Shellfish Critical Mass Development Plan Pilot - Clyde

Mussel farm, Loch Striven Photo courtesy of Janet Brown

FINAL REPORT

SUBMITTED TO

CROWN ESTATE SCOTLAND (INTERIM MANAGEMENT)

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Abbreviations and Acronyms

ASSG	Association of Scottish Shellfish Growers
AV	Added Value
CES	Crown Estates Scotland
CMP	Clyde Marine Plan
DSP	Diarrhetic Shellfish Poisoning
EAA	Ecosystem Approach to Aquaculture
EBIT	Earnings Before Interest and Taxes
EU	European Union
HAB	Harmful Algal Bloom
HMNB	Her Majesty's Naval Base
ICZM	Integrated Coastal Zone Management

IMTA	Integrated Multi-Trophic Aquaculture
IRR	Internal Rate of Return
LPA	Local Planning Authorities
MCA	Maritime and Coastguard Agency
MLLW	Mean Lower Low Water
MOD	Ministry of Defence
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
MSS	Marine Scotland Science
NPMi	National Marine Plan interactive
NZ	New Zealand
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PEXA	Practice and Exercise Areas (Maritime Military)
PMF	Priority Marine Features
POM	Particulate Organic Matter
PSU	Practical Salinity Unit
RAMSAR	Ramsar Convention on Wetlands of International Importance
RMP	Remote Monitoring Point
RYA	Royal Yachting Association
SAC	Special Area of Conservation
SAMS	The Scottish Association for Marine Science
SARF	Scottish Aquaculture Research Forum
SEPA	Scottish Environment Protection Agency
SIC	Shetland Islands Council
SPA	Special Protection Area
SPA	Special Protection Area
SSDCM	Scottish Shellfish Development Critical Mass
SSSI	Site of Special Scientific Interest
SWH	Significant Wave Height
UNCLOS	United Nations Convention of the Law of the Sea
USFDA	United States Food and Drug Administration
WFD	Water Framework Directive

1 INTRODUCTION

1.1 STUDY BACKGROUND

The opportunity for the further sustainable development of the Scottish mussel farming sector is being hampered by the ongoing difficulties associated with securing suitable new sites. The main issues faced by potential investors include identifying potential sites that are suitable for mussel farming operations and then navigating the current set of disproportionately expensive and somewhat inconsistently applied planning processes in order to secure such sites.

This study looks at possible solutions to the aforementioned challenges and builds on previous work[1] that promoted a collaborative, loch wide approach to developing new mussel farming operations.

Scotland Mussel farming - Current situation

In the latest Marine Scotland Science Scottish Shellfish Farm Production Survey 2018, mussel production for the table decreased by 16% from the previous year. In 2017 mussel production, for the table, increased by 6% in 2017 to 8,232 tonnes. This is the highest level of mussel production recorded in Scotland, 81% (6,647 tonnes) of which was from Shetland. In 2018 this dropped to 6,874 tonnes, with Shetland accounting for 75% (5,160 tonnes), all of the drop in production was in Shetland where it fell by 22%, whilst in the rest of Scotland production increased by 8%.

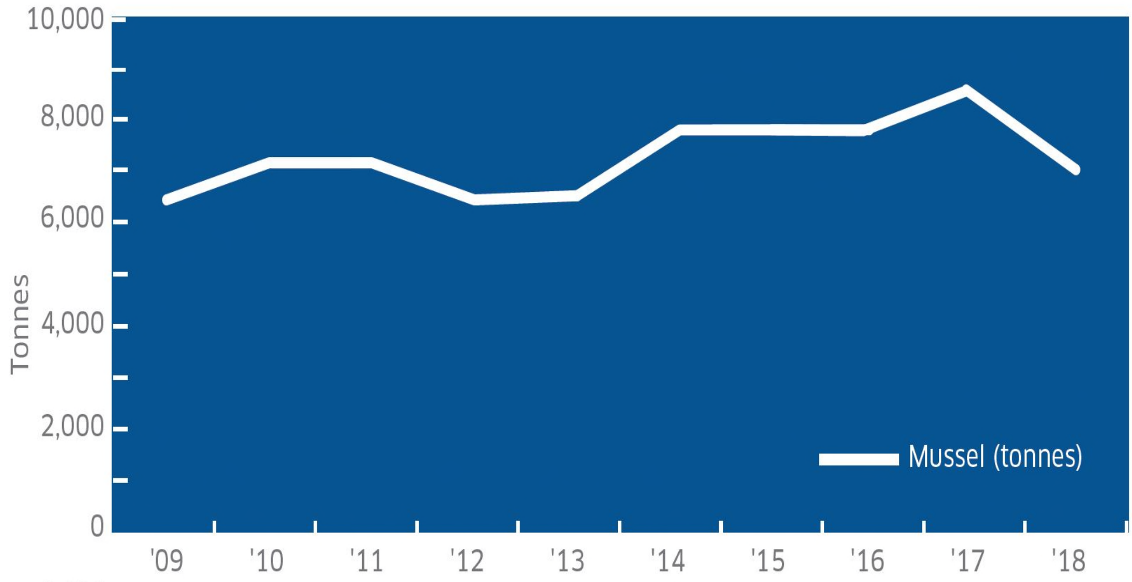

Figure 1: Table mussel production 2009-2018

Source: MSS Scottish Shellfish Farm Production Survey 2018

Business production levels by species are shown in **Error! Reference source not found.**, below. There were 15 businesses producing more than 100 tonnes of mussels (compared to 18 in 2017), out of these 9 produced more than 200 tonnes. These 9 businesses produced 74% of the total mussel production in Scotland.

[1] https://www.crownestatescotland.com/maps-and-publications/download/118

Species	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-200	>200	Total
Pacific oyster (000s)	9	1	0	2	2	2	1	2	0	0	1	7	**27**
Native oyster (000s)	1	0	0	0	0	0	0	0	0	0	1	0	**2**
Scallop (000s)	1	2	0	0	0	0	0	0	0	0	0	0	**3**
Queen (000s)	1	1	0	0	0	0	0	0	0	0	0	0	**2**
Mussel (tonnes)	6	2	2	3	2	2	3	0	2	1	6	9	**38**
Total	**18**	**6**	**2**	**5**	**4**	**4**	**4**	**2**	**2**	**1**	**8**	**16**	**72**

Table 1: Business production levels by soecies 2018

Source: MSS Scottish Shellfish Farm Production Survey 2018

1.2 OBJECTIVES

The two objectives for this study are:

- To identify potential areas for mussel farming within the Clyde region and provide investment ready detail to facilitate potential uptake for a commercial development.
- To provide a process framework used to achieve the above that can constitute a template for use elsewhere in Scotland for similar development purposes.

The above have been addressed in separate reports with this report focusing on the first objective.

1.3 APPROACH

The work was carried out mainly as a desktop review of available data and information augmented through discussions with relevant stakeholders and, specifically in relation to site selection, with industry contacts.

The Clyde region was chosen as the target location for developing this study due to its suitability for farming shellfish and, moreover, because it is one of only two UK regions that have a marine management plan under development. This provided the opportunity to engage with that process and help to identify and develop key tools that could be used to inform and support a more equitable approach to gaining planning consent for shellfish farming projects.

2 SITE SELECTION AND CARRYING CAPACITY

2.1 BACKGROUND ON THE CLYDE REGION

The Clyde has a surface area of just over 4,000 km^2, which itself includes the Clyde Estuary, the Firth of Clyde and the Clyde sea lochs. In general, the waters are relatively shallow but reach depths of over 100 m in the fjordic sea lochs of the Clyde, with a maximum depth of 151m and an average depth of 40m. The area exhibits a considerable tidal range, illustrated by mesotides (2-4 m) in the Clyde area.

The Clyde hosts a wide range of maritime activities and consequently subject to a number of pressures. Aquaculture, particularly salmon and shellfish production, takes place in a number of sea lochs and there is widespread fishing, mainly for Nephrops and scallops. There are significant ports, shipping and ferry activities with 20% of Scottish cargo volume passing through the Clyde ports. These are the busiest areas for ferry traffic with key links to various islands and peninsulas, as well as Northern Ireland, accounting for 64% of overall Scottish passenger traffic. Scotland’s only Naval base is on the Clyde. The areas are popular for recreational sailing, supporting 44% of Scottish boat berths. There are also popular bathing beaches on the Ayrshire coast. The Clyde Estuary and Ayrshire coast are relatively urbanised and industrialised compared with other parts of Scotland. This results in discharges from waste water treatment works and industrial effluents to estuary and coastal waters, as well as water abstraction, mainly for power generation, there are also seabed telecommunication cables, power cables, and wind farms. Pressures resulting from these activities include the introduction of contaminants from industrial effluents and sewage works and dumping of dredge spoil from harbour maintenance. Fishing using trawls and dredges results in the abrasion of the seabed. There are also local effects of aquaculture on seabed ecology.

The Clyde still has potential for hosting further development, in all sectors such as recreation/tourism, industrial facilities and aquaculture, particularly shellfish, in a sustainable manner in accord with the Clyde Marine Plan (CMP). The aim of this study is to build upon the Scottish Shellfish Development Critical Mass (SSDCM) model and report using the Clyde region as a practical example to demonstrate the required criteria and process to achieve sustainable growth in mussel production, highlight any constraints hindering such development and recommendations to overcome them, particularly in regards the planning process.

2.2 CARRYING CAPACITY

2.2.1 Introduction

Carrying capacity is an important concept for ecosystem-based management, which helps set the upper limits of aquaculture production given the environmental limits and social acceptability of aquaculture. In general terms, carrying capacity for any sector can be defined as the level of resource use both by humans or animals that can be sustained over the long term by the natural regenerative power of the environment. Carrying capacity is a major component of EAA (Ecosystem Approach to Aquaculture), but defining what is meant by carrying capacity, how to evaluate it and how to implement standards is not a straightforward matter. Assessment of carrying capacity is one of the most important tools for technical assessment of the environmental sustainability of aquaculture, it is not limited to farm or population sizes issues, but it can also be applied at the ecosystem and social level, and has been developed further into a more comprehensive four-category approach based on physical, production, ecological and social carrying capacity (Inglis, Hayden and Ross, 2000; McKindsey et al., 2006).

· Physical carrying capacity is based on the suitability for development of a given activity, taking into account the physical factors of the environment and the farming system. In its simplest form, it determines development potential in any location, but is not normally designed to evaluate that against regulations or limitations of any kind. In this context, this can also be considered as identification of sites or potential aquaculture zones from which a subsequent more specific site selection can be made for actual development. This capacity considers the entire waterbody, and identifies the total area suitable for aquaculture.

· Production carrying capacity estimates the maximum aquaculture production and is typically considered at the farm scale. For the culture of bivalves, this is the stocking density at which harvests are maximized. Estimates of this capacity are dependent upon the technology, production system and the investment required.

· Ecological carrying capacity is defined as the magnitude of aquaculture production that can be supported without leading to significant changes to ecological processes, services, species, populations or communities in the environment.

· Social carrying capacity has been defined as the amount of aquaculture that can be developed without adverse social impacts.

The process starts with site identification, this study is primarily concerned with site selection, so this initial stage (Phase 1) will be given most consideration, the other categories will be considered in the process but not fully assessed.

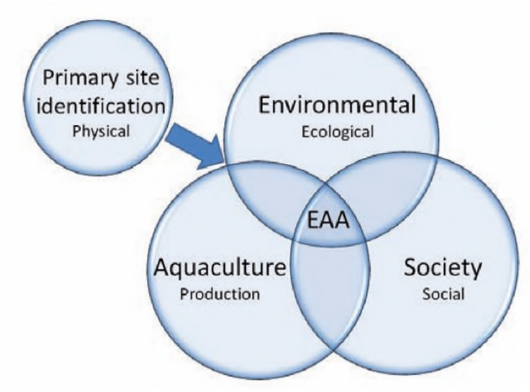

Figure 2: Interaction of the different categories of site identification and carrying capacity to arrive at an ecosystem approach to aquaculture. After primary site identification the process can pass on to any or all of the three other areas.

Source: FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO.

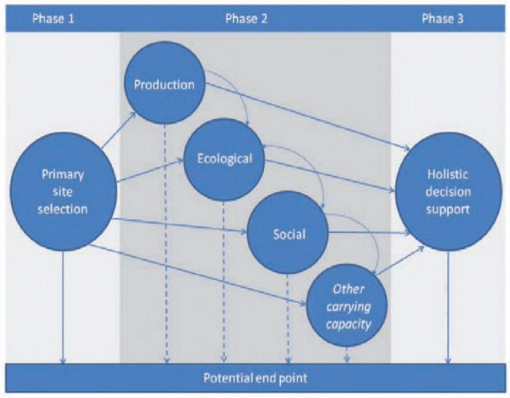

Figure 3: Schematic approach to the relationships and possible sequencing of the different carrying capacity categories, showing the range of end-points in the decision process.

Source: FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO.

McKindsey et al. (2006) proposed a hierarchical structure to determine the carrying capacity of a given area, where the first stage would involve determining the physical carrying capacity or suitability of a site based on the natural conditions and needs of the species and culture system. (Figure 4 below). Once an area or region was identified simple models could be used to calculate the production carrying capacity of the available area. Other models would also be used in the next stage to estimate the ecological carrying capacity and evaluating the range of potential outcomes for production ranging from no production to maximum production level, as determined in the previous step. The final stage would be to assess the different scenarios based on the outcomes from each of the previous steps and then introduce the social carrying capacity towards a decision on the level of acceptable productivity.

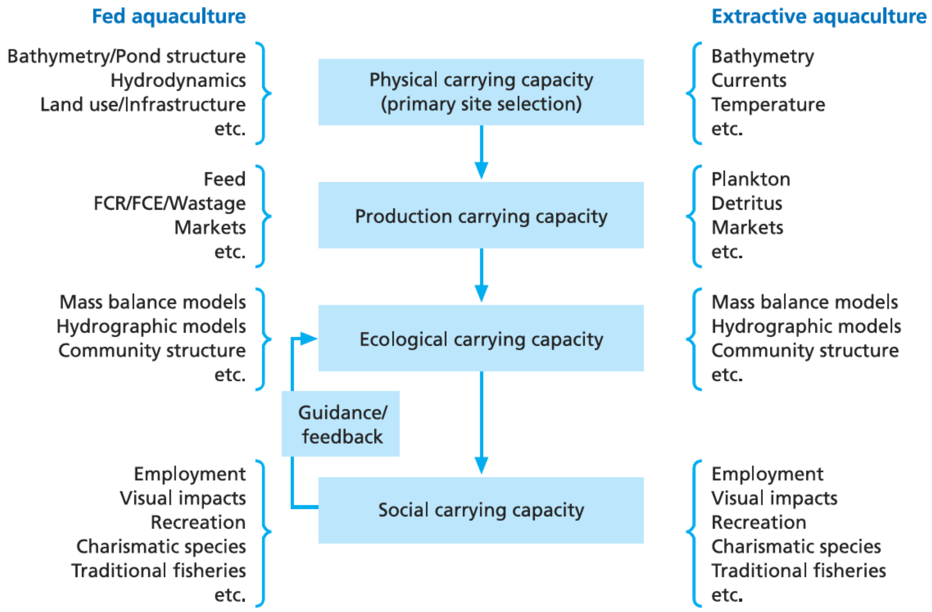

Figure 4: Hierarchical structure to determine carrying capacity of a given area. Social carrying capacity feeds back directly to ecological carrying capacity

2.2.2 Carrying Capacity Assessment used in this study

The primary emphasis of this study is Phase 1 (Figure 4), the primary site selection with a consideration of the later stages. The physical carrying capacity is based on criteria such as bathymetry and other parameters as outlined in figure 2. Once a potential area was identified an estimate of the possible production was made based on an assumed mussel production of 25 tonnes per hectare. This production figure is based on data from Scottish long-line mussel production as specified in the Scottish Shellfish Development Critical Mass (SSDCM) model and the Stirling Aquaculture study of the prospects and opportunities for shellfish farming in Scotland. Translating a production figure per long line into an area value per hectare is difficult because of the three-dimensional nature of long-line production (dropper depth), and the different yield of systems such as the traditional pegged ropes or the more recent New Zealand type technology, with a shorter rearing cycle. Some countries such as Chile and Greece which have more favourable conditions and shorter growing cycles report yields of 90 and 100 tonnes per hectare respectively. In Scotland similar high yields of 50 tonnes per hectare have also been reported on some of the better sites utilising modern NZ technology. The value of 25 tonnes per hectare is based on a production capacity of 40 tonnes average yield per 200m longline. This value is reported in both the SSDCM and Stirling reports mentioned earlier and is based on the following assumptions ( ).

