CREW CENTRE OF EXPERTISE FOR WATERS

Towards an Economic Value of Native Oyster Restoration in Scotland:

Provisioning, Regulating and Cultural Ecosystem Services

CREW CENTRE OF EXPERTISE FOR WATERS

Published by CREW – Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes supported by MASTS. The Centre is funded by the Scottish Government.

Author: Hazel Allen
Athena Solutions

Dissemination status: Unrestricted

Acknowledgements: The author would like to take this opportunity to thank the many people who have assisted in the production of this report. The DEEP project partners including Professor Sanderson, Heriot-Watt University and Professor Ferrier of the James Hutton Institute provided guidance, information and information sources, and contacts for follow up. The Glenmorangie Company assisted my greater understanding of the issues of the whisky industry and solutions, including site tours and explanations of the AD process, and a very welcome invitation to the Native Oyster Restoration Initiative conference. The input from stakeholders in the oyster and shellfish industries and their openness and contributions on the issues and solutions has been instrumental in the development process. I am very grateful to all those who have kindly given their time, information, and welcomed site visits for use in this study including Loch Nell Oysters, Loch Ryan Oyster Company, Maorach Beag, Morecambe Bay Oysters, Orkney Shellfish Hatcheries, Loch Fyne Oysters and West Coast Sea Products. My particular thanks to Peter Murphy of UK Water for his guidance and support. Officers from the Association of Scottish Shellfish Growers, HIE, SAIC, Scotland Food and Drink Partnership, Scottish Enterprise, Seafish, SNH, Stranraer Development Trust, and Zero Waste Scotland all provided information and time to assist in the wider considerations of native oyster restoration and aquaculture impacts. My apologies to those I was not able to meet as part of the research process. I would also like to thank Dr Ioanna Akoumianaki for providing useful comments on an earlier version of the report.

The Scottish Government Water Industry Team is acknowledged for their support of this project.

ISBN: 978-0-902701-67-0

Contents

Executive Summary 1
Actions to achieve these benefits 2
1 Introduction 3
2 Relevant background 3
2.1 Native Oysters: distribution, aquaculture, restoration, and ecosystem services 3
2.1.1 Native Oyster historical distribution and restoration in the UK and Europe 3
2.1.2 Aquaculture of native oysters 6
2.1.3 Challenges to restoration 6
2.1.4 Ecosystem services of restored native oyster reefs 7
2.2 DEEP: innovation, benefits and impact 12
2.2.1 Overcoming challenges through innovation 12
2.2.2 Strengthening the supply chain 15
› Loch Ryan 15
› Lochnell Oysters 16
› Maorach Beag 16
› Orkney Shellfish Hatchery (OSH) 17
› Shellfish processors: Scottish Shellfish Marketing Group and West Coast Sea Products 17
2.2.3 Summary: present social and economic impacts of DEEP 18
3 Helping deliver Ambition 2030: opportunities and barriers to growth 18
3.1 Opportunities for Growth: the food market 18
3.2 Opportunities for Growth: the restoration market 20
3.3 Delivering growth: the opportunities 21
3.3.1 Potential economic benefits from native oyster aquaculture and restoration 22
3.3.2 Employment and Gross Value Added 22
3.3.3 Community and social benefits 23
3.3.4 Oysters and tourism 23
3.4 Summary: Wider economic impact potential of Native Oyster Aquaculture 24
3.5 Barriers to growth 24
3.6 Finance and investment in the supply chain and restoration 25
4 Towards an ecosystem value 26
4.1 Wider applications of the DEEP approach 26
4.2 DEEP – imputed value of cultural and social services 27
4.3 The native oyster USP: cultural and social values 27
5 Native Oyster Restoration 27
5.1 Opportunities to deliver policy objectives 27
5.2 River Basin Management – a role for Ostrea edulis? 28
5.3 Towards Zero Waste: Scotch Whisky industry reusing co-products in circular economies 32
5.4 Summary: Benefits of the DEEP approach to the Hydro Nation Strategy 34
6 Summary 35
7 References 37

