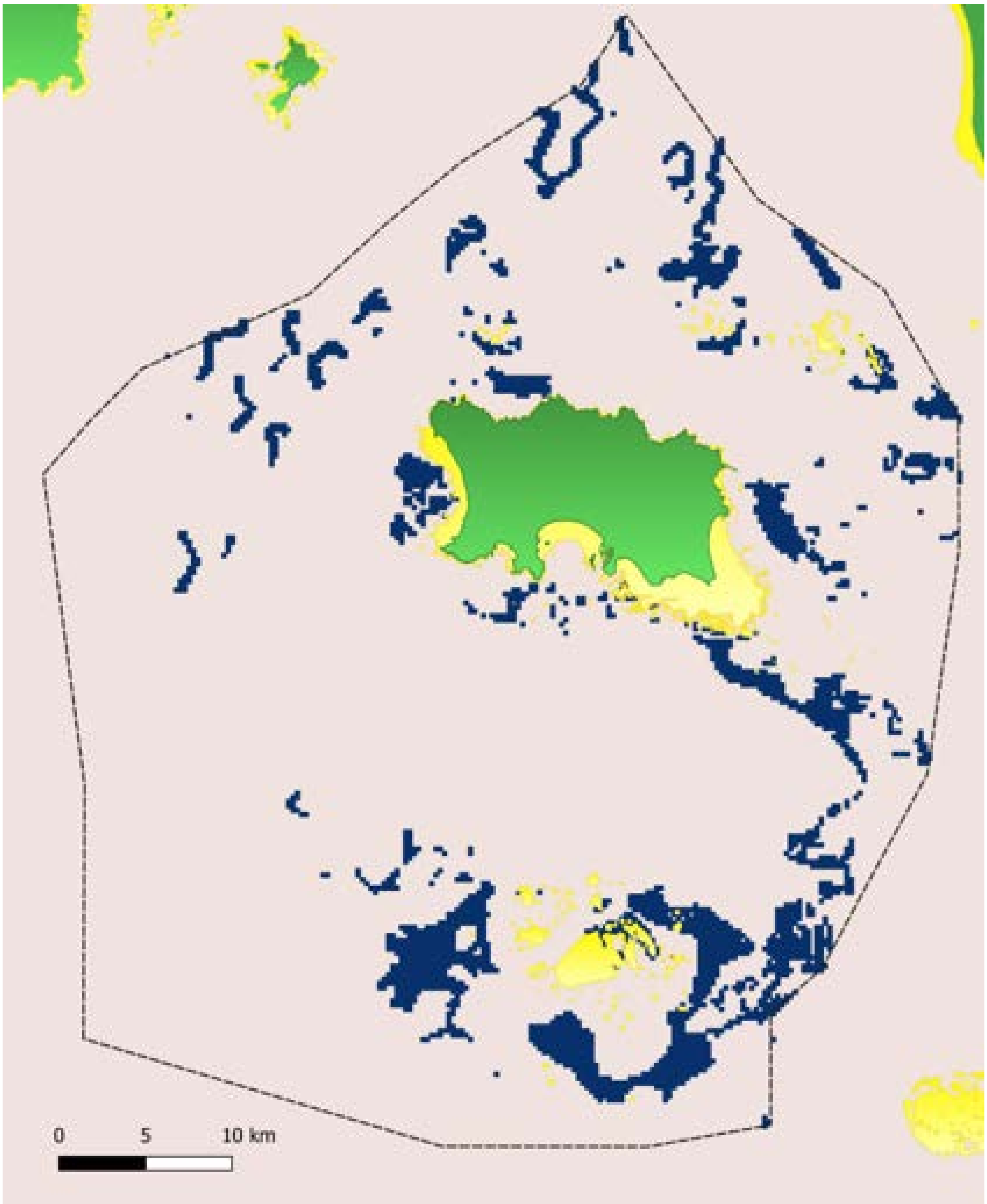


JNCC SS.SSa.IFiSa.IMoSa - EUNIS A5.231 - Description: Mobile sand

Infralittoral mobile clean sand with sparse fauna

This is a high energy biotope formed from well-sorted unconsolidated coarse to medium sand which will become mobile during periods of strong tidal currents and storms. The sand will usually exhibit large bedform structures such as megaripples, sand waves (often large), scour and streaks. In areas of very strong tidal flow elongate 'banner banks' (sometimes composed of gravelly sand) may form downstream from large seabed obstacles such as reefs or headlands (e.g. L'Écrevière Bank and Le Banc du Château). The mobile nature of this habitat means that it is generally species poor with few attached or encrusting organisms and a limited burrowing fauna. Scavenging fish species and some polychaete and crustacean species can tolerate the shifting sands.

Within Jersey's territorial waters areas of mobile sand/gravel occur as shallow water (<20 metres below chart datum) banner banks or more extensive sand patches that form in tide-swept areas on the open seabed (>15 metres below chart datum) or within reefs (<15 metres below chart datum). With the latter some intermixing or gradation with the biotope IR.HIR.KSed.XKScrR is possible.