40 tonne 200m longline production asssumptions		
Length of head rope	220	m
Dropper rope depth	10	m
Dropper rope spacing	0.45	m
Total Dropper rope length	10,000	m
Harvest net per m	4.00	Kg

Table 2: Production assumptions for 40 tonne 200m mussel longline

2.2.3 Production carrying capacity in the Clyde site selection process

Having identified an area and translated this into a gross physical carrying capacity, a utilisation factor was then applied, this was estimated based on the site size, dimensions and characteristics, with the aim to generate a reduction factor to account for non-production areas between groups of long lines (mooring, access/separation between farms/long line groups). This utilisable area was considered the physical carrying capacity, and was further reduced on an arbitrary precautionary principle to account for the production carrying capacity.

The methods for assessing carrying capacity for finfish are quite well developed in Scotland. Marine Scotland Science (MSS) has expertise on identifying and quantifying some of the potential impacts from nutrient enhancement and benthic impacts through the production of locational guidelines (Marine Scotland Science, 2018). These guidelines are aimed at finfish, primarily Salmon production (fed aquaculture), so model assimilative capacity (based on water flow and loch flushing characteristics). The methods for assessing carrying capacity in mussel farming (extractive aquaculture) are less developed, and the data source inputs to them (phytoplankton levels etc) are limited. Models are available but beyond the remit of this study, they are reviewed in Scottish Aquaculture Research Forum (SARF) report R.2466, “Considerations for Locational Regulation of Shellfish Aquaculture in Scotland”, March 2016. Often decision makers, regulators and planners use a combination of production and ecological capacity models to estimate the level of development which can take place within a given environment or set of boundary conditions. A variety of predictive models at different levels of sophistication are used for defining aquaculture production levels.

In Scotland consideration of the biological carrying capacity for coastal locations for aquaculture is a part of the planning application process, and is undertaken by MSS through statutory consultation from the Local Planning Authorities (LPA). MSS consider carrying capacity with respect to the location of the site, its flow characteristic (tidal water flow is not restricted so that food availability for the shellfish becomes an issue). In areas of restricted flow (for example within sea lochs, inlets and sounds) simple models are used.

MSS publish Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters, (the most recent in December 2018) and these publish loch benthic impact indices and flushing data which can be of use in shellfish farming as they give an indictive assessment on the ecological carrying capacity for the various lochs and waters of the Clyde, data from the locational guidelines was utilised regards loch water exchange (flushing) and benthic impacts, when considering sites.

The Clyde has generally been and still is a highly productive region supporting a wide range of wildlife, fisheries, and aquaculture, with the capacity to support the expansion of mussel farming.

2.3 SITE SELECTION

2.3.1 Methodology

Expansion of aquaculture in Scotland is limited by the planning and licencing regime, real and perceived conflict with other sectors such as fishing and marine recreation, varying levels of social licence to operate linked with governance and corporate social responsibility, biological constraints such as predators and disease, and biophysically-determined spatial boundaries. The site selection process for aquaculture, and shellfish in particular, is quite well documented in the scientific literature, the process is well established and described.

The AquaSpace project[2] (Ecosystem Approach to making Space for Aquaculture) is a recent and on-going project which aims to deliver the science base to identify the potential for aquaculture to expand in Europe and to support the corresponding licensing process in the context of Integrated Coastal Zone Management (ICZM) or Marine Spatial Planning (MSP), and has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement n° 633476. SAMS, Oban is the UK partner. The central goal of the AquaSpace project is to optimise and increase the area available for aquaculture, in both marine and freshwater environments, by adopting the Ecosystem Approach to Aquaculture (EAA), and spatial planning for aquaculture in the wider context of the Maritime Spatial Planning (MSP), Water Framework Directive (WFD), and Marine Strategy Framework Directive (MSFD) and other policy mechanisms.

These principles have been adapted to utilise readily available tools such as navigational charts, the NMPi (National Marine Plan interactive) and other data in the public domain as part of a basic site selection process. The template used follows existing industry standard site selection procedures and tools and to enable this process, various assumptions and criteria have been established based on the existing industry, legal, policy and administrative framework in Scotland. The focus of this study relates to mussel farming in the Clyde, however it can be adapted and applied to other species and regions. This study aims to identify sites in the Clyde for the hypothetical establishment of an annual mussel production of between 2,000-3,000 tonnes.

A brief insight of the AquaSpace tool is illustrated below, this concept has been followed in the process of site selection for the Blue mussel (*Mytilus edulis*)

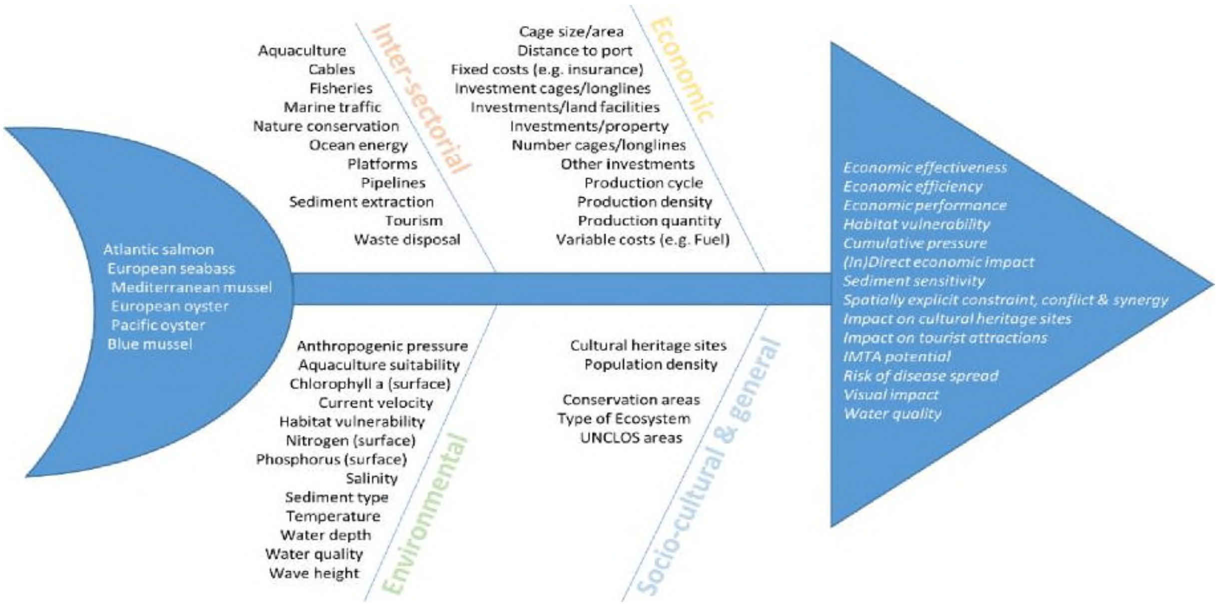

Figure 5: AquaSpace tool schematic

[2] http://aquaspace-h2020.eu

The AquaSpace tool categories (from left to right) are as follows: i) all species considered, ii) data and information AquaSpace tool assessments are built on and iii) (additional) site-specific information received by applying the AquaSpace tool functions (Economic performance = Revenue, Added Value (AV); Economic effectiveness = Return on Fixed Tangible Assets, Opportunity costs; Economic efficiency = Net Present Value; Economic impact = (In)Direct impact on the AV, (In)Direct impact on employment; IMTA = Integrated Multi-Trophic Aquaculture, UNCLOS = United Nations Convention of the Law Of the Sea).

For the purposes of this report the and based on the utilisation of readily available data the following parameters or indicators were considered.

Spatial Interaction, possible conflicts and constraints

- Aquaculture
- Fisheries
- Offshore Wind farms, Platforms (oil, gas)
- Cables and pipeline
- Sediment extraction
- Ports and Harbours
- Marine traffic
- MPAs, SSSI etc
- Waste disposal
- Military facilities

Environmental effects

- Depth
- Wave height specific exposure of the site (m)
- Current velocity (m/s)
- Sediment type
- Productivity - Chlorophyll a (mg/m3; surface)
- Temperature (°C)
- Salinity (PSU)
- Habitat vulnerability
- Predators and fouling
- Risks - HAB's
- Disease - management areas/movement orders
- Carrying capacity - biological and environmental

Socio-cultural effects

- Visual Impact (landscape, seascape, distance to populated areas)
- Cultural heritage (shipwrecks, archaeological sites)
- Tourism, social boating and recreation

Economic effects

- Logistical support - proximity to services, labour, harbour, shore base
- Economic efficiency - cluster potential, economies of scale

Other specific and policy considerations

- Spat settlement
- Designated waters
- Perceived quality/Market factors

These are discussed in further detail in Appendix 1, the key parameters are presented in the tables below.

Spatial Interaction, possible conflicts and constraints	Buffer (m)	Description
Aquaculture	500	Separation distance, radial from existing sites
Fisheries	300	Separation distance, radial from existing sites
Offshore Wind farms, Platforms (oil, gas)	1000	Radial buffer around point features
Cables and pipeline	100	Buffer either side of linear features
Sediment extraction	1000	Buffer, radial from designated area
Ports and Harbours	300	Radial buffer around point features
Marine traffic	1000	Buffer over route
Shipwrecks	1000	Radial buffer around point features
Protected Environments - MPAs,PMFs,SACs,SPAs,SSSIs	100	Separation distance, radial from existing sites
Waste disposal	500	Radial buffer around point features
Military facilities	100	Buffer, radial from designated area

Table 3: Constraints, buffers and separation distances applied

Environmental Parameters	Threshold Low	Optimal Low	Optimal High	Threshold High	Study Parameters
Depth (m)	10	12	35	50	15-40
Current velocity (cm/s)	10	40	85	110	ND
Temperature (°C)	2	8	18	27	>8
Salinity (PSU)	4	22	30	40	>20

Table 4: Key environmental parameters applied

2.3.2 Clyde site selection

Introduction

The Clyde Marine Regional Assessment 2017 reported “Shellfish farming in the Clyde is generally smaller scale, single owner businesses. Activity is largely concentrated at Loch Fyne which has five production sites with other sites located at Loch Striven, Loch Riddon and Lamlash Bay, Arran.

The sector remains important for supporting rural and coastal communities both directly and through supply chain linkages, however, there has been an overall decline in employment.” Due to economic and environmental pressures mussel production has since declined in the Clyde.

The primary purpose of the site selection component of this study was to identify new areas with sufficient space for the development of large-scale mussel farms (500 tonnes plus, ideally 750 tonne farms) or farm clusters, that enable economies of scale and efficient operation. Proximity to supporting infrastructure (land base, harbours, labour) and avoiding areas of conflict with other users or environmentally sensitive areas were key considerations.

Mussel farming is the diminishing sector of the Clyde shellfish industry, there are many licenced sites that are inactive or underutilised, these sites that have a past record of productive spat settlement (but are no longer viable as independent units) could be developed as spat collection sites to supply the new identified sites. The criteria identified in section 2.3.2 were applied to the Clyde region, initially a base layer of bathymetric data (15-40 m) was highlighted. Using the NMPi and data from Crown Estates Scotland regards existing sites, leased areas and those under application, these and other constraints were mapped. The NMPi was used as the main platform for this as it is available on the public domain.

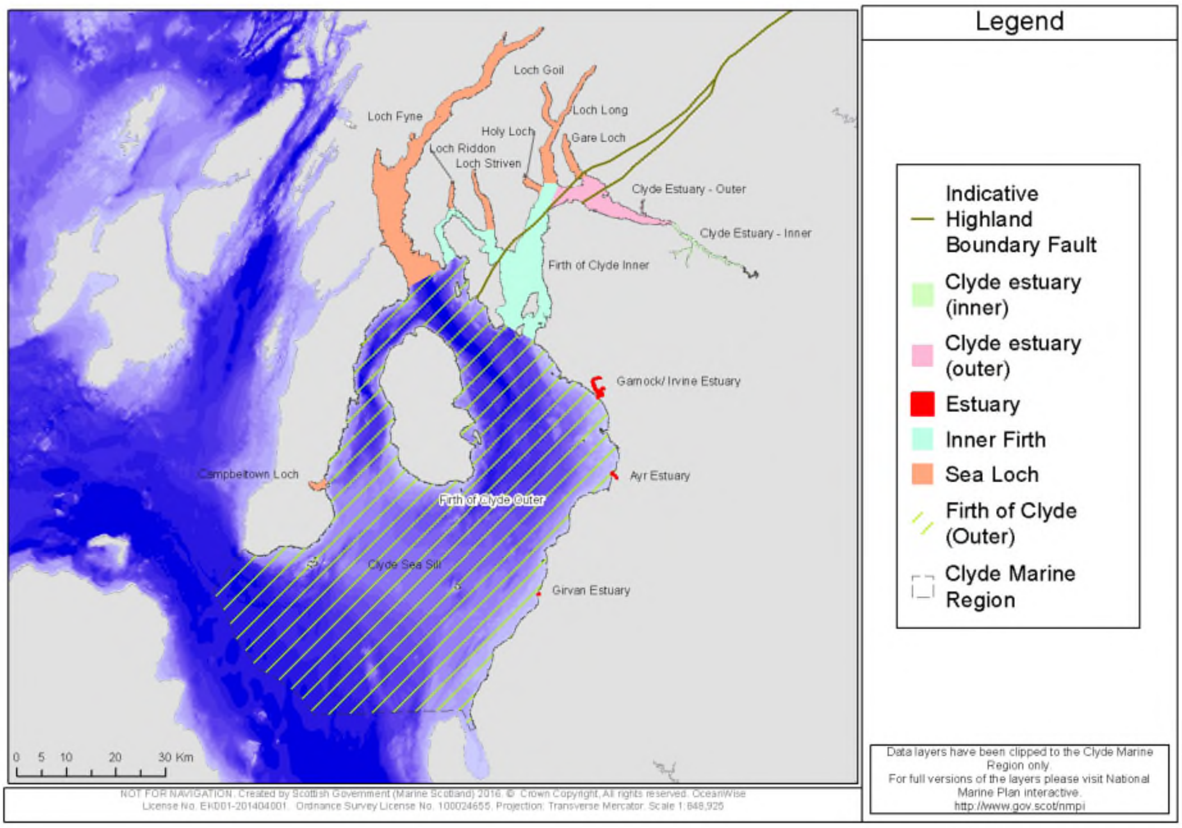

Figure 6: Clyde Marine Region indicating sea lochs, estuaries, inner and outer Firth, and Clyde Sea Sill

Source: Clyde Marine Region Assessment 2017

The Clyde is demarcated into the following areas, and these were initially appraised

- Clyde estuary inner and outer, this region was not considered, it is industrialised and hosts an extensive RAMSAR site. Other estuaries were also not considered.
- The Inner Firth, this area has heavy shipping and recreational boating traffic, with the exception of the Kyles of Bute it was not considered. The Kyles of Bute do have some active and inactive aquaculture sites, and other areas that could be used for the location of spat settlement sites.
- The Outer Firth is relatively shallow (compared to the sea Lochs), is more exposed but remains reasonably sheltered due to the protection provided by Northern Ireland and Kintyre from the prevailing south-westerly winds. Water circulation is weak, the sea surface temperature varies from 4^{o}C in winter to 18^{o}C in summer. It has large areas of favourable bathymetry, although more exposed areas could also be developed using submerged long line technology.
- Sea Lochs
  - Gare Loch has potential, with the entire loch having suitable depths, but is the home of Her Majesty's Naval Base (HMNB) Clyde, known as Faslane. There is also a high potential conflict with other users, fishing, shellfish fisheries and recreational boating outside the MoD exclusion zones.
  - Loch Long and Loch Goil including Holy Loch. These also house Military facilities and high potential conflicts with other users. Loch Goil is a Nature Conservation Marine Protected Area (MPA). They have limited potential regards suitable depth and condition of phytoplankton has been of concern in Loch Long and Loch Goil. This is probably caused by diffuse pollution, combined with the long flushing time for these

enclosed lochs, which would limit the carrying capacity so the sites were not considered. Holy Loch also has a historic input and persistence of hazardous substances in sediments.