List of Tables and Figures

Figure 1.	Mapped extent of exploited Ostrea edulis beds in the North Sea, 1883	5
Figure 2. :	Diagram of Chesapeake Bay Oyster Reef Ecosystems Projects	8
Figure 3.	Green infrastructure benefit groups: comparison to "service provision approach"	9
Table 1.	Oyster Capacity for Nutrient Fixing	12
Table 2.	DEEP: Addressing Challenges to Native Oyster Restoration	15
Table 3.	Summary of DEEP social and economic benefits to date	18
Figure 4.	Shellfish Production in 2018	18
Figure 5.	UK exports of live Pacific oysters, 2018	19
Table 4.	Gross value added per sectoral employee	22
Table 5.	Gross Value Added from Growth in Native Oyster Aquaculture Production	23
Table 6.	Wider economic impact potential from developing current production sites	24
Figure 6.	Aquaculture Growth to 2030: Strategic Priorities	24
Figure 7.	Ecosystem valuation: a services and benefits approach	26
Figure 8.	Pressures on water quality on water bodies in Scotland	28
Figure 9.	Priority areas for rural diffuse pollution	29
Figure 10.	What might future sewer networks look like?	30
Figure 11.	Infographic: The Billion Oyster Project 2010 – 2018 impact	31
Figure 12.	Hudson Bay Estuary: Pollution Infographic	31
Figure 13.	Current uses for Whisky By-products in Scotland	33
Figure 14.	"Hotspots" for resource recovery in the Beer, Whisky and Fish industries	33
Table 7.	Summary: Benefits of native oyster restoration to water quality management	34

Executive Summary

Native oyster beds (*Ostrea edulis*) are one of the most endangered marine habitats in Europe, with associated population losses of over 95%, mainly due to overfishing in the 19th and early 20th century. The loss of this keystone species has also meant a loss of oyster reef habitat for other shell and fin fish, and a loss of key ecosystem services for filtration and sequestration of pollutants. Difficulties and costs of native oyster (*Ostrea edulis*) aquaculture means that for the last 30 years, commercial oyster aquaculture in the UK has focused on the faster-growing non-native Pacific oyster (*Crassostrea gigas*).

The Dornoch Environmental Enhancement Project (DEEP) project is investing £6.4m in restoring 40 hectares of native oyster reef off the shore at Dornoch, to provide a bioengineering solution to treatment of the last 5% of biological oxygen demand pollution from the Glenmorangie Distillery at Tian. As part of the overall project DEEP is investing £1.4m on sourcing native oysters, and this spend has already helped to overcome both known challenges to aquaculture of native oysters and identified barriers to setting up a shellfish supply chain. The process so far has already created measurable economic benefits including;

- safeguarding three SMEs by providing additional markets for their product and assisting in access to new supply chains thus helping protect eleven existing jobs in economically fragile areas;
- enabling these SMEs to develop expansion plans for increasing production and investment; and assisting in the development of a Scottish multi-species hatchery; and
- providing four knowledge transfer and partnership working with SMEs.

Research questions

Against this background, three objectives underlie this work;

- o What are the benefits of native oyster restoration in Scotland in terms of provisioning, regulating, and cultural ecosystem services?
- o What are the wider applications and opportunities arising from initiatives such as Dornoch Environmental Enhancement Project (DEEP) which inform the potential restoration of native oyster beds?
- o What is the potential for economic growth and in meeting wider policy objectives?

Main findings

The main findings from this study are;

- A review of the literature identified the economic benefits of; provisioning (e.g. seafood), regulating (e.g. water filtration), habitat (e.g. bioengineering, species protection) and cultural (e.g. sense of place and research) ecosystem services of restored native oyster beds as well as the environmental, economic and social benefits of restoration. The review also identified the challenges to native oyster restoration and barriers to the growth of native oyster aquaculture in Scotland.
- The water filtration, bioengineering and cultural services of native oyster reefs have been studied extensively. Oyster aquaculture and reef restoration are widely recognised by the regulating authorities as a "best practice method" for reducing pollution in the marine environment. In the UK, native oyster restoration also resonates with developing social values around the marine environment by people and communities because of the historical aspects of native oyster consumption.
- The DEEP project has identified and addressed the challenges to native oyster restoration including; limited brookstock numbers, lack of suitable substrate, diseases and pests, invasive species, disturbance and pollution, as well as lack of regulation, investment and leadership.
- The implementation of DEEP has highlighted a number of constraints to the growth of the native oyster aquaculture such as human capital and financing, the latter being the single biggest challenge.
- The supply chain created for DEEP has the Unique Selling Point of producing disease-free native oysters in high quality shellfish waters under the Scottish "brand". The Scottish supply chain has a current advantage in that its on-growing production is ahead of almost all European production. This creates an immediate potential to supply both into the growing European restoration market and also into an existing, but currently very small, world-wide markets for native oysters.
- The supply chain thus created could enable economic activity from native oyster cultivation to equal the current Scottish levels for Pacific Oysters within 5 years, adding 5% growth. This has the potential to create up to 50 FTE jobs and £3.5m gross value added. These jobs would be in the most fragile rural communities, helping sustain some of the most economically marginal areas of the Western and Northern Highlands and Islands, bringing not only economic but social value to areas depopulated by migration and struggling with an aging demographic.