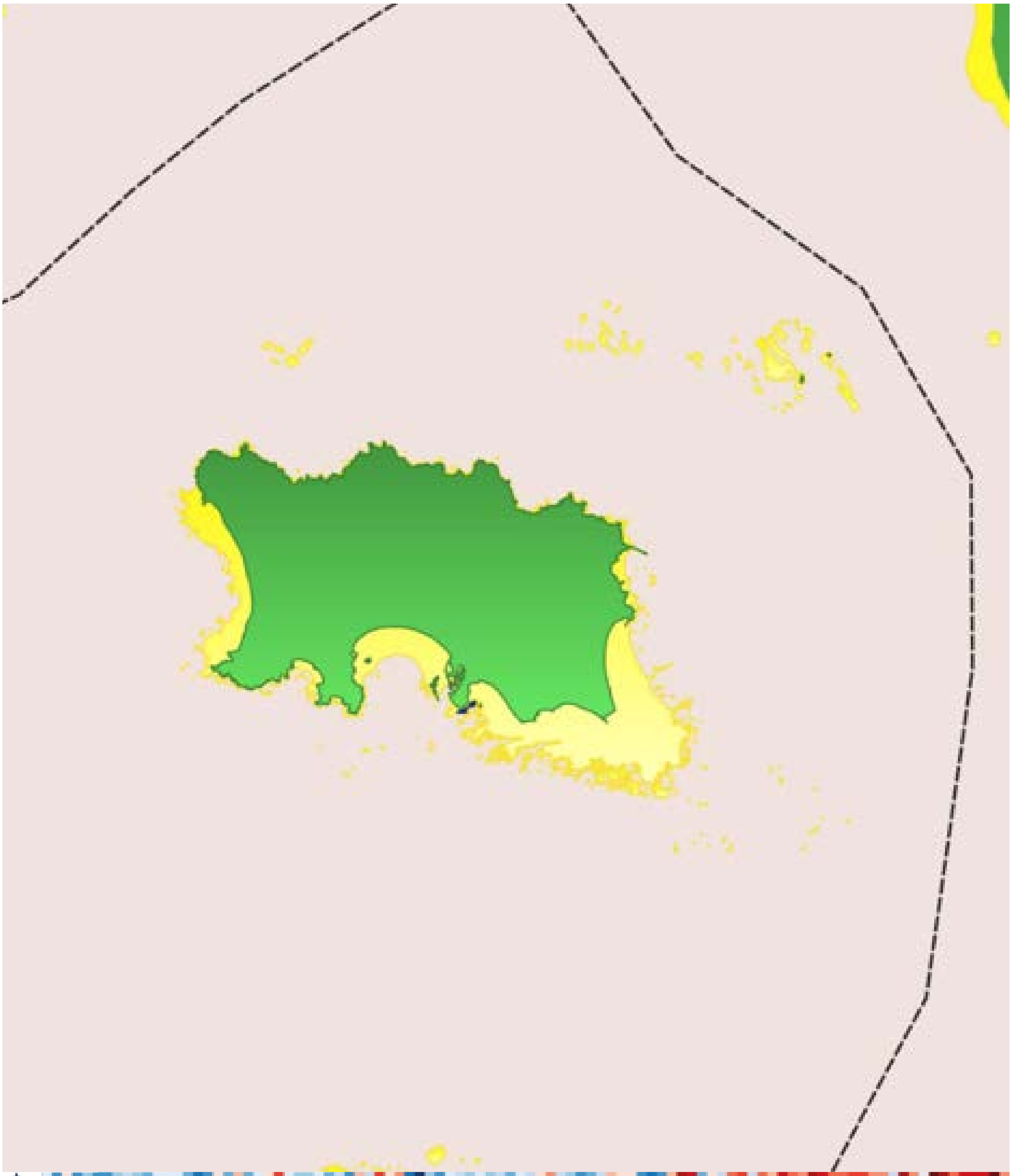


JNCC SS.SSa.IMuSa - EUNIS A5.24 - Description: Inshore fine to silty sand/Fringe Stable Sand

Infralittoral muddy sand

This is a biotope that is dominated by well-sorted fine sand which has a small silt component. It is stable, often water saturated with minor bedforms such as small ripples. Within the Normano-Breton Gulf this is primarily an intertidal habitat associated with large bays and estuaries in more sheltered positions. The biota associated with this habitat is similar to SS.SSa.IFiSa and, as such, this also represents an important feeding habitat for fish and seabirds, and a nursery habitat for a variety of species.

Around the Channel Islands muddy sand environments are mostly intertidal and do not extend far into subtidal areas. There may be areas of the French coast, such as the Bay of St Malo, where it is subtidal and performs an important ecosystem service. Around Jersey it is primarily restricted to the coves and bays of the east and south coasts (especially St Aubin's Bay).