- Loch Striven has some potential primarily as a site for spat collection. The loch has a limited area of suitable depth and had thriving mussel farms, but now has no operating mussel farms. Loch Striven suffers from frequent and recurring harmful algae blooms (HAB's), these though not toxic to mussels prohibit the harvest of mussel for market (prolonged shut downs of production affecting production and cash flow making farms unprofitable). However, it has had a good record of spat fall, so could host dedicated collectors to supply spat to on-growers in the Clyde.
- Loch Riddon is in a National Scenic Area Coastal Site, with an established shellfish farm and fishery. It is also an area with low and fluctuating salinities, it has limited potential as an on-growing area due to a high level of conflict with other users primarily tourism and recreational boating. It could be utilised as a spat collecting area.
- Loch Fyne is divided into, upper and lower Loch Fyne. Upper Loch Fyne is a Nature Conservation Marine Protected Area (MPA), it has established aquaculture sites with limited potential for expansion or new sites except for spat collection (existing and inactive mussel sites could be converted to spat collection). Lower Loch Fyne has some aquaculture sites and due to its large area (also not as deep as the upper Loch) has large areas available for potential development of new sites.
- Campbeltown Loch is a small loch with natural mussel and cockle bed, it is of limited potential for on-growing but could be a good spat collecting site.

2.3.3 Selected sites

The constraints, potential conflicts and environmental sensitivities were mapped, only some key constraints are illustrated, the rest are listed in Appendix 2. The primary criterion was bathymetry (15-40m), this is highlighted in the maps below, this highlighted an area of 86,400 Hectares, which is 21.6% of the total area available.

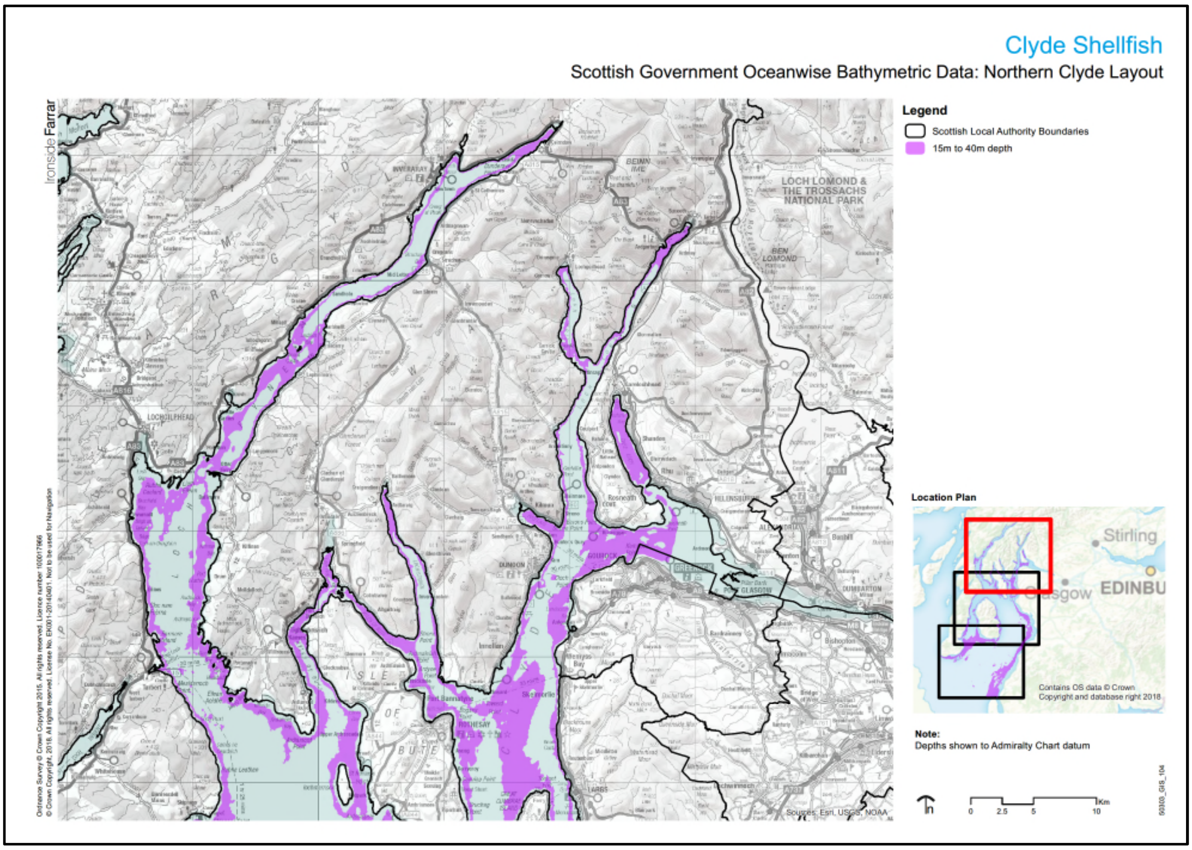

Figure 7: Northern Clyde 15m to 40m depth

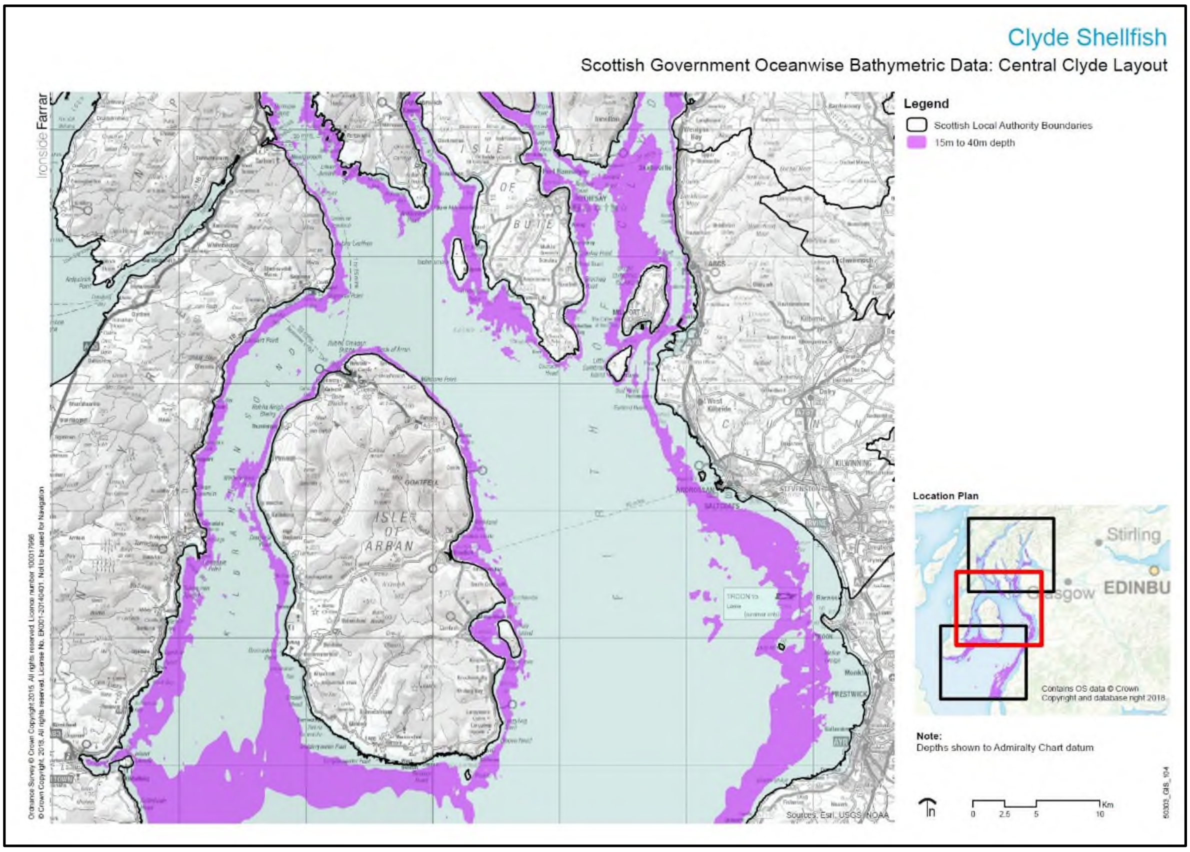

Figure 8: Central Clyde 15m to 40m depth

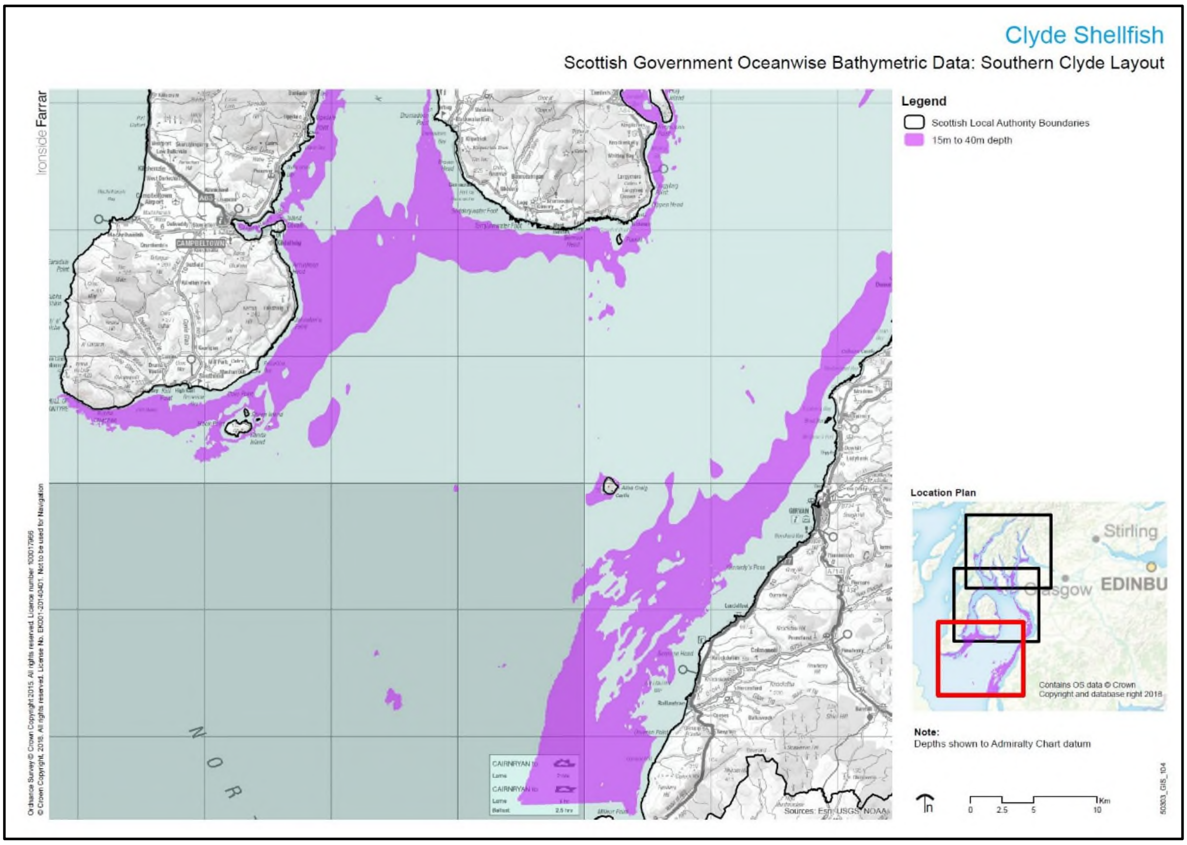

Figure 9: Southern Clyde 15m to 40m depth

From this area constraints (from NMPi – Appendix 2), conflicts and unsuitable areas were removed and positive areas considered. This left the following large areas listed in **Error! Reference source not found.** below, of which sites in areas (1) and (2) were identified. Apart from these, it would appear that other potentially suitable sites are available in the areas (1) and (2) as well as in the remaining areas (3 to 5) and also in other parts of the Clyde.

Main Positive Factors	Main Negative Factors
1) Lower Loch Fyne	
Good harbours and infrastructure	HAB's recorded
Existing Aquaculture sites	Loch Fyne ICZM plan limits development
Designated Shellfish Water	
Sheltered sites	
2) East coast of the Kintyre peninsula from Skipness Point to Carradale Point	
Available harbours and infrastructure	
Existing Aquaculture sites	
Sheltered from prevailing SW winds	
3) East coast of the Kintyre peninsula from Carradale Point to Campbeltown Loch	
Available harbours and infrastructure	Exposed to SE winds
Sheltered from prevailing SW winds	
4) East coast of the Kintyre peninsula from Campbeltown Loch to Johnston's Point	
Available harbours and infrastructure	Exposed sites
5) South west coast of Isle of Bute	
	Exposed to prevailing SW winds

Table 5: Top 5 mussel farming regions identified within the Clyde area

From **Error! Reference source not found.**, sites from region 1 and 2 were selected as having the most potential for mussel farming.