- The DEEP approach and consideration of oyster restoration has provided complementary opportunities to enhance the delivery of policies set by the Scottish Government such as Aquaculture Growth to 2030, Ambition 2030, the Hydro Nation Strategy and Zero Waste strategies and the water quality environmental objectives set by SEPA.
- The actions required to achieve the benefits and opportunities arising from the DEEP approach are set out below:

Creating native oyster aquaculture capacity to supply European-wide restoration markets

- Regulatory change to permit DEEP to continue to expand restoration of native oysters for non-aquaculture purposes
- Continuing support for research into efficient and effective hatchery and on-growing techniques
- Capital and set-up investment in native oyster aquaculture
- Completion of existing government agency actions to simplify regulations for new shellfish aquaculture sites
- Continuing enforcement and awareness-raising of disease and non-native species exclusion from Scottish waters and specifically potential oyster restoration / aquaculture sites

Supporting native oyster aquaculture capacity to supply world-wide Scottish Shellfish markets

- Industry collective action for branding, marketing and selling
- Support for branding and marketing of native oysters into Asian and Middle Eastern markets as part of Ambition 2030
- Continuing dialogue on the standards for Scottish Shellfish Waters and their monitoring and protection
- Access to working capital support for native oyster aquaculture

Use of native oysters for Bioengineering in Water Quality Management

- Closer policy integration and working between government agencies and delivery bodies to develop a collective policy approach for integrating ecosystem benefits and their multiple values into Hydro Nation, Circular Economy, and Zero Waste strategies and applications
- Development of a regulatory framework for oysters and other shellfish as non-food bioengineers
- Detailed locality modelling of potential take-up of nitrogen, phosphorus, and faecal indicator organisms, pesticides and sediments in catchment basins
- Locality ecosystem valuation of the provisioning, regulatory, and cultural / social values of the native oyster including cost avoidance
- Development of impact investment or other trading or compensatory models to match costs and ecosystem benefits

1 Introduction

Native oyster beds (*Ostrea edulis*) are one of the most endangered marine habitats in Europe, with associated population losses of over 95%, mainly due to overfishing in the 19th and early 20th century. The loss of this keystone species has also meant a loss of oyster reef habitat for other shell and fin fish, and a loss of key ecosystem services for filtration and sequestration of pollutants. Difficulties and costs of native oyster (*Ostrea edulis*) aquaculture means that for the last 30 years, commercial oyster aquaculture in the UK has focused on the faster-growing non-native Pacific oyster (*Crassostrea gigas*).

The primary aim of this research was to elucidate the current state of knowledge of oyster restoration within Scotland, the UK and in other global contexts. What have been the lessons learnt in terms of the impact of oyster restoration on economic, social and environmental considerations and how are these expressed in terms of ecosystem service benefits? The research also considered the significant progress of a contemporary large-scale restoration plan with the Dornoch Firth. The Dornoch Environmental Enhancement Project (DEEP) project (a partnership between Glenmorangie Company, Heriot-Watt University, and the Marine Conservation Society) is presently investing £6.4m in restoring 40 hectares of native oyster reef off the shore at Dornoch, to provide a bioengineering solution to treatment of the last 5% of biological oxygen demand pollution from the Glenmorangie Distillery at Tian. As part of the overall project DEEP is investing £1.4m on sourcing native oysters, and this spend has already helped to overcome both known challenges to aquaculture of native oysters and identified barriers to setting up a shellfish supply chain.

Consideration was also given to opportunities for economic growth from both restoration and from aquaculture to support the food market and industry ambitions. Finally, the potential benefit of oyster restoration in delivering wider environmentally policy objectives was evaluated.

Research questions

Against this background, three objectives underlie this work;

- o What are the benefits of native oyster restoration in Scotland in terms of provisioning, regulating, and cultural ecosystem services?
- o What are the wider applications and opportunities arising from initiatives such as Dornoch Environmental Enhancement Project (DEEP) which inform the potential restoration of native oyster beds?
- o What is the potential for economic growth and in meeting wider policy objectives?