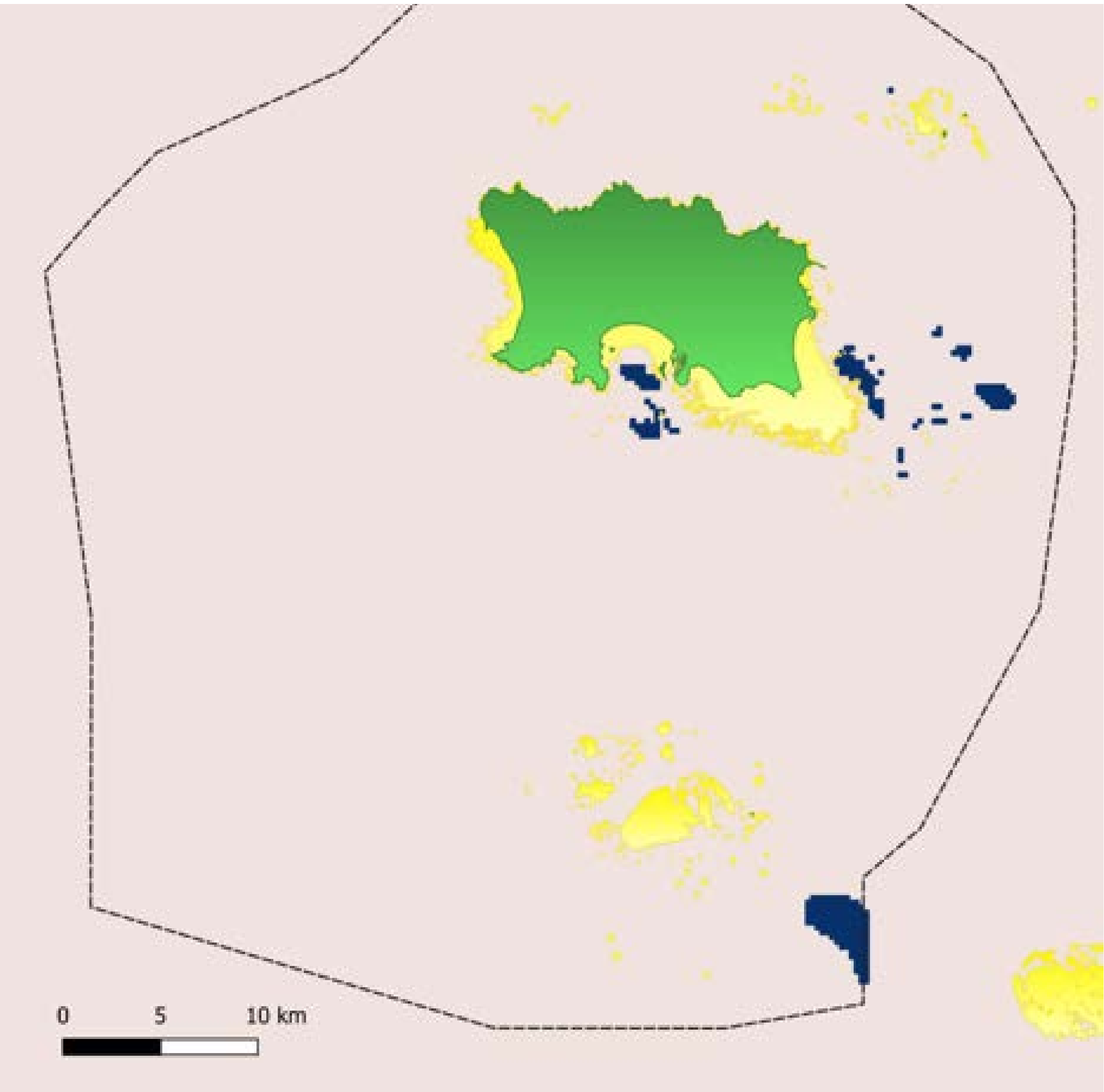
JNCC SS.SMx.IMx.CreAsAn - EUNIS A5.431 - Description: Slipper limpet beds

Crepidula fornicata *with ascidians and anemones on infralittoral coarse mixed sediment*

This biotope is a biogenic derivative of the invasive species *Crepidula fornicata* (American slipper limpet) which was unknown in the region prior to the 1960s. By the 1980s slipper limpets had become widespread and common across the Bay of Granville and, in the right circumstances, were forming dense aggregations covering large areas of seabed. As layers of dead slipper limpets accumulated, fine sediment and excretions from the limpets became trapped with the dead shells, creating anoxic conditions which stifled existing seabed life. The result is a low diversity habitat of low value which supports only a handful of species.

Slipper limpet beds are found in shallow (<15 metres below chart datum) basin fringe areas. On some Jersey slipper limpet beds the surface coverage of shells may be 100% to a thickness of several centimetres. In such situations silt and faecal matter will accumulate to produce a thick, anoxic layer just below the surface. In areas where coverage hasn't reached this stage there may be open patches of sediment, often of maerl or Sandmason Worms, between the accumulations of shell.

The presence and spread of slipper limpet habitats is of serious concern, not least because of the association with key habitats such as maerl. Recent research suggests that deep accumulations form in areas that have been subjected to commercial dredging over many years and, given its association with current and former scallop grounds around Jersey, this may be the case here too.