Constrains from NMPi

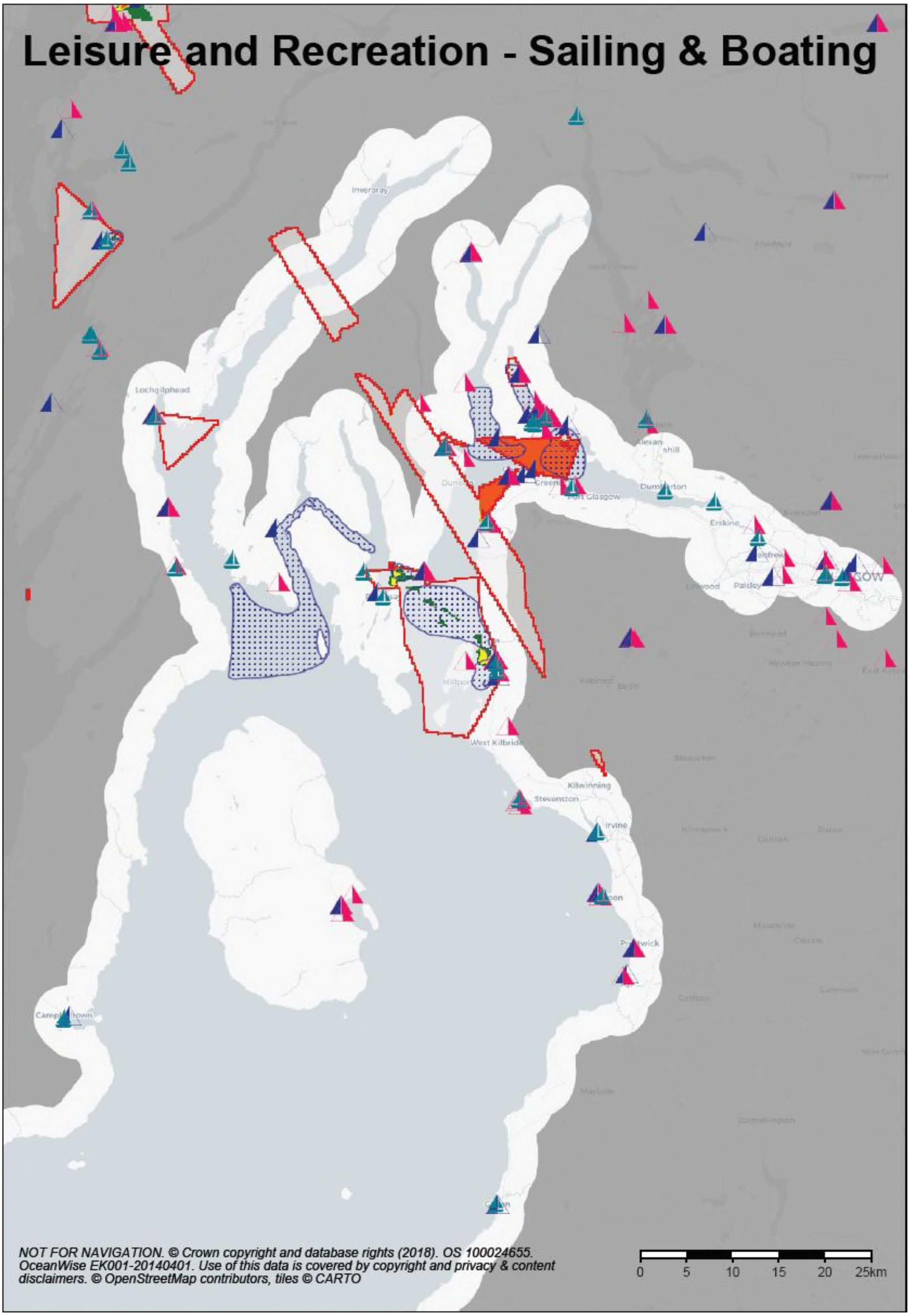

Figure 10: Recreational boating in the Clyde

Source: NMPi 2019

Figure 11: Constraints; active shellfish sites

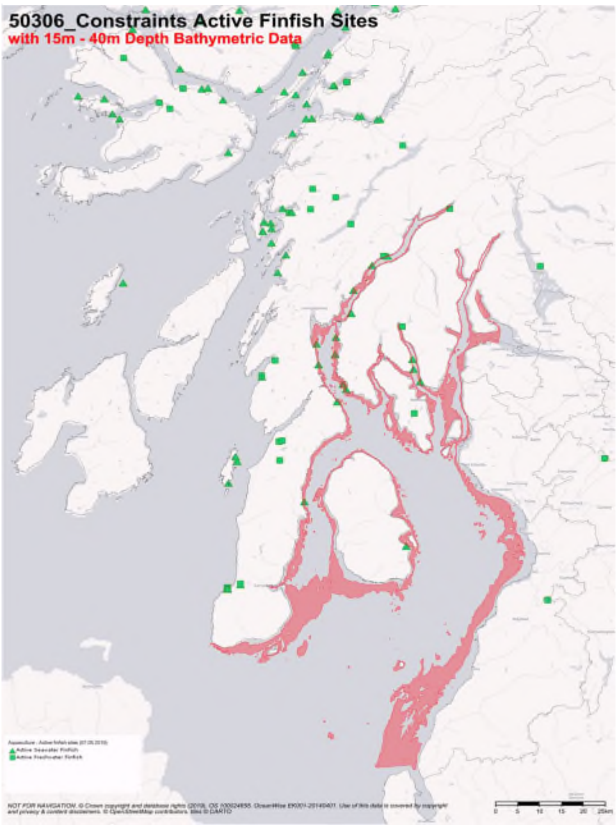

Figure 12: Constraints; active finfish sites

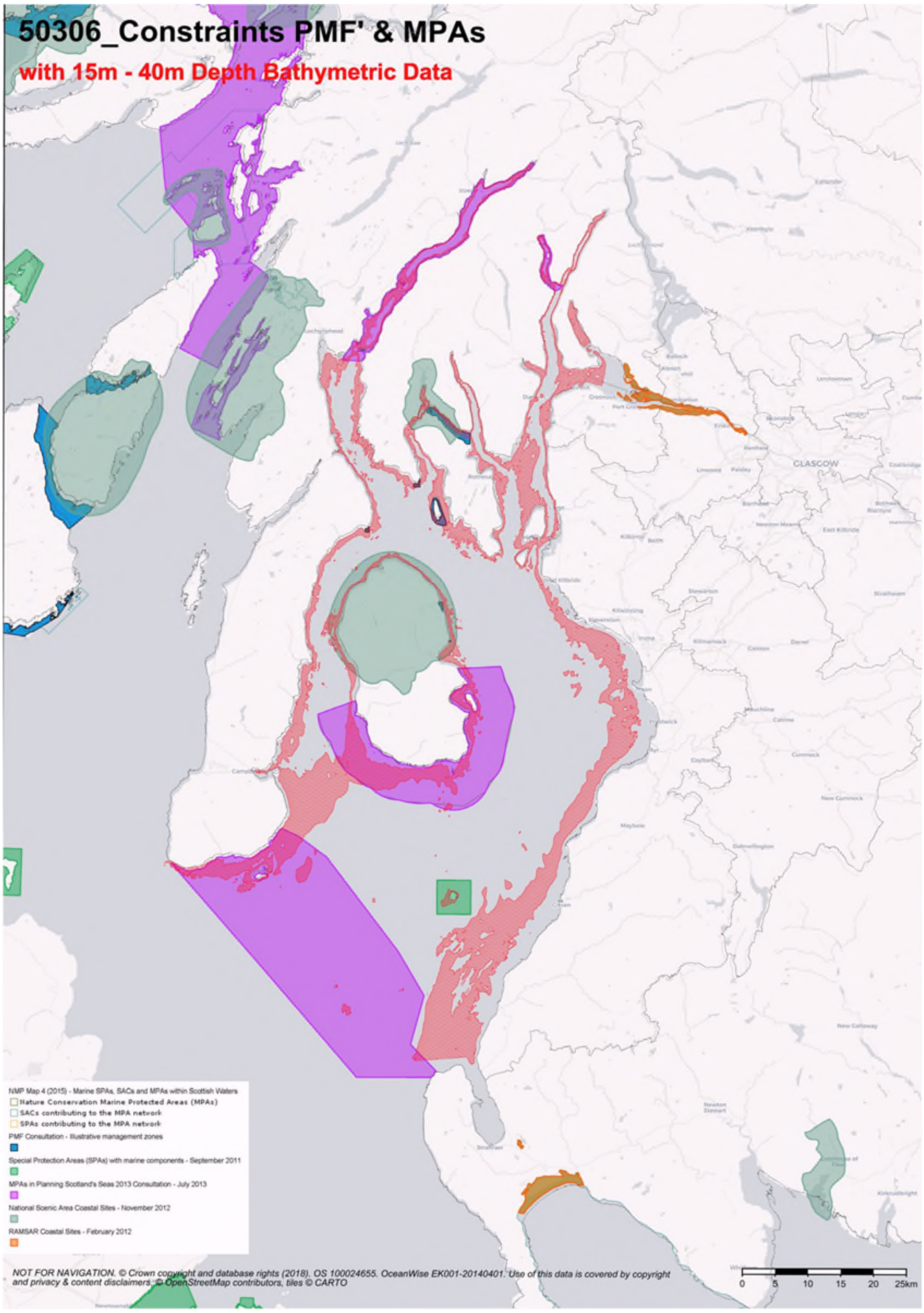

Figure 13: Constraints; PMF' and MPAs

Constraints from Clyde Marine Region Assessment

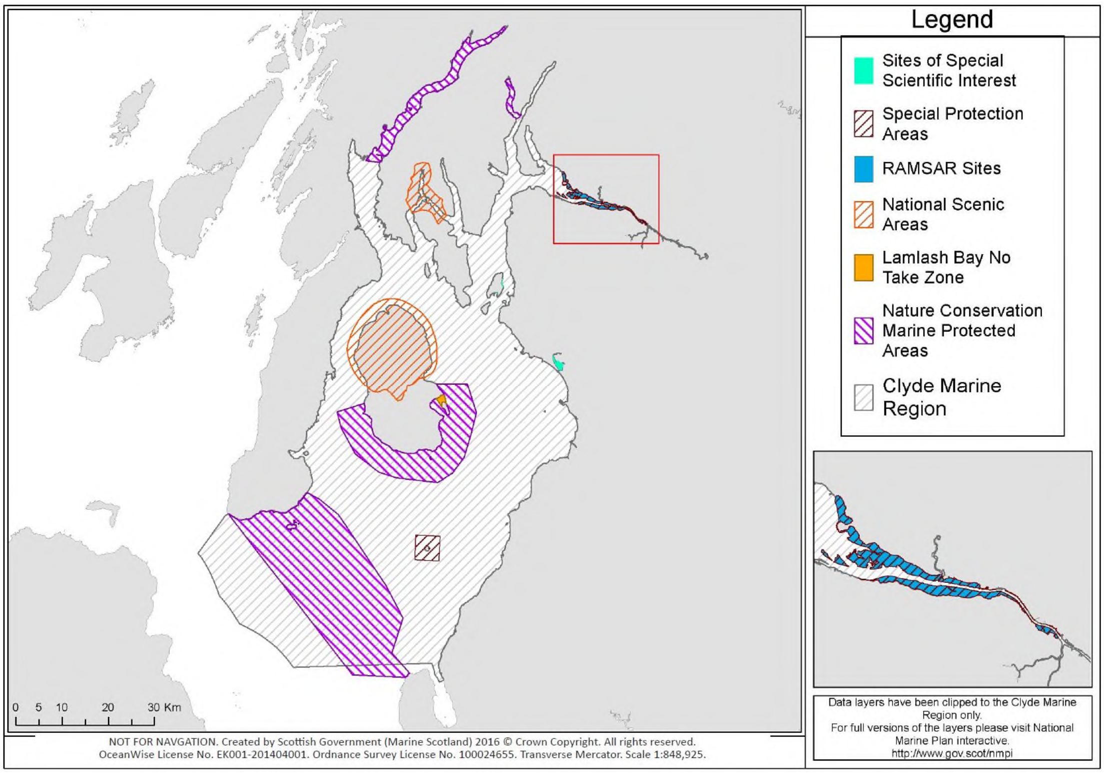

Figure 14: Environmentally sensitive areas in the Clyde Marine Region
Source: Clyde Marine Region Assessment 2017

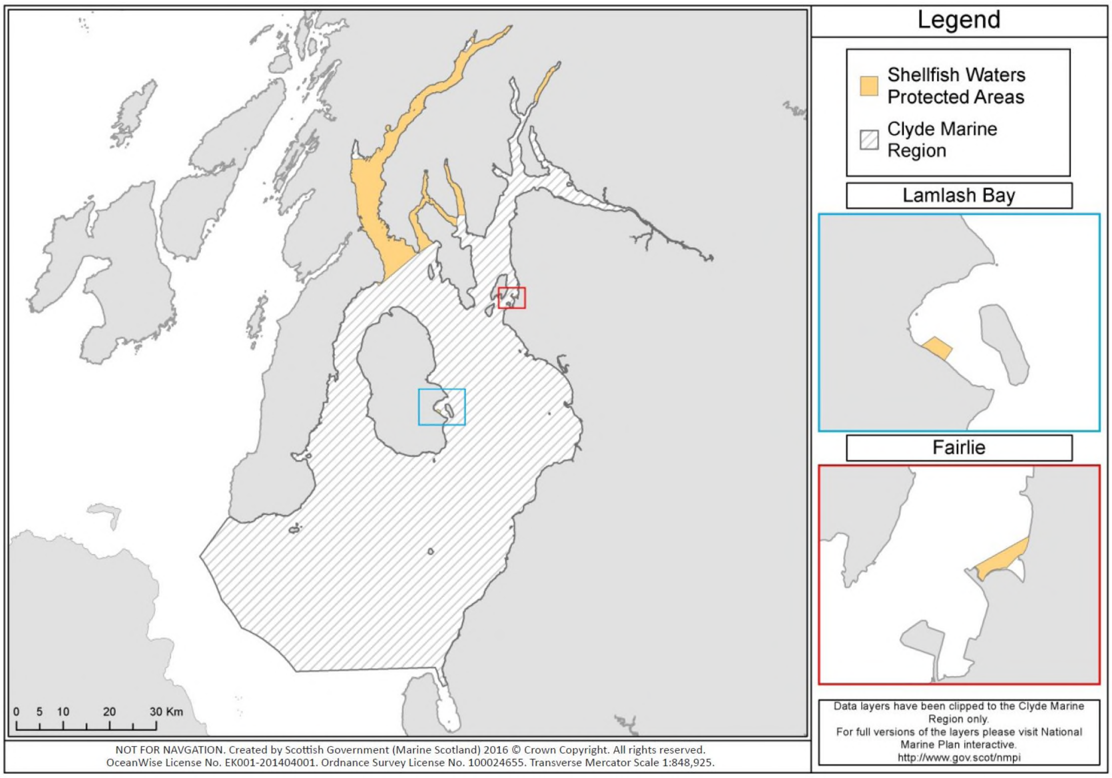

Figure 15: Shellfish Waters Protected Areas in the Clyde Marine Region
Source: Clyde Marine Region Assessment 2017

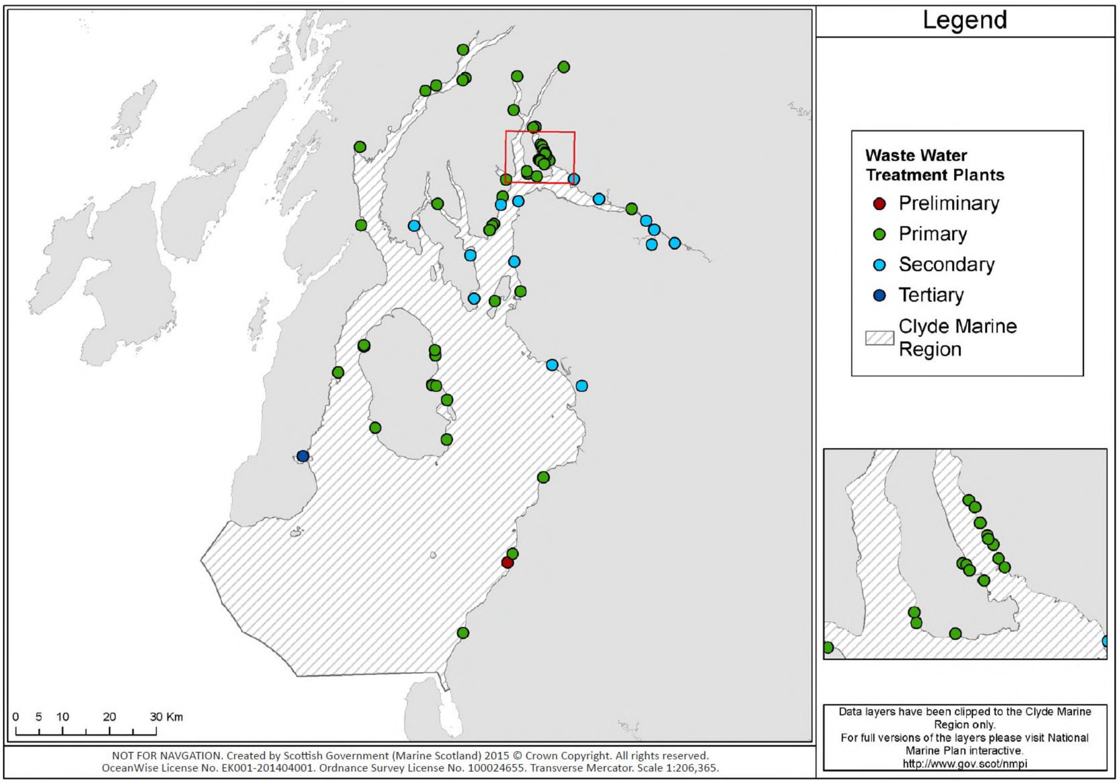

Figure 16: Waste Water Treatment Plants in the Clyde Marine Region
Source: Clyde Marine Region Assessment 2017

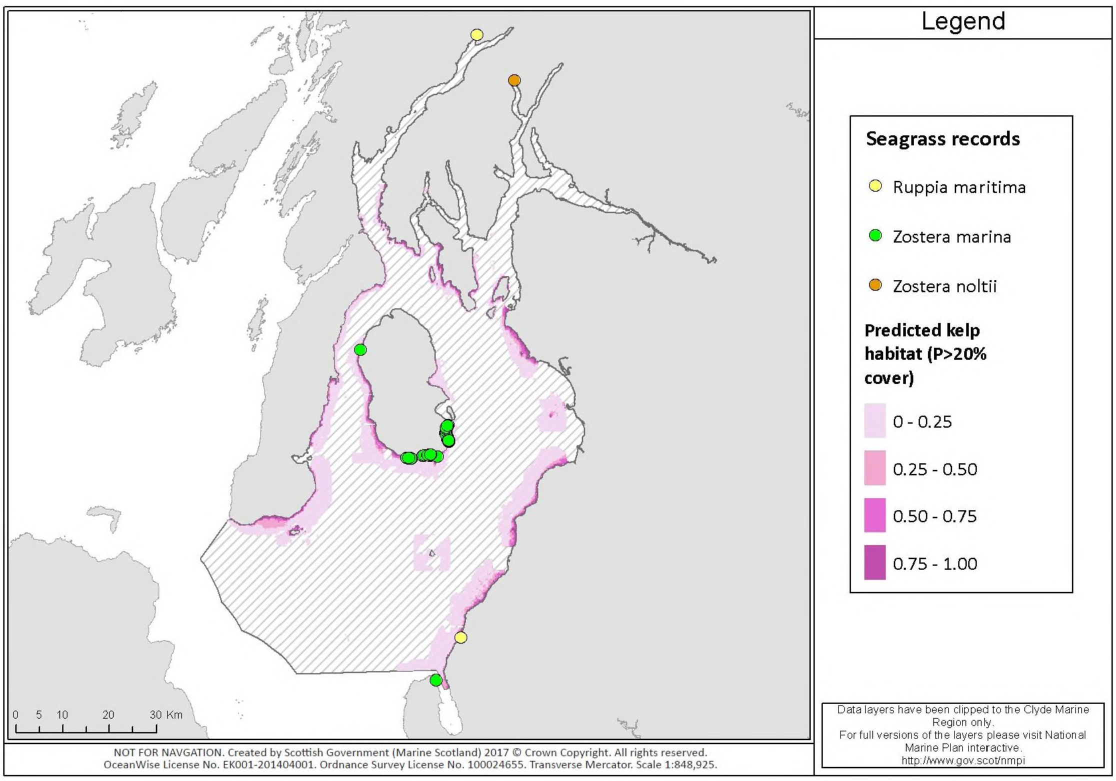

Figure 17: Seagrass records in the Clyde Marine Region
Source: Clyde Marine Region Assessment 2017