2 Relevant background

2.1 Native Oysters: distribution, aquaculture, restoration and ecosystem services

2.1.1 Native oyster historical distribution and restoration in the UK and Europe

Wild native oyster beds of *Ostrea edulis* are one of the most endangered marine habitats in Europe. In the UK wild native oyster populations have declined by over 95%. The loss of the wild native oysters is largely a result of historic overfishing with stock depletion being recorded as early as the first century AD (Figure 1).

There have been attempts over the past century to recover the native oyster population mainly as a shellfishery resource. *Ostrea edulis* has a wide geographical range which extends from the North of Norway, along the west coast of Europe as far as Spain, and further south along the Atlantic coast of Morocco. It extends into the Mediterranean, primarily along the north coast and penetrates the Black Sea as far as the Crimea. It once formed extensive beds all around the UK coast, but these natural populations have declined considerably.

Left undisturbed, oysters will form complex reef structures, which provides habitat and refuge for a diversity of organisms, such as juvenile fish, crabs, sea snails and sponges. Native oyster reefs and beds (hereafter reefs) are formed when large numbers of living oysters and dead shells form an extensive biogenic habitat on the sea floor. Oyster reefs typically form on mixed substrate, in shallow waters less than 10 meters deep, although they have been found to depths of up to 80 meters.

The history and the present depleted populations of the native oyster in Scotland, both in the wild and its exploitation for wild and managed fisheries have been extensively documented e.g. by SNH's Commissioned Report on *Ostrea edulis* in Scotland (UMBS, 2007) "the 2007 report". The 2007 report gathered evidence for the existence or otherwise of native oysters in what was considered their former range. It noted that, "Native oyster *(Ostrea edulis*) populations in Scotland have declined significantly in abundance and distribution since the 19th century, mainly as a result of over-exploitation. Most of the remaining populations are thought to exist in west coast sea lochs. The native oyster is the subject of a UK Species Biodiversity Action Plan, the Native Oyster Species Action

Plan (NOSAP), so there is a requirement to consider what conservation measures are appropriate."

The 2007 report examined current and historical records for the exploitation of oysters around the coasts of Scotland, searching for extant native oyster populations to provide a baseline for conservation under the OSPAR Commission report (OSPAR Commission, 2011), which identified native oyster beds as a priority marine habitat and therefore subject to protection under the EU Habitats Directive. The Scottish Government's Fisheries Management Review of Priority Marine Features noted that the native oyster range in Scotland is reduced compared to historical accounts and is currently confined to the west coast and islands. It stated that most contemporary records for native oysters are species records, with oyster beds only recorded in Loch Ryan, Loch Sween, Loch Scridain and Loch Eishort.

The 2007 report documented attempts made in the 19th and 20th centuries to restock the over-exploited oyster populations by translocation of oysters from one wild fishery area to another. Oysters were translocated between Brittany, Scotland, Denmark, France, the Netherlands; and between various locations in Scotland. The result of the practice of translocations is that the populations certainly in northern Europe remain genetically diverse despite centuries of management (Beaumont et al., 2006; University Marine Biological Station Millport, 2007).