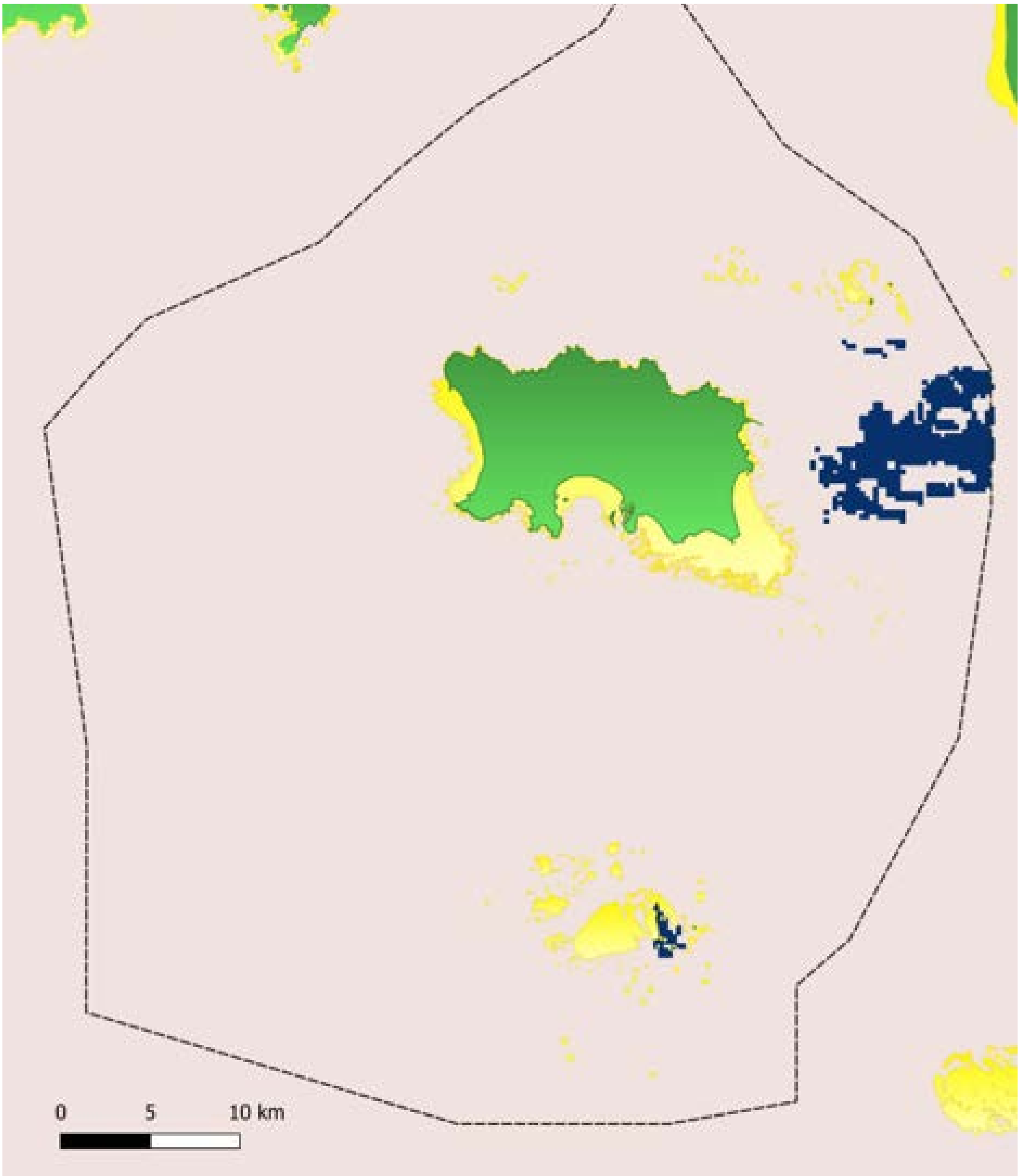


JNCC SS.SMx.OMx.PoVen - EUNIS A5.451 - Description: Basin Gravel/Sand

Polychaete-rich deep Venus *community in offshore mixed sediments*

This biotope is similar to SS.SCS.ICS.MoeVen and consists of mixed coarse sand, gravel and shell material but with a small content of finer sediment and maerl. The burrowing fauna is dominated by large quantities of the dog cockle (*Glycymeris glycymeris*), burrowing/tube forming polychaetes, crustaceans, sipuncilids and smaller bivalves. The epifauna may also be diverse and include gastropod molluscs, crustaceans and demersal and semi-demersal fish. Short reds seaweeds may occur in more stable areas where there are suitable attachment points.