Selected sites

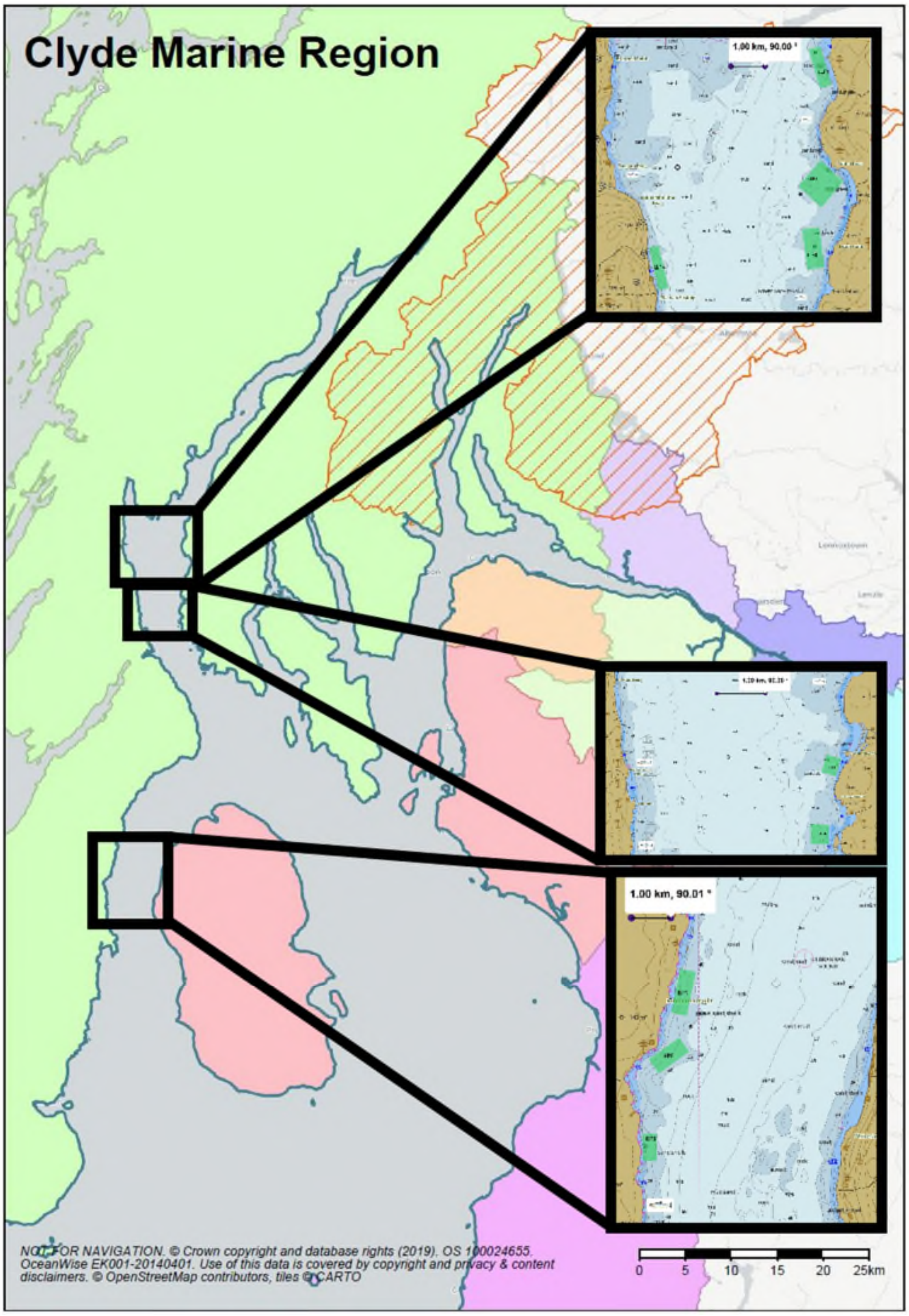

Figure 18: Overview of location of selected sites; Region 1 (Lower Loch Fyne; North & South) and Region 2 (East coast of the Kintyre peninsula)

Region 1

Lower Loch Fyne has existing aquaculture facilities and is a productive area, it also has good infrastructure with Tarbert being the main harbour with good facilities. The Loch Fyne ICZM plan 2009, did not propose mussel farm development in lower Loch Fyne, no development in accord with the plan has since occurred and as the plan was non-binding and advisory, its recommendations with regards to mussel farming (recommended development in upper Loch Fyne only) have been overlooked. Six sites have been identified, these are outlined in **Error! Reference source not found.**, Figure 19 and Figure **20** below.

Site Ref.	Area (Ha)	Utilisation Factor (%)	Working Area (Ha)	Assumed Mussel yield (Tonnes per Ha)	Physical Carrying Capacity (Tonnes)	Assumed Carrying Capacity (Tonnes)
LLF1	37.6	55	20.7	25	517	259
LLF2	85.6	40	34.2	25	856	428
LLF3	57.9	45	26.0	25	651	325
LLF4	36.1	55	19.9	25	497	249
LLF5	12.2	65	7.9	25	199	99
LLF6	15.1	60	9.1	25	227	113
Totals	**244.5**		**117.8**		**2,946**	**1,473**

Table 6: Carrying capacity Region 1; Lower Loch Fyne selected sites 1 to 6

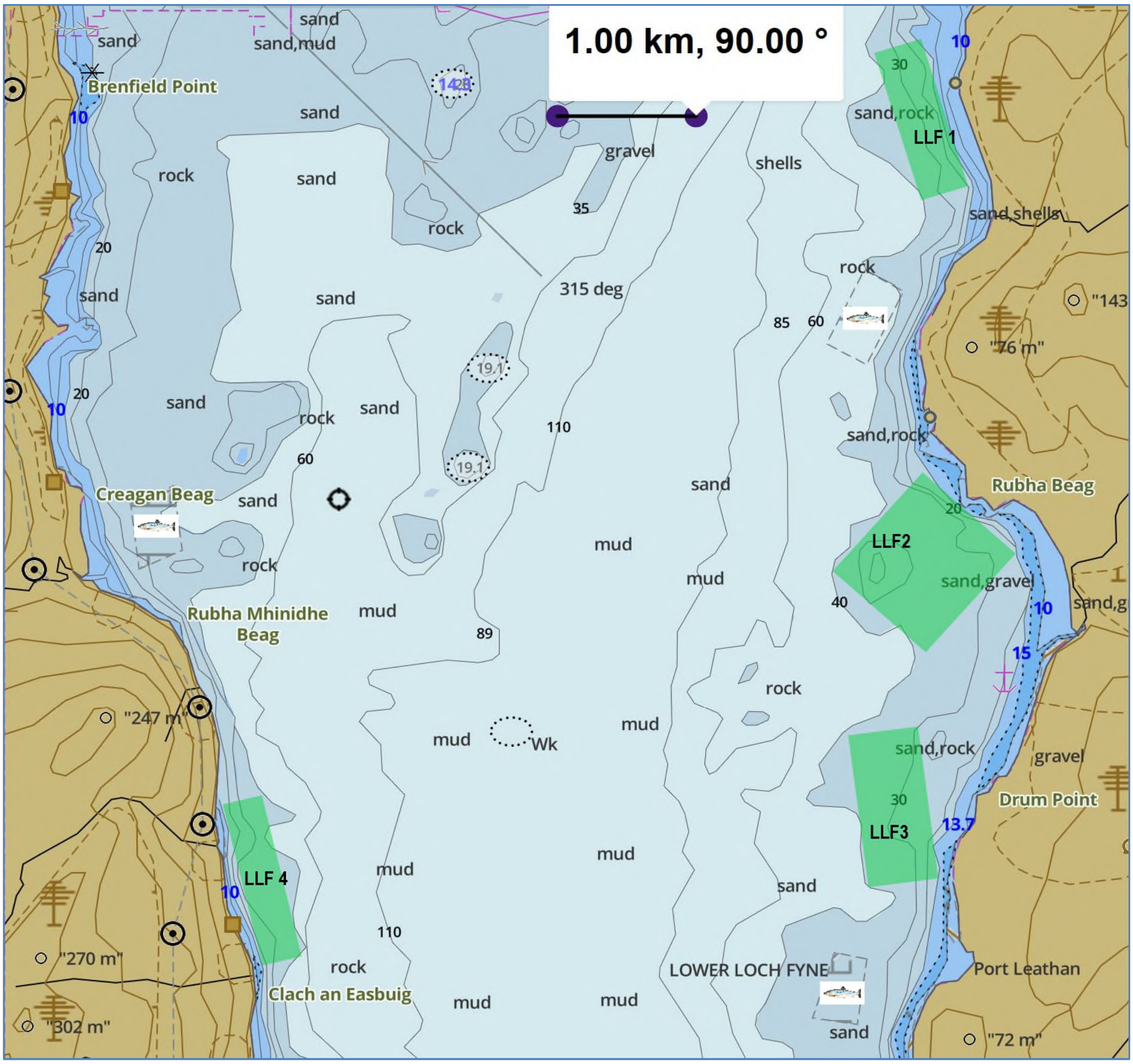

Figure 19: Lower Loch Fyne (North) Sites 1-4

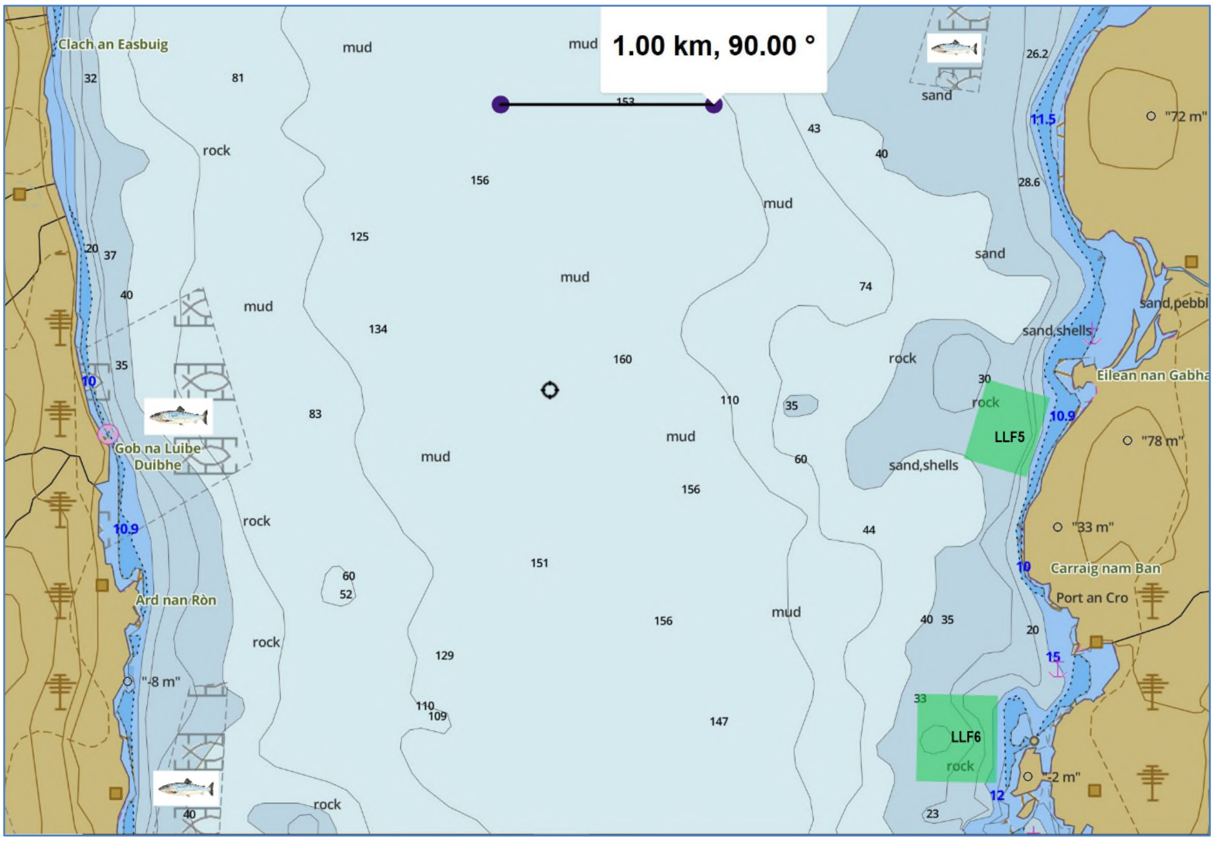

Figure 20: Lower Loch Fyne (South) Sites 5 & 6

Region 2

The east coast of the Kintyre peninsula from Skipness Point to Carradale Point, has an existing aquaculture facility and is a productive area, it also has good infrastructure with Carradale harbour nearby (also Campbeltown further south) and is sheltered by the Isle of Arran. Three sites have been identified these are outlined in **Error! Reference source not found.** and Figure 21 below.

Site Ref.	Area (Ha)	Utilisation Factor (%)	Working Area (Ha)	Assumed Mussel yield (Tonnes per Ha)	Physical Carrying Capacity (Tonnes)	Assumed Carrying Capacity (Tonnes)
KP1	46.8	55	25.8	25	644	451
KP2	40.2	55	22.1	25	552	387
KP3	24.1	60	14.5	25	361	253
Totals	**111.1**		**62.3**		**1,558**	**1,090**

Table 7: Carrying Capacity Region 2; East coast of the Kintyre peninsula from Skipness to Carradale Point, selected sites 1 to 3

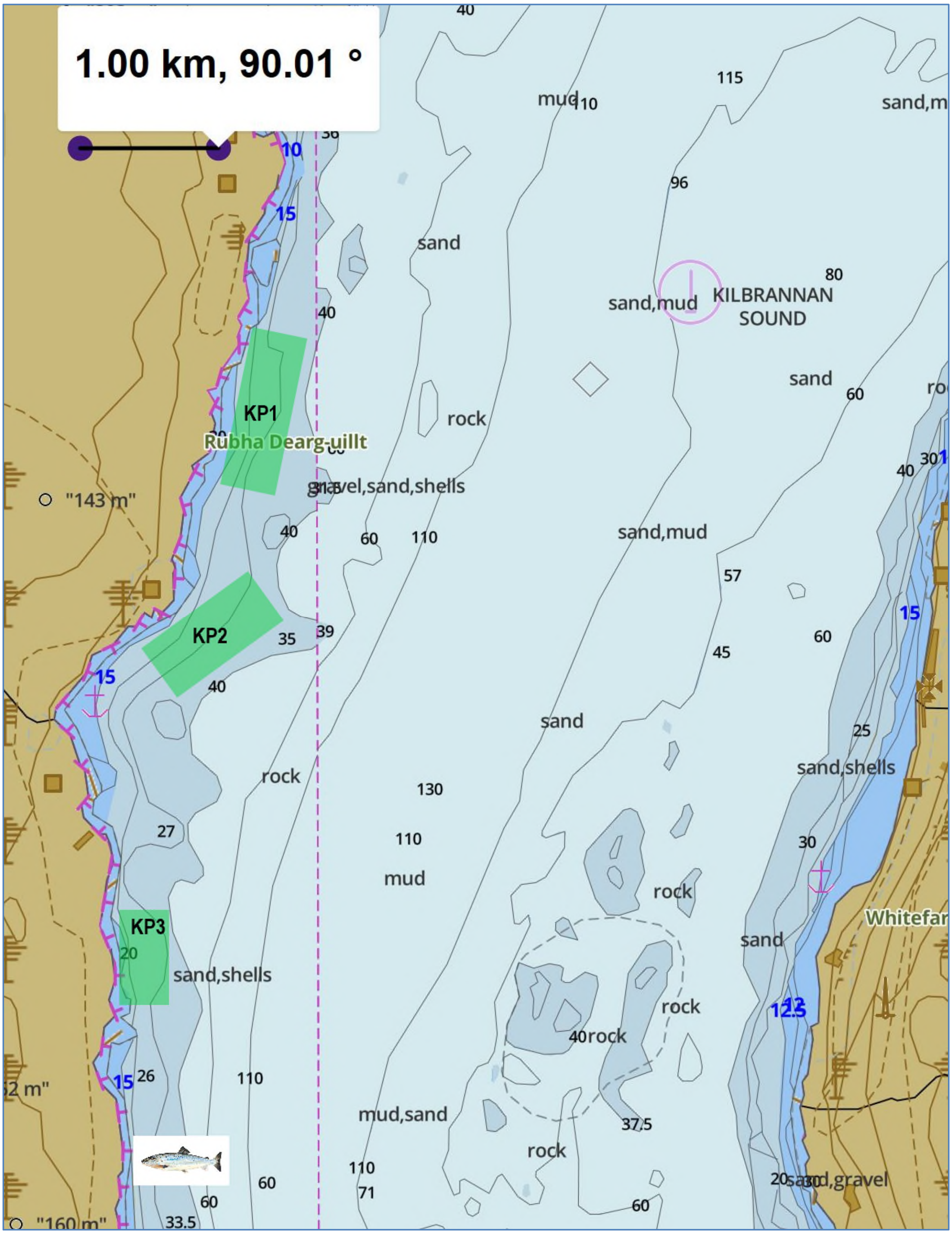

Figure 21: East Coast of the Kintyre Peninsula from Skipness to Carradale Points, Sites 1 to 3

Operational considerations

An important consideration for shellfish farmers in relation to site selection is the ability to be able to access and work the site at key times during the year. Some of the main factors impacting upon this include;

- distance from production site to a safe haven: this determines the category of boat required under MCA regulations with less than 20 miles being the only sensible option.