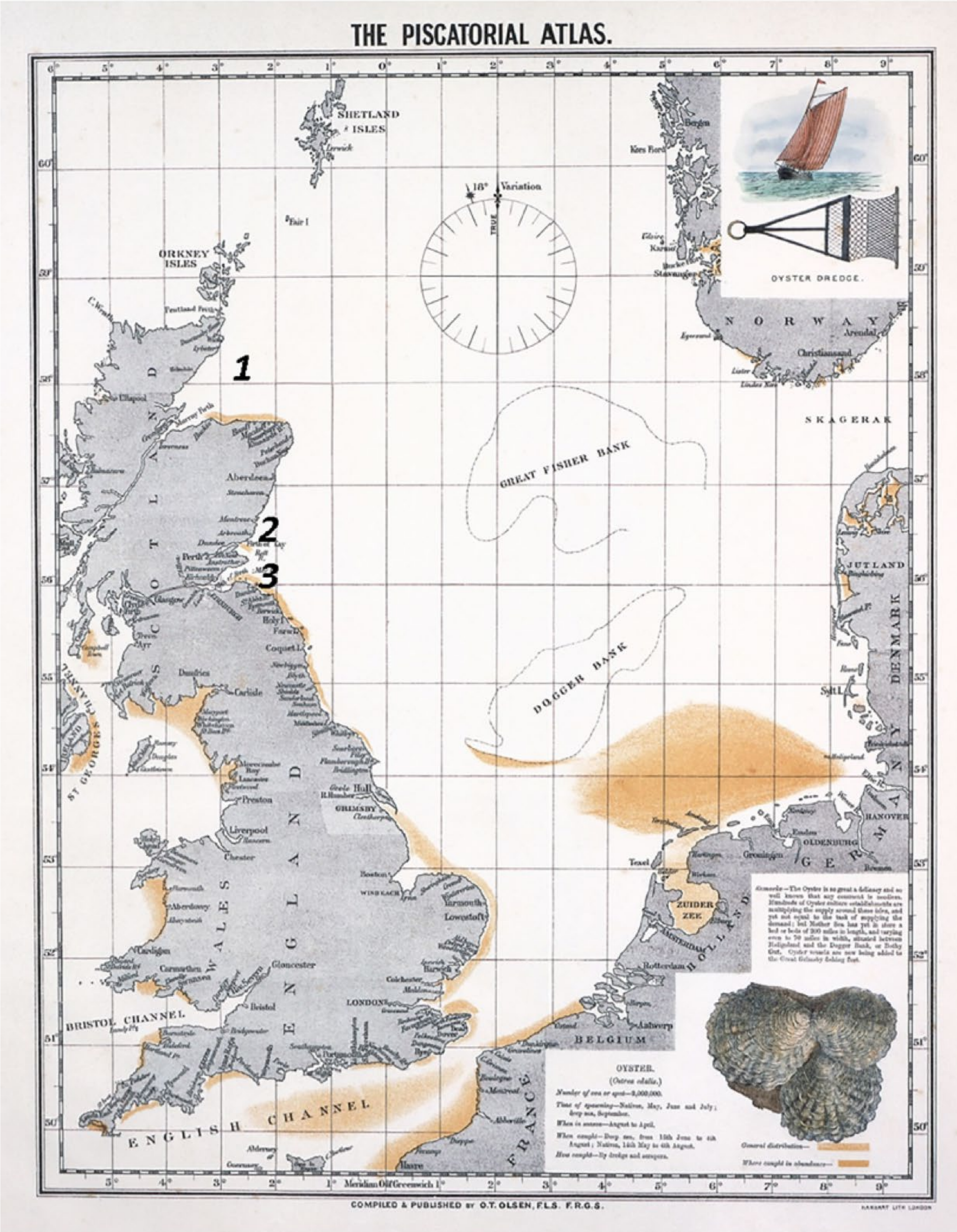

Figure 1 Entry for *Ostrea edulis* in Olsen's (1883) Piscatorial Atlas of the North Sea. Fishermen accounts at the time indicated abundant oyster beds (in orange) in east Scotland along the south shore of the Moray Firth (1), the Firth of Tay (2) and the Firth of Forth (3). Numbering added by Farinas-Franco et al (2018).

Efforts in the 2000's to recover these stocks are documented, for example, in Laing et al., (2005) report for CEFAS on the feasibility of native oyster stock regeneration in the UK. In the last 5 years, the various efforts to restore and recreate wild or managed native oyster populations have expanded and now include projects in the UK, Ireland, France, Germany, the Netherlands, and Sweden (Native Oyster Restoration Alliance , 2019) (NORA). These projects are of four types: restoration of a managed fishery; restoration of depleted wild oyster beds; reintroduction to historic sites; and investigating the use of oysters as bioengineers in offshore windfarms. The projects have a common approach: conservation of any existing stocks through exclusive access to the seabed; use of relatively small numbers of broodstock from managed sources to increase the mature population; laying of cultch (shells) to encourage spatfall (larval deposition); and monitoring. One project has established a small hatchery (Pogoda, 2019) to provide oyster seed to restoration projects particularly for those where existing broodstock are limited or non-existent and has demonstrated significant success in survival of larvae to spat populations, citing an average of 80% survival. These projects are all in their early stages. While all are informed by and subject to ongoing research and monitoring, short to medium-term (5 year) outcomes are not yet published.

2.1.2 Aquaculture of native oysters

Wild stocks of native oysters have been managed for greater production since at least Roman times, when the Romans built ponds to stock and sort oysters. Bloodstock oysters and spat collection and translocation has been ongoing since records began, trying to improve fishery production despite continued over-exploitation of a slow-maturing resource.

Fished oyster populations were already crashing when a massive mortality widely struck European flat oyster populations in 1920. The population later recovered but was replaced by cupped oysters in several traditional rearing areas. Two diseases (*Marteilia refringens* and *Bonamia ostreae*) spread in the early 1970s and 1980s, drastically reducing the production of *Ostrea edulis* in almost all European traditional rearing areas – although not in the UK.