Within Jersey waters this biotope occurs in the central part of Les Écréhous basin where it forms a well-defined band between less stable seabed and more scoured areas and more stable, often higher biodiversity biotopes such as SS.SCS.ICS.MoeVen and SS.SMp.Mrl. This is a commercially important biotope that contains significant quantities of scallops, whelks and bivalves.



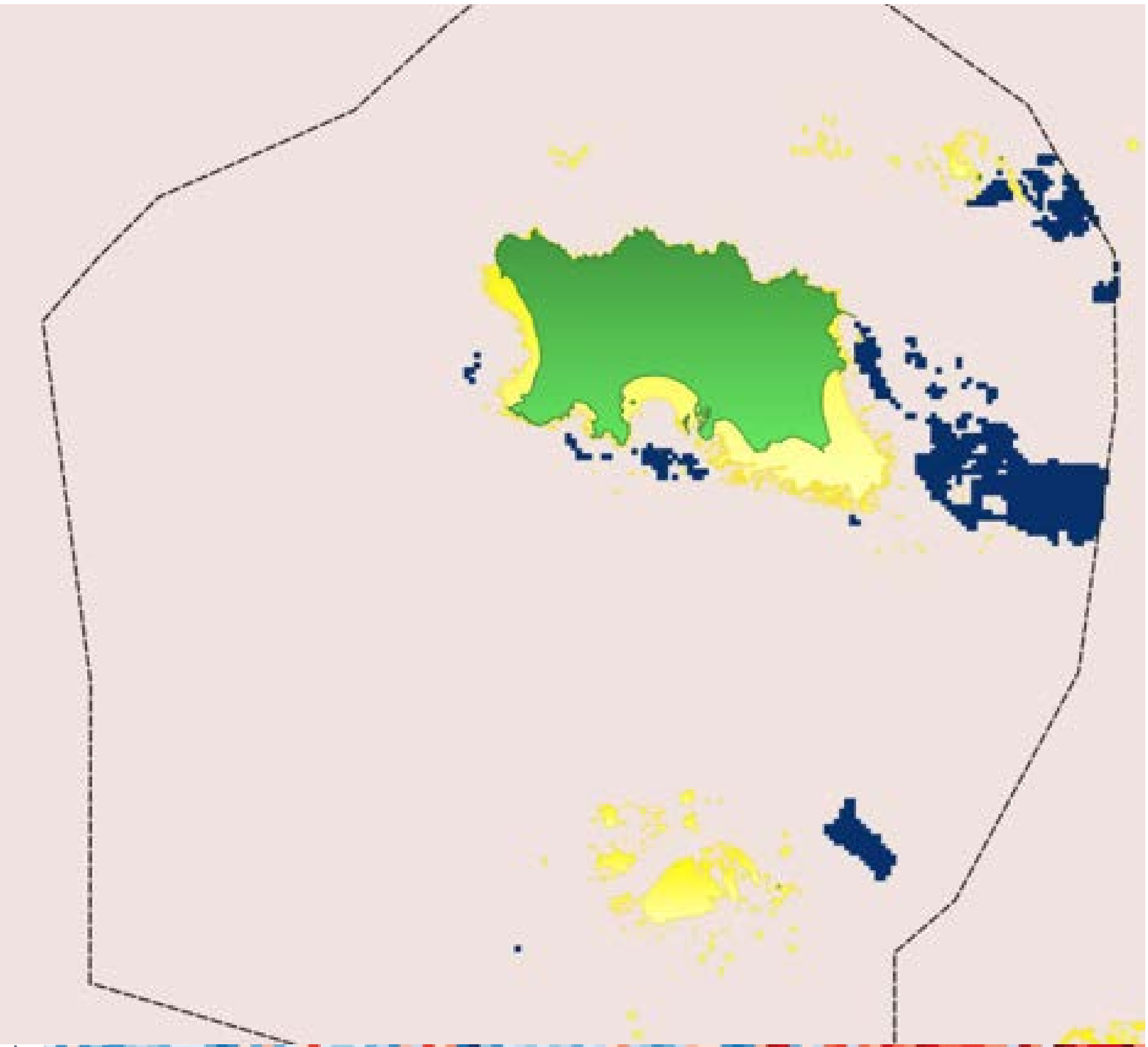
JNCC SS.SMp.Mrl - EUNIS A5.51 - Description: Maerl beds