- Site exposure: the less sheltered the site the more likely that operational days could be lost although this could be at least partially offset by selecting more robust production structures (along with a bigger, more expensive workboat).
- Harmful Algae Blooms (HAB): the occurrence of HABs will adversely impact on the harvesting of market sized mussels.

Of the above issues, one that is often overlooked during site selection is the occurrence of HABs. This can be due to a lack of awareness of the potential problem or due to the absence of existing sampling points within the area. Even when relevant sampling points do exist, the historic data is not readily available in a meaningful format that can inform potential mussel farmers of the associated risk. Of the two regions selected in this study there is an existing representative monitoring point (RMP), Balliemore, located not more than 10 kilometres from the sites identified in Region 1 and an analysis of historic biotoxin data shows a number of HAB occurrences, predominantly during the summer months, over a seven-year period from 2013 to 2018.

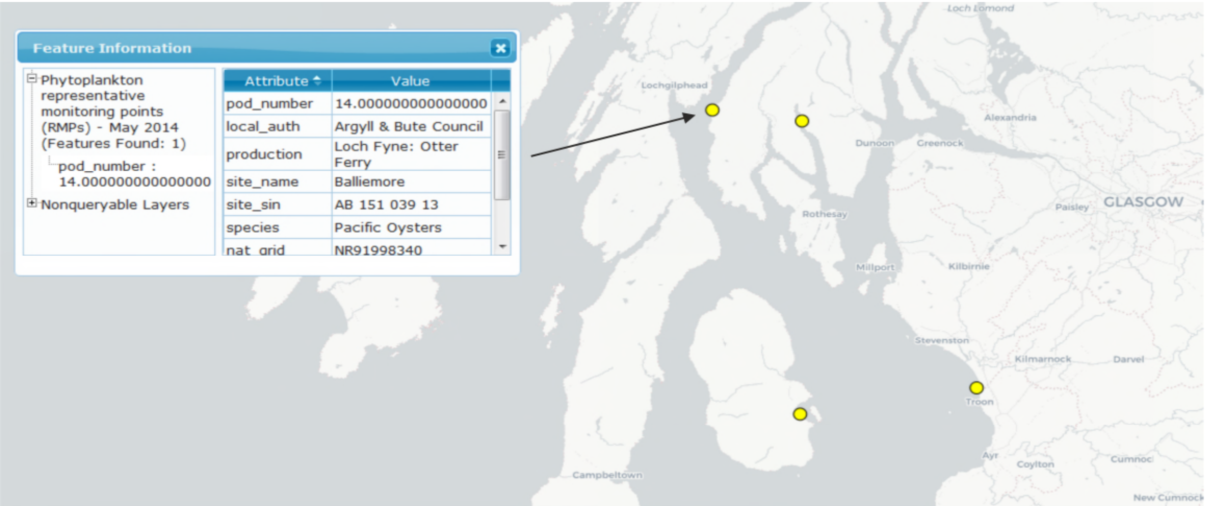

Figure 22: HAB RMP Balliemore, Clyde

Data from another HAB RMP in Shetland (Seggi Bight) has also been provided for comparison purposes.

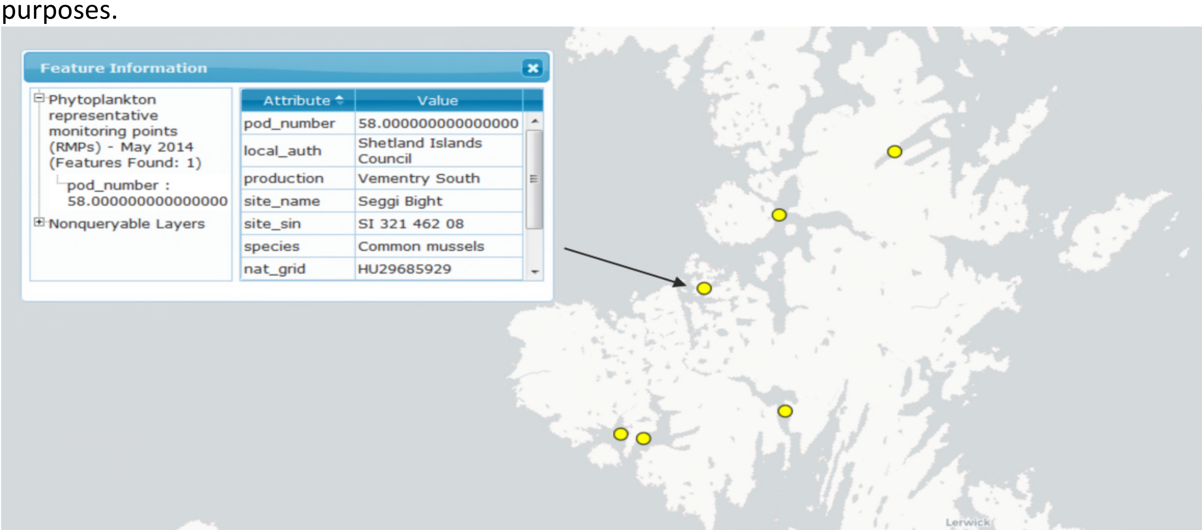

Figure 23: HAB RMP Seggi Bight, Shetland

Taking one of the HAB species monitored at the RMPs as an example (*Dinophysis*), this microalgae species produces biotoxins which, when present at significant levels (>100 cells per litre), can cause Diarrhetic Shellfish Poisoning (DSP). By analysing the data it is possible to produce a 'heat map' which gives an easy, visual representation of the information (Figure 24) with the red areas on the maps showing weeks when HABs were higher than the trigger level thus leading to a "no harvest" scenario. For context, the longest period of closure of a shellfish farm in England due to HABs was 17 weeks and this occurred in 2017.

	Week																																																		
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
2012																			0	0	40	100	0	40	0	0	0	360	0	20	20	140	20	80	100	240	2,020	0	40	0	0	20										
2013										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	60	20	20	100	0	40	20	0	40	0	160	0	0	0										
2014										0	0	0	20	40	180	0	0	0	0	0	0	0	0	20	60	0	0	20	20	120	0	20	0	120	0	0	20	40	0	20	0	0										
2015										0	0	0	0	0	0	0	20	0	0	120	60	360	0	980	180	360	0	0	40	20	300	60	0	20	300	60	0	60	40	120	0	0										
2016										0	0	0	0	60	0	20	0	0	0	20	0	240	140	520	20	20	40	340	0	0	240	120	20	0	20	0	0	0	0	0	0	0										
2017									0	0	0	0	0	0	0	20	0	0	0	0	80	40	140	0	80	0	20	0	0	20	20	0	0	0	20	60	20	0	0	0	0	20										
2018										0	0	20	0	0	0	0	0	0	0	0	40	0	0	0	40	20	120	0	80	0	40	0	60	80	20	60	0	0	40	0	0	0	40									

KEY: Not measured; 0 Measured but not detected; 20 Present but below trigger level; 110 Present above trigger level

Figure 24: Heat map sowing occurrence of HAB *Dinophysis* at Balliemore, Clyde 2013-2018

A heat map for the same HAB but over a slightly longer time period is shown for a mussel farming area of Shetland (Seggi Bight) in Figure 25 (courtesy of Dr Callum Whyte, SAMS)

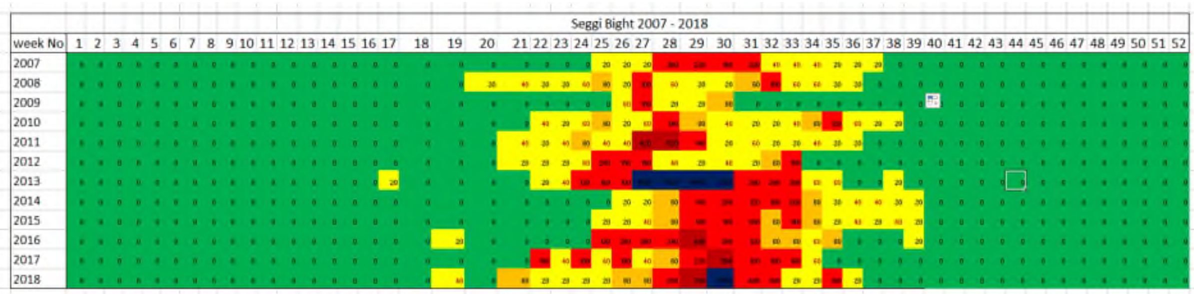

Figure 25: Heat map showing occurrence of HAB *Dinophysis* at Seggi Bight, Shetland 2007-2018

Further analysis of the data can then provide a rudimentary probability figure for the likelihood of a particular (or indeed any) HAB incidence occurring in any particular week of a given year based on historic information. Applying this approach to the *Dinophysis* data gives an indication that there is a relatively low risk of prolonged closure of any mussel sites in Region 1 due to the potential presence of harmful levels of biotoxins caused by *Dinophysis*.

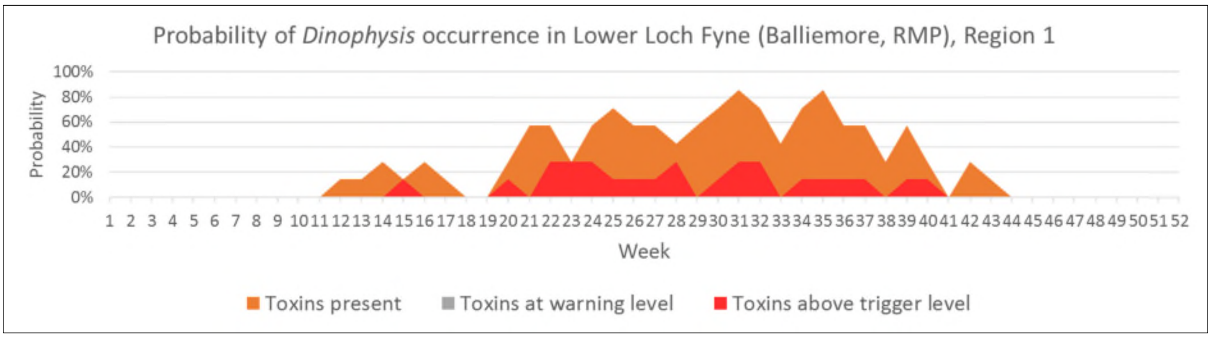

Figure 26: Probability of Dinophysis occurring at Balliemore, Clyde

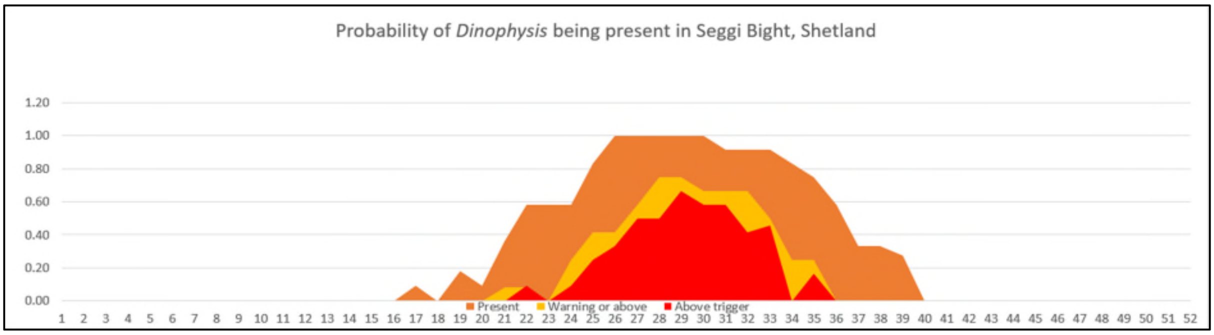

Figure 27: Probability of Dinophysis occurring at Seggi Bight, Shetland

3 BUSINESS MODEL AND PRODUCTION PLAN

3.1 ASSUMPTIONS

Based on the carrying capacity estimations for the selected areas of the Clyde outlined previously in this document (section **Error! Reference source not found.**) and using the results and recommendations from earlier published work (see footnote below), the total assumed annual production target for the business model is 750 tonnes for either of the two areas identified as having a sufficient number of potential sites located within their boundaries. Furthermore, it is assumed that this volume will be achieved through a collaborative approach of three farms each operating as discrete, separate sites and with each producing 250 tonnes per annum. These farms would share some capex items (specifically a second workboat) and also some labour (two workers) as outlined in previous work as “Loch scale model 2c”[3]. This model would also be applicable for a large company that wanted to develop a multi-site operation focused around a single, shared land support base.

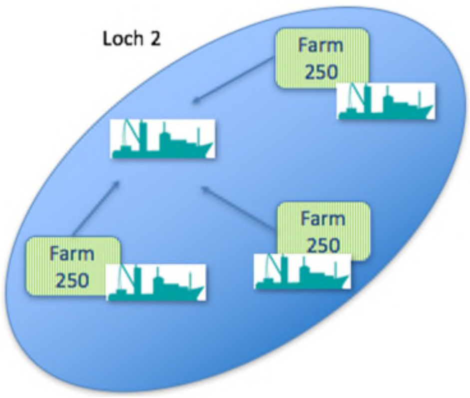

Figure 28: Schematic of loch-scale scenario 2c

3.2 FINANCIALS

3.2.1 Production plan

The model has been developed based upon a production plan wherein both spat collection and grow-out operations are carried out in-house. Whilst the model assumes each 250-tonne farm has their own spat collection operation, in practice, and depending upon the level of integration and cooperation between the farms, this could be a shared activity (subject to any regulatory constraints) with spat lines positioned in the most favourable location. In the model, the spat collecting and related processes are assumed to last less than 1 year whilst the grow-out phase is set at 2 years maximum. In practice, the actual duration of these production phases will vary and are site specific.

<u>Spat phase</u>

The approach used in the model is based on a system with twin headline with 10-meter deep ropes resulting in 9000 meters of spat collecting rope per longline. Initial mussel seed size is 0.15mm in length and final size at spat harvesting is projected at 25mm with an associated weight of circa 2 grams. A conservative figure has been assumed for the model for spat productivity which equates to 2.5 kilos of spat per meter of collecting rope. In reality much higher levels are often achieved although this can lead to additional challenges with spat being lost during the harvesting process due to the excessive weight of biomass on the ropes. The actual time from setting to harvesting the spat lines is

[3] Scottish Shellfish Critical Mass Study (download)

expected to be circa six months although the limitations of the model mean that this phase appears to last up to 1 year.

Grow-out phase

Using the New Zealand approach, a continuous growing rope is attached between two headlines every 0.45 meters and hung to a depth of 10 meters giving a total of 10,000 meters of mussel growing rope per longline. Mussel spat (contained in socks) are attached at a target density of 500 spat per meter. The duration of this phase is shown in the model as lasting 3 years however when taking into account the actual duration of the spatting phase, this is effectively equivalent to a two-and-a-half year grow-out process. At harvest, the assumed productivity is 4 kilos of market sized mussels per meter of growing rope giving a harvest of 40 tonnes per longline.

Operations

An overview of the main operational tasks associated with mussel farming is shown below.

Overview of main operations	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Maintaining grow-out operations and light harvests of market sized mussels												
Increased harvest (for Easter). Prepare systems and equipment for spatting												
Suspension of harvesting during mussel spawning period												
Lay spatting lines. Annual maintenance work (and staff holidays) scheduled during spawning season												
Bulk of harvesting done during this period												
Harvesting spat for socking & seeding onto grow-out lines												
Harvesting (light in November followed by heavier for December & New Year demand). Maintain systems and equipment in preparation for winter												

Table 8: Overview of main monthly activities for mussel farming operations

Mussel farming activities revolve around two fundamental requirements; a dedicated workboat and a land support base.

The workboat is needed for the following tasks:

- Deployment and retrieval of spat collectors
- Processing/socking of spat
- Deployment of grow-out ropes and socked mussels
- Maintenance of production structures (removal of fouling, checking and adding flotation)
- Harvest operations

The land support base is needed for the following main functions:

- Landing/access platform for servicing and operating the mussel farm

- Storage of equipment and systems
- Maintenance and workshop capabilities

In addition, the support base could also provide the following optional bolt-on capabilities (at additional cost):

- Handling and processing capabilities (e.g. depuration and packing facilities)
- Storage of harvested mussels (cold/chilled storage facilities)

3.2.2 Capex

250 tonnes per annum production

Estimates of the capital investment (Capex) requirements for a 250 tonne per annum mussel farm are shown below. The cost estimates have been compiled on the basis that no grant funding support is available and thus in an effort to help offset this loss, it is assumed that some of the items would be purchased second hand where this would not undermine the business through a significant increase in operational risk.

Capex Items	Year 1
Workboat purchase price	110,000
2nd Workboat (spat/re-socking activities)	0
Small support boat	20,000
Specialist boat mounted mussel equipment	80,000
Helical screw anchors	19,600
Headline Flotation system	66,000
Spat Rope	11,839
Grow out rope	31,349
Snoods & other accessories	2,277
Hanging brackets	9,301
Mooring equipment	5,440
Installation of systems onto sea site (charter vessel cost)	7,110
Installation of systems land based support (Telehandler & operative cost)	3,104
Work vehicle (pick-up)	25,000
Forklift (2nd hand)	10,000
Shed for storage & Ops. (cost per tonne of mussels produced)	62,500
Misc. Items	0
Sub-total	£463,520
Contingency	£23,176
Grand Total	£486,696

Table 9: Projected Capex cost estimates for a 250 tonne per annum mussel farm

Renewal of amortized capex items in Year 8; for simplicity it is assumed that the costs for these items is the same as they were when originally purchased in Year 1

Capex Items	Year 8
Spat Rope	11,839
Grow out rope	31,349
Snoods & other accessories	2,277
Hanging brackets	9,301
Work vehicle (pick-up)	25,000
Forklift (2nd hand)	10,000
Misc. Items	0
Sub-total	£89,766
Contingency	£4,488
Grand Total	£94,254

Table 10: Estimated Capex replacement costs for a 250 tonne per annum mussel farm in Year 8

Assumptions for Capex estimates

The single most costly item is a workboat and it is assumed that the most cost-effective solution for a new start up business would be to purchase a second hand vessel with the most likely options being either a landing craft or to convert a fishing boat. The actual cost of having an operationally ready and capable vessel would depend upon the amount of conversion work needed along with the level of automation that is targeted through the installation of various mussel handling equipment (e.g. line stripper, de-clumper and grader) onto the vessel. With respect to the latter, an allowance of £80,000 has been included in the budget however the actual cost for such equipment can be up to £160,000 (for systems capable of handling 5 tonnes of mussels per hour) although it is not necessary to go for the latter capacity level for a 250-tonne farm. Another issue to take into consideration is that, depending upon the size of the workboat, it may not be capable to undertake the initial deployment of the grow-out longlines in which case this task would have to be outsourced. An assumption for this eventuality has been included in the model at a daily hire rate for a larger boat of £2000 per day wherein such a vessel would be capable of deploying circa 1000 meters of longline per day. In addition, a land-based telehandler (and operative) would also be needed to prepare and assist with getting the longlines into the water and an indicative cost for this (if also outsourced) would be circa £830/day for handling 1000 meters of longlines per day.

All mussel production equipment (ropes, brackets and other accessories) has been costed using prices for the purchase of new materials/products and it is assumed that these shall have a nominal life of seven years after which time they are replaced (again with new items).

The cost for a land support base has been estimated on the basis of 1.25 square meters per tonne of mussel production capacity and using an indicative cost of £200 per square meter to build and fit out the facility.

<u>750 tonnes per annum production</u>

When considering the Capex requirements based on the 750 t.p.a. total annual output there is the opportunity to benefit from increased efficiencies derived from sharing and rationalising production operations. The main benefit comes from the possibility to have an extra (shared) vessel which would then allow a greater degree of specialisation of production operations. For example, during the spatting season one of the vessels could be left set up with the spatting and re-socking gear. Moreover, by having an extra (4^{th}) vessel shared between a number of mussel farms, there is the additional option to slightly reduce the specification of the individual mussel farm vessels. This could translate into a significant saving in the total Capex spending as outlined in Table **11** below.

Capex Items	Year 1
Workboat purchase price	210,000
2nd Workboat (spat/re-socking activities) see separate annual cost below	
Small support boat	40,000
Specialist boat mounted mussel equipment	160,000
Helical screw anchors	56,000
Headline Flotation system	184,800
Spat Rope	35,518
Grow out rope	94,046
Snoods & other accessories	6,830
Hanging brackets	27,902
Mooring equipment	16,000
Installation of systems onto sea site (charter vessel cost)	20,912
Installation of systems land based support (Telehandler & operative cost)	9,130
Work vehicle (pick-up)	75,000
Forklift (2nd hand)	30,000
Shed for storage & Ops. (cost per tonne of mussels produced)	112,500
Misc. Items	11,250
Additional annual contributions towards shared Capex items (over 10-year period)	
2nd Workboat (spat/re-socking activities)	50,000
2nd (central) shed (storage & operations)	7,500
Sub-total (Year 1 only)	£1,147,389
Contingency	57,369
Total (Year 1 only)	£1,204,758
Total (Year 1 to 10 excluding renewals but including 5% contingency)	£1,722,258

Table 11: Projected Capex cost estimates for a 750 tonne per annum mussel farm

As for the 250 tonne Capex budget, there is an assumed requirement for the renewal of amortized capex items in Year 8 and these have been costed the same as they were when originally purchased in Year 1

Capex Items	Year 8
Spat Rope	35,518
Grow out rope	94,046
Snoods & other accessories	6,830

Hanging brackets	27,902
Work vehicle (pick-up)	75,000
Forklift (2nd hand)	30,000
Misc. Items	11,250
Sub-total	£338,047
Contingency	£16,902
Grand Total	£354,949

Table 12: Estimated Capex replacement costs for a 750 tonne per annum mussel farm in Year 8

3.2.3 Opex

Projected Operating costs have been summarized in the form of a 6-year Profit and Loss account for both the 250 and 750 tonnes per annum farming scenarios. Some of the key assumptions are:

- Sale price (ex-farm) of £950 per tonne
- Labour costs have been calculated using realistic market rates (£30,000 p.a. for a worker and £50,000 p.a. for a farm manager) even though (at least) any managerial staff are likely to be owner-operators in the case of 250 t.p.a scale farms so they may not draw a fixed wage.
- All spat is wild sourced and collected in-house and the cost shown in the Opex budget reflects staff and boat operational costs along with the depreciation cost allowance for the spat rope. However, the use of hatchery reared spat would be preferred (if available at a cost-effective price) as this could lead to range of potential benefits including:
  - continuity of supply,
  - improved performance (e.g. triploid seed to prevent lost sales during the spawning season)
  - long term quality improvement (e.g. selective breeding to assess and reduce/eliminate any hybridisation with *Mytilus trossulus*)
- a 3-year production cycle (from spat to market size) with sales starting in the 4th year.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Income						
Revenue from sale of full-grown mussels	0	0	0	237,500	237,500	237,500
Expenditure						
Direct						
Mussel Seed (including spat rope depreciation)	6,116	6,116	6,116	6,116	6,116	6,116
Labour (Full & Part-time)	110,000	110,000	110,000	110,000	110,000	110,000
Freight	2,000	2,000	2,000	2,000	2,000	2,000
Boat operations	5,106	5,691	6,120	6,120	6,120	6,120
Energy & Utilities	5,000	5,000	5,000	5,000	5,000	5,000
Total	128,222	128,807	129,236	129,236	129,236	129,236

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Gross margin	-128,222	-128,807	-129,236	108,264	108,264	108,264
Indirect						
Repairs and renewals	13,627	13,627	13,627	13,627	13,627	13,627
Shore base rent	7,500	7,500	7,500	7,500	7,500	7,500
Seabed Concession rent	451	902	1,218	1,218	1,218	1,218
Misc. costs	3,500	3,500	3,500	3,500	3,500	3,500
Depreciation (no grant & excl. spat rope depreciation)	39,753	39,753	39,753	39,753	39,753	39,753
Total	64,832	65,283	65,598	65,598	65,598	65,598
Total expenditure	193,054	194,090	194,834	194,834	194,834	194,834
Profit (loss) (EBIT)	-193,054	-194,090	-194,834	42,666	42,666	42,666
EBIT Ratio	0%	0%	0%	18%	18%	18%
Profitability Ratio	0%	0%	0%	22%	22%	22%

Table 13: Projected Opex and 6-year P&L budget estimate for a 250 tonne per annum mussel farm

As with the Capex situation, some economies of scale are possible if the three 250 tonne farms are operated in a collaborative manner. This includes a projected saving in labour costs arising from a reduction in the number of employees required. Further cost savings could also be made if the three farms were owned by the same business entity as this would remove the need to have high level (owner-operator?) management in place for each of the three farm units.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Income						
Revenue from sale of full-grown mussels	0	0	0	712,500	712,500	712,500
Expenditure						
Direct						
Mussel Seed (including spat rope depreciation)	27,211	27,211	27,211	27,211	27,211	27,211
Labour (Full & Part-time)	220,000	220,000	220,000	220,000	220,000	220,000
Freight	13,125	13,125	13,125	13,125	13,125	13,125
Boat operations	7,660	9,337	10,527	10,527	10,527	10,527
Energy & Utilities	45,000	45,000	45,000	45,000	45,000	45,000
Total	312,996	314,673	315,863	315,863	315,863	315,863
Gross margin	-312,996	-314,673	-315,863	396,637	396,637	396,637
Indirect						

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Repairs and renewals	31,000	31,000	31,000	31,000	31,000	31,000
Shore base rent	27,500	27,500	27,500	27,500	27,500	27,500
Seabed Concession rent	1,263	2,526	3,428	3,428	3,428	3,428
Misc. costs	21,000	21,000	21,000	21,000	21,000	21,000
Depreciation (no grant & excl. spat rope depreciation)	121,720	121,720	121,720	121,720	121,720	121,720
Total	202,483	203,746	204,648	204,648	204,648	204,648
Total expenditure	515,480	518,419	520,511	520,511	520,511	520,511
Profit (loss) (EBIT)	-515,480	-518,419	-520,511	191,989	191,989	191,989
EBIT Ratio	0%	0%	0%	27%	27%	27%
Profitability Ratio	0%	0%	0%	37%	37%	37%

Table 14: Projected Opex and 6-year P&L budget estimate for a 750 tonne per annum mussel farm

3.3 DISCUSSION

The projected financials reaffirm earlier work which indicated that in order to be economically viable, a mussel farm needs to be at a scale that supports the production of at least 250 tonnes per annum. Even at this level, a potential return on investment of just over 13% (in Year 6) calculated using the Internal Rate of Return (IRR) as the measure for the investment appraisal is modest given the level of risk associated with mussel farming operations. Furthermore, in order to achieve such a return, any investor would need to secure or provide a significant level of funding totalling £973,131 over a three-year period to support the project until it becomes self-financing in the fourth year from start-up. If debt finance is available (which is unlikely without being secured against suitable assets) and it is used as part of any funding package, then it would further reduce the return on investment and may make the project unviable from a risk-reward investment perspective.

A much larger scale project producing 750 tonnes per annum would provide a more acceptable investment opportunity with an IRR of nearly 18% in Year 6 however, it would need a much higher level of funding estimated at £2,526,283 over a 3-year period.

Production scale	Funding requirement	Return on Investment (IRR) excl. basic pre-project costs
250 tonnes per annum	£973,131	13.8%
750 tonnes per annum	£2,526,283	18.0%

Table 15: Funding requirements and investment appraisal for 250 and 750 tonnes of production

Any additional burden including significant up front (pre-project) costs and associated delays whilst navigating and complying with the current planning and related consents needed to start operating a mussel farm runs the risk of bringing the project to a tipping point wherein potential investors may decide it is not worth undertaking the venture in the first place.

A brief review of the basic pre-project requirements (including planning fees, visual Impact assessment (VIA) and a Marine license) suggests that the combined cost of these could range from circa £9000 to £14,000 for a 250 t.p.a. mussel farm and from £11,000 to nearly £17,000 for a 750 t.p.a. farm. To put that into context, these pre-project requirements could cost a similar amount per tonne of production capacity for a salmon farm however, the potential revenues from producing these two species are vastly different with salmon farming achieving circa two orders of magnitude more in earnings per unit area of sea/seabed occupied by production equipment. This highlights one of the finer issues within the current regulatory regime wherein no account is taken to factor in the financial burden (of pre-project costs) in relation to the potential revenue generating capacity of a project. Moreover, with respect to the environment impact of a project from a regulatory viewpoint, the emphasis is on assessing and mitigating any potential adverse aspects with no actual value being attached to any positive impacts. The presence of shellfish, particularly bivalves, can have a beneficial effect on the marine environment and its associated processes, depending upon the nature and diversity of the seabed, through providing a number of services including water purification and biogeochemical cycling. Water filtration services in the marine environment play a vital role for the ecosystem in much the same way as land-based water treatment services are fundamental for the provision of safe domestic water supplies. Using domestic water treatment costs[4] as a readily available comparison to estimate an indicative value of water filtration services provided by mussels, it would suggest that the cost of filtering (i.e. the removal of suspended solids) for any given volume of water if performed using the processes implemented for domestic water treatment would equate to an economic value derived from the environmental benefit provided of circa £26 million for a 250 t.p.a. mussel farm and circa £78 million for a 750 t.p.a. farm. Whilst it is accepted that the validity of applying a domestic water treatment cost to value the filtration processes provided by marine bivalves is somewhat debatable and may be viewed as blue-sky thinking, such a comparison serves to underline the potential positive impact of mussels (and bivalves in general) on providing filtration services to the marine environment. Even the pseudo-faeces which are deposited on the seabed as a result of the filtration process play a positive role (as part of biogeochemical cycling).

[4] Jersey Water treatment cost as at 2014

4 CONCLUSIONS

4.1 CONCLUSIONS

Suitable sites were identified within the Clyde region based upon a desktop study which could be expected to support significant levels of mussel production.

Projected financials indicate that both the 250 and 750 tonnes per annum scale of operations are economically viable based on the assumptions used. However, from an investment appraisal perspective, only the larger of the two production outputs provides anything approaching a reasonable return on investment. The current regulatory burden, both in terms of time and cost, is likely to be a negative factor for investors when considering any potential investment to start a new mussel farming project.

4.2 RECOMMENDATIONS

Financial assistance

With the withdrawal of EU grant funding following Brexit, new and innovative ways to help facilitate the funding of aquaculture projects is an important priority to help support and maintain the competitiveness of Scottish shellfish farming and the aquaculture sector in general.

Product quality

Increasing issues relating to the fragility of mussel shells leading to elevated levels of broken mussels during handling and packaging suggest this should be considered a priority for research efforts particularly if one of the key factors is potentially related to hybridisation with *Mytilus trossulus*.

Spat supply

A source of hatchery reared spat which could ensure adequate supplies are available to support industry needs whilst also investigating the potential for producing a triploid mussel would be an advantageous development if achievable on a cost-effective basis.

Environmental goods and services

The functional benefits associated with the marine environment are often overlooked and poorly understood. Any attempt to quantify the value of components or impacts is often done in a subjective and selective manner which usually favours maintaining or protecting the status quo at the expense of any new approaches or developments. This is often done without adequate science and facts to back up such a policy.[5] Despite this approach, a review by the Millennium Ecosystem Assessment found that 'nearly two thirds of the services provided by nature to humankind are found to be in decline worldwide'. In effect, the benefits reaped from our engineering of the planet have been achieved by running down natural capital assets'[6]. There is an increasing awareness by governments that addressing this issue through attempts to value ecosystem services will contribute towards better decision making by ensuring policy appraisals fully take into account the costs and benefits to the natural environment[7], and by highlighting more clearly the implications for human wellbeing while providing policy developers with new insights. An assessment of the role and value (in terms of environmental goods and services) provided through the farming of marine bivalves could be a useful additional tool when assessing shellfish planning applications.

[5] Ashley Wilson, former Technical Adviser; Fisheries Management and Marine Policy, DEFRA, UK (pers. comm.)

[6] Statement from the MA Board: http://www.millenniumassessment.org/documents/document.429.aspx.pdf

[7] http://www.unep.org/dewa/Portals/67/pdf/Marine_and_Coastal_Ecosystem.pdf

5 REFERENCES

Aquaspace - Gimpel, A., Stelzenmüller, V., Töpsch, S., Brigolin, D., Galparsoro, I., Gubbins, M., Marba, N., Miller, D., Moraitis, M., Murillas, A., Murray, A.G., Papageorgiou, N., Pastres, R., Pinarbasi, K., Porporato, E., Roca, G., and Watret, R. 2017. AquaSpace tool to support MSP. Thünen Institute, Hamburg and AquaSpace project (H2020 no. 633476), Oban. Deliverable 3.3. Pdf obtainable from http://www.aquaspace-h2020.eu

Clyde Marine Regional Assessment 2017 - Mills, F., Sheridan, S. and Brown S., (2017) Clyde Marine Region Assessment. Clyde Marine Planning Partnership. pp 231.

FAO Fisheries and Aquaculture Proceedings No. 21. "Site selection and carrying capacities for inland and coastal aquaculture" 2010, Rome, FAO.

Inglis, G.J., Hayden, B.J., Ross, A.H., 2000. An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. NIWA Client report CHC00/69. 690 Christchurch, New Zealand. 31 pp.

Longdill, P.C., Healy, T.R., Black, K.P., Mead, S.T., 2007. Integrated sediment habitat mapping for aquaculture zoning. Journal of Coastal Research 50, 173–179.

Marine Scotland Science Scottish Shellfish Farm Production Survey 2018

McKindsey, C.W., Thetmeyer, H., Landry, T., Silvert, W., 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261 (2), 451–462.

Mitchell, I.M., 2006. In situ biodeposition rates of Pacific Oysters (Crassostrea gigas) on a marine farm in Southern Tasmania (Australia). Aquaculture 257, 194–203.

Ross L.G., Telfer T.C., Falconer L., Soto D & Aguilar-Manjarrez J., eds. Site selection and carrying capacities for inland and coastal aquaculture, pp. 19–46. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Scottish Aquaculture Research Forum, SARF096 (2014), "New Approaches to Mussel Seedstock Acquisition".

Scottish Aquaculture Research Forum (SARF) report R.2466 (2016), "Considerations for Locational Regulation of Shellfish Aquaculture in Scotland".

Scottish Marine and Freshwater Science - C Greathead, E Guirey and B Rabe, 2012. Development of a GIS Based Aquaculture Decision Support Tool (ADST) to Determine the Potential Benthic Impacts Associated with the Expansion of Salmon farming in Scottish Sea Lochs. September 2012. Vol 3 No 6.

Stirling Aquaculture: Prospects and opportunities for shellfish farming in Scotland. David Scott, Douglas McLeod, James Young, Janet Brown, Anton Immink, John Bostock A study of the prospects and opportunities for shellfish farming in Scotland. Study funded by Marine Scotland and undertaken by Stirling Aquaculture, May 2010.

The Loch Fyne ICZM plan 2009, "Integrated Coastal Zone Management Plan Loch Fyne. A Spatial Planning Framework for Future Development". Marine & Coastal Development Unit, Planning Services, Argyll & Bute Council.

Wilding T.A., Nickell T.D., Changes in Benthos Associated with Mussel (Mytilus edulis L.) Farms on the West-Coast of Scotland. 2013, PLoS ONE.

ANNEX A:

Site Selection Parameters

The below are based on a review of published scientific papers, reports, the Aquaspace WATER toolbox, discussions with producers and are adapted with view to utilising data available from the public domain such as the NMPi and other sources, where available. The data is incomplete or does not cover the entire Clyde region, so assumptions have been made and judgements made based on available criteria. The results of this process to identify potential sites is not definitive, sites excluded may have been done so for various reasons such as lack of available data, or for existing constraints (possible pollution concerns) that are temporal. Areas highlighted as “no-go” regions may in the future change status, and areas selected as having good potential may prove to be unavailable at the licencing stage due to unknown conflicts or prior use.

Spatial Interaction, possible conflicts and constraints

- Aquaculture

Existing Aquaculture activities and inactive but still licenced sites, sites identified as pending application, and Crown Estate leased areas (such as sea bed leases for shellfish fisheries) will all be excluded, with a buffer zone of 500m established (to maintain a minimum 500m separation distance from any new identified sites). Most licencing authorities in Scotland do not specify separation distances between sites, only Shetland Islands Council (SIC) specifies a 500m separation distance.

- Fisheries

Existing licenced Fisheries will be avoided, with an exclusion zone of 300m established (to maintain a minimum 300m separation distance from any new identified sites)

- Offshore Wind farms, Platforms (oil, gas)

No such facilities currently occur in the Clyde but oil platform mooring/decommissioning sites could be established as could Wind Farms. Any identified potential sites for such activities will be avoided, however there could be synergies between Wind Farms and specialised mussel production facilities but such scenarios will not be considered.

- Cables and pipeline

A 100m exclusion zone either side of any submerged cables or pipelines will be established. This is precautionary approach based on “Marine infrastructure e.g. wind farms and pipelines with a 1 km buffer for points and a 100 m buffer for linear features” used in the Scottish Marine and Freshwater Science Vol 3 No 6 study. Many countries do permit aquaculture facilities over submerged pipelines, as they consider this safe, so this restraint could be subject to review.

- Sediment extraction

Sites where sediment extraction or dredging spoil discharge is allowed will be excluded with 1,000 m exclusion zone.

- Ports and Harbours

Port and Harbour exclusion zones with a 1000 m radial buffer around point features, was used in the Scottish Marine and Freshwater Science Vol 3 No 6 study on the expansion of salmon farms, however the same study reported “the masking layer for ports and harbours could be completely removed as not all ports and harbours exclude aquaculture” and considers removing the exclusion. For the purposes of this study the 1000 m exclusion is retained for large Ports and harbours and reduced to 300 m for all small ports and anchorages.

- Marine traffic

Transportation routes e.g. ferry routes with a 1000 m buffer.

- Shipwrecks

All wrecks in Seazone list with a 1000 m buffer.

- Protected Environments - MPAs, PMFs, SACs, SPA’s, SSSI’s, etc

All designated protected areas (Ramsar sites such as the inner Clyde Estuary are included in SPAs) will be avoided.
Note: Some MPA's refer to fishing with bottom gear, location of mussel culture facilities could be allowed under special consideration of environmental impact (benthic impact, including moorings).
MPA – Marine Protected area
PMF – Priority Marine Features
SAC – Special Area of Conservation, SNH
SPA – Special Protection Area
SSSI's – Site of Special Scientific Interest

- Waste disposal

Industrial discharge and waste water treatment plants, a 1000 m radius from point of discharge. For SEPA outfall pipes from wastewater treatment, a 500m buffer around the outfall (this meets USFDA requirements in terms of water classification and potential contamination). Where there are major outfalls (depending on treatment level – tertiary and volume), this distance will increase to 1000 m.

- Military facilities

MOD exclusion zones (PEXA Areas), Crown/naval ports - Gareloch and Loch Long.

<u>Environmental effects</u>

- Depth (m)

Mussel surface longlines can be located in water depths 10-40m above the chart datum (lowest astronomical tide and mean lower low water MLLW) ideally (deeper waters can be considered but increase mooring/maintenance costs). The potential use of new/alternative submerged technology is not considered in this study but would allow development in deeper waters if required.
A study of the prospects and opportunities for shellfish farming in Scotland by Stirling Aquaculture reported "The most common approach in Scotland is the use of horizontal longlines moored in sea lochs where depths are between 15 and 40 m". For the purposes of this report a similar depth of 15 to 40 m was considered.

- Wave height specific exposure of the site (m)

Waves detrimentally effect mussel longlines, increasing mooring and structural costs, causing stock to detach from the growing substrate and reducing working access and confounding operations.
Significant wave height (SWH) is a commonly used measure in suitability assessment and site selection for marine aquaculture, this needs long-term data or modelling of SWH. Fetch length (distance of open water), along with the wind speed, determines the size of waves produced. Only sites with a reasonable fetch were considered along with the presence of existing aquaculture facilities in the vicinity indicating suitability (no significant wave action).

- Current velocity (m/s)

Water circulation is known to be beneficial to shellfish culture in the supply of dissolved oxygen, food particles and dissipation of waste products while slack water and strong currents or wave action have detrimental effects. Additionally, excessive current increases drag on ropes and moorings of long-lines and can negatively impact the operation and cost of the installation (ropes and mooring). Currents in the region of 10-85cm per sec., would be preferred. Suitability assessment and site selection for mariculture needs long-term historical information on the speed and variability of currents, however such data is often not readily available. In the absence of such data a judgement was made on the potential currents, and by utilising the presence of existing aquaculture facilities in the vicinity implying current velocity suitability.

- Sediment type

Sediment type plays a key role in defining the magnitude of potential impacts of shellfish aquaculture at a site (Longdill et al., 2007). Bio-depositional impacts from a shellfish aquaculture site will depend in part on the existing habitat or sediment type, e.g. a rocky community will be more affected than a soft sediment community which will be able to break down deposited material more efficiently and effectively than areas lacking a range of benthic organisms (Mitchell, 2006). Soft sediment habitats,

comprised of fine silty and muddy sediments with low organic content, are determined to be the most suitable benthic environments above which to site suspended shellfish aquaculture (Longdill et al., 2007). Mooring costs are less expensive in these areas so rocky areas will be avoided.
Sediments will be classified on the base of the sediment type, i.e. rocks (5), mixed sediment (4), coarse & gravel (3), sand (2) and mud (1). Utilising navigational charts and other available data/studies the sea bed will be classified accordingly where possible, lower ranked sites will be prioritised.

- Productivity - Chlorophyll a (mg/m3; surface)

Primary productivity. Available food in terms of phytoplankton biomass, chlorophyll a (Chl a) and particulate organic matter (POM), has an interacting effect upon assimilation efficiency in shellfish filter feeders. If data is available this will be considered towards an estimate of productivity, in the absence of data an assumption/judgement will be used.

- Temperature (°C)

Sea Water Temperature. Mussels are capable of surviving temperatures from 2 to 27^{o}C, so survival is not an issue, however temperatures above 8^{o}C favour growth (8-18^{o}C optimal), so areas with higher than average temperatures will be preferred.

- Salinity (PSU)

Mussels grow well above 20 PSU (22-30 PSU optimal), salinities below this will be avoided (areas such as heads of Lochs, which experience fresh water inputs). Additionally, this will control infestation by *M. Trossulus* which prefers lower salinities

- Habitat vulnerability/Benthic impact

Vulnerable habitats (sea grass, horse mussel beds etc) will be avoided, essential but highly sensitive benthic habitats were scored for their vulnerability using the AquaSpace tool assessment criteria.
All aquaculture activity has an impact on benthic diversity and some negative impact. Mussel longlines have a minor impact and this is restricted to the immediate area, a study on the West Coast of Scotland (Wilding TA, Nickell TD 2013), concluded “The data presented here suggest that detecting mussel-farm impacts, related to macrobenthos and starfish, beyond 10 m from the farm periphery will be challenging where they are located on soft sediments”. The protection of diversity of benthic fauna is an important factor to take into account in shellfish site selection, as a precautionary approach a distance of 100m from sensitive habitats will be observed.

- Predators, Disease and Fouling

Predators, Disease, Competitors, and fouling organisms. Predation from wild ducks, starfish (which settle on the lines), crabs and fouling by sea squirts, can be dependent on sites so will be given consideration, however these issues can be addressed by precautionary management. These will be assessed (using any available data) as to potential risk in considering site selection. Any existing management areas/movement orders will be considered, as outlined in Scotland’s National Marine Plan (The Scottish Government, Edinburgh 2014, planning policy AQUACULTURE 6). New aquaculture sites should not bridge Disease Management Areas although boundaries may be revised by Marine Scotland to take account of any changes in fish farm location, subject to the continued management of risk.

- Risks - HAB's and pollutants

Harmful Algae Blooms (HAB’s) also referred to as Toxic algae. Though not harmful to mussels, closure of an area due to high biotoxin levels can cause disruption to harvest schedules and cash flow. Areas with a prior recorded high incidence of occurrence of blooms of toxic algae will be avoided.
Metals and organic xenobiotics such as, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Areas with a prior recorded high level of pollutants in the water or sediment will be avoided.

- Carrying capacity - biological and environmental

System carrying capacity is a key consideration, as outlined in Scotland’s National Marine Plan (The Scottish Government, Edinburgh 2014 planning policy AQUACULTURE 1). Marine planners and decision makers should seek to identify appropriate locations for future aquaculture development and use, including the potential use of development planning briefs as appropriate. System carrying capacity (at the scale of a water body or loch system) should be a key consideration.

Socio-cultural effects

- Visual Impact (landscape, seascape, distance to populated areas)

As specified in Scotland's National Marine Plan (The Scottish Government, Edinburgh 2014, planning policy AQUACULTURE 5). Aquaculture developments should avoid and/or mitigate adverse impacts upon the seascape, landscape and visual amenity of an area, following SNH guidance on the siting and design of aquaculture. Landscape assessments (from NMPi), and an exclusion zone of 3km from populated areas, were utilised to make a judgment of visual impact, this was considered and taken into account as part of the site selection process, with view to selecting sites that most probably and in the view of the authors of this study, will not attract a negative visual impact assessment at the licencing stage. The presence of other aquaculture installations in the vicinity was considered a positive factor regards visual impact.

- Cultural heritage (archaeological sites)

A 500m buffer will be applied to any archaeological sites identified

- Tourism, Social boating and recreation

Tourism and social boating are major sources of income and amenity in rural areas. Conflict with such activities will be avoided and a 200m buffer zone applied to any RYA sailing routes.

Economic effects

- Logistical support - proximity to services, labour, harbour, shore-base.
- Economic efficiency - cluster potential, economies of scale.

Other specific and policy consideration

- Spat supply and spat settlement sites

Following anecdotal industry reports of poor spat settlement and mortality in 2010, Marine Scotland Science developed a questionnaire which was sent to all authorised aquaculture production businesses farming mussels. The results of this 2011 investigation indicated that poor spat settlement and mortality were not widespread in Scottish waters, although they had major impacts on certain individual producers. The causes were associated with environmental variables, guiding the industry to consider focused spat fall monitoring. In 2014, SARF096 "New Approaches to Mussel Seedstock Acquisition", study identified four potential strategies that could be applied to resolve at least some of the uncertainty associated with the process of seed provision:

1. Adaptations of existing practice

2. Buying in mussel seed

3. Deploying specific collector systems in new locations

4. Hatchery production

These four approaches can be divided roughly into two camps. Approaches (1) and (2) require relatively modest investment, with approaches (3) & (4) would require considerable capital expenditure, especially option (4) which at this point is economically unviable. The industry has responded by adapting its practises with the development of specialised settlement sites (natural spat fall occurs in the surface layers and in more consistent in specific sites or areas) and dedicated spat collectors. The purchase of seed was also utilised.

Subsequently, as a result of talks between the Association of Scottish Shellfish Growers, Marine Scotland policy and Marine Scotland scientists, to determine the focus of possible research and development, a spat collection question was introduced to the 2013 survey. This question focused on mussel spat collection and was in two parts: is this a spat collection site; if yes, was spat settlement sufficient for production purposes? The responses of these surveys have been collated in table 8 below.

Year	Responses Received	Number of Spat sites	Percentage of Spat sites	Sufficient Spat settlement
2018	232	136	59%	40%
2017	234	104	44%	74%
2016	248	108	44%	63%
2015	249	111	45%	69%
2014	218	105	48%	57%
2013	176	97	55%	43%

Table 16: Scottish Shellfish Farm Production Survey 2013-2918, reported spat settlement

To identify trends a longer time series is required, but it appears that reported spat settlement was improving over the same time period till 2017, and spat collection sites were becoming more efficient, as the percentage of sites utilised for spat settlement fell from 55% to 44%. 2018 however was a bad year, utilising this data and recent communications from mussel farmers spat settlement is a matter of concern, the decline that was a concern in 2010 which was halted, has repeated in 2018. Though spat can be imported, availability of local sustainable and consistent supply, through dedicated settlement sites and spat collectors should be an industry priority.

- Designated Waters

Sites in designated shellfish waters will be prioritised as advised in Scotland's National Marine Plan (The Scottish Government, Edinburgh 2014, planning policy AQUACULTURE 4). There is a presumption that further sustainable expansion of shellfish farms should be located in designated shellfish waters, if these have sufficient capacity to support such development. Sites in undesignated areas will also be considered at a lesser ranking though consideration will be given to proximity of sources of faecal coliforms, and any available monitoring data.

- Perceived quality/Market factors.

Supermarket buyers and public awareness of product origin can lead to a (sometimes erroneous) negative perception regards quality due to region of origin. Some outlets demand the highest quality standards regards water quality and shellfish water classification, with this in mind Classification A or B waters will be prioritised, and areas with a perceived negative origin (proximity to industrial regions, nuclear facilities etc) will be avoided.