There was considerable interest in Scotland aquaculture of native oysters, but this has never occurred at any volume because of the particularities of the species compared to its more amenable relative, the Pacific oyster. The native oyster requires specific environmental conditions to produce spat; unlike the Pacific oyster, it fertilises the eggs in-shell and incubates its fertilised eggs for 8 to 10 days before releasing them into the water. It produces an order of magnitude fewer spat – around a million per oyster[1]. Its spat do not survive well in hatcheries, with a 20-30% survival rate experienced by Seasalter (Walney) Ltd.

There are high costs associated with oyster hatchery production mainly due to the large requirement for live algae, especially through the nursery stage, but also due to losses of spat after settlement and high capital and operating costs. Hatcheries need to produce large numbers of *C. gigas* spat in order to make production more profitable. With a potentially much smaller market, the production of *Ostrea edulis* spat will have to be highly efficient if the hatchery is to produce them profitably at selling prices competitive with those for *C. gigas*. (Scottish Aquaculture Research Forum, 2014).

Native oysters suffer a further mortality during their first year of on-growing, of around 20 – 30% as experienced by growers. Finally, and unlike the Pacific oyster, it can take 4 to 5 years for native oysters to reach marketable size; the Pacific oyster takes 2 to 3. The grower will only recoup their initial cash outlay on hatchery supply, equipment and labour between 4 and 5 years after laying it out, creating an inherent cash flow issue that acts as a barrier to start-ups. The additional costs of time and labour can only be recouped if the native oysters are sold as a premium product. As a result of the triple pressures of a delayed cash return, higher hatchery costs, and greater risk, native oyster farming in the UK is based on micro-enterprise aquaculture selling a low volume of native oysters at a relatively high price (£1.50 to £2.50 per oyster) at the farm gate, directly to local restaurants, and in festivals and fetes.

Faced with the costly and cash-flow realities of native oyster aquaculture, and the significant risk of losing the animals before maturity, almost all oyster production and sale in the UK and elsewhere is by farming Pacific oysters. Native oyster farmers also farm Pacific oysters for diversification and financial viability.

2.1.3 Challenges to restoration

SNH's commissioned review of marine habitats and species (Mazic et al., 2015) concluded that there were three factors that limited *Ostrea edulis*: diminished brood stock, shortages of settlement surfaces, and high adult mortality due to disease, pests, and extraction.

Limited broodstock numbers: native oysters are so depleted that in most sites there are insufficient mature oysters to allow the population to increase naturally; Mazic et al., (2015) explained that a small population may mean less genetic diversity and more vulnerability to disease and other stresses, with increasing mortality and decreasing reproduction compounded by decreased density. Oyster

[1] https://www.marlin.ac.uk/species/detail/1146

beds depend on a sustainable rate of mortality to provide oyster shell, which is the preferred surfaces for spat settlement. The successful reproductive rates of the native oyster are further reduced by levels of spatfall, which varies significantly from year to year (personal communication derived from Loch Ryan Oysters Records from1701) and the survival rates of spat in the wild, which is as low as 20% (FAO, 2009) (Laing et al., 2006, p. 52).

Lack of suitable substrate: oysters prefer to use shells from their own species; they will settle on other shells and then other materials such as compacted silt, stone or even metals, but these other materials result in poor settlement and higher mortality (UMBS, 2007). Many oyster restoration projects have focussed on the re-provisioning of suitable substrate or cultch for the oysters to adhere to and grow on; for example the Essex Native Oyster Restoration Initiative has recently sought to increase its oyster bed recovery by importing waste Pacific oyster shell from the food chain to settle on the sea bed[2].

Disease and pests; native oysters are adversely affected by three "listed diseases", as defined by EU legislation (Directive 2006/88): *Bonamia ostreae, Marteilia refringens* and the Oyster Herpesvirus. All of these are present in UK and Irish waters, although only *Bonamia* is present in Scotland, and only in two locations (Loch Sunart and West Loch Tarbet; Scottish Government, 2019). Disease prevention and control remains a major threat to aquaculture and to restoration, particularly as transmission methods are not well understood[3]; *Bonamia* is known to kill over 80% of an infected population (Laing et al., 2005)) ; and there has been no success to date in managed breeding of *Bonamia*-resistant stock even from Bonamia-outbreak survivors4. *Bonamia* is prevalent in Ireland, France, Spain, and the Netherlands. However, Atlantic Shellfish Ltd report selling over 80 tonnes of