Maerl beds

Maerl beds are internationally recognised as a threatened key habitat which requires a high level of protection. This biotope can be divided into several subcategories based on the species of maerl present and sediment type. However, although some of this information is available for Jersey waters, here the biotope is being used in its broader sense of 'maerl bed' which, following the OSPAR definition, means that at least 20% of the substrate is formed from living maerl thalli. As well as living and dead maerl, this biotope is characterised by mixed coarse sediment, often with a significant amount of finer sand and silt, plus broken shell. It generally forms in shallower water (>15 metres below chart datum) sheltered areas that are subject to strong tidal currents.

Maerl beds are covered by the OSPAR Convention (plus several other agreements) and are regarded as internationally important habitats. As well as having an exceptional diversity and abundance of species, maerl beds are important for their settling, nursery and carbon capture provisioning. Studies around Jersey suggest that maerl beds are the most diverse and fragile of the island's marine habitats.

Within Jersey waters maerl beds are primarily basin fringe deposits that have developed in association with significant topographic features such as offshore reefs. In deeper water maerl beds will grade into coarse bivalve-dominated habitats (SS.SCS.ICS.MoeVen and SS.SMx.OMx.PoVen) and in shallower water will grade into more sandy habitats such as SS.SCS.ICS.Slan. On the east and south coast areas of maerl are being subsumed by the invasive species *Crepidula fornicata* (SS.SMx.IMx.CreAsAn).



JNCC SS.SMp.SSgr.Zmar - EUNIS A5.5331 - Description: Seagrass meadows

Zostera marina *beds on lower shore or infralittoral clean or muddy sand*

Seagrass (eelgrass) meadows are internationally recognised as a key habitat which have a high ecosystem service value in terms of biodiversity, coastal health, climate change and human activities including fisheries. Within Europe seagrass meadows are variable but locally they are characterised by dense occurrences of *Zostera marina* which colonises gravelly coarse sand (generally within offshore reefs) or mixed sand, gravel and silt (generally more inshore locations). Seagrass meadows will bridge the intertidal and subtidal on the extreme lower shore and offshore to a depth of about five metres. This biotope is separate to the intertidal seagrass meadows (*Zostera noltii*) that are found in St Aubin's Bay and along Jersey's east coast.

Local and international studies have found seagrass meadows to be species rich especially for fish and crustaceans which use this habitat as a nursery area. Current studies are looking at seagrass meadows for its carbon burial/sequestration potential and as an indicator of coastal water quality.

Within Jersey waters seagrass meadows are a fringe littoral habitat found in topographically complex areas with a high tidal flow. The largest expanse of seagrass runs south from St Catherine's Breakwater along the east coast to Icho Tower. Outside of this seagrass tends to occur as small to large isolated patches within reef complexes or on the edge of wide bays. In the 1930s European seagrass meadows suffered a catastrophic decline (probably disease inspired) which, in Jersey, saw their overall area decrease by 90%. Starting circa 2006, local seagrass beds began to expand spreading into tides-wept areas of sand and gravel so that it currently occupied around 50% of the area that it did in 1933 (Société Jersiaise, pers. comm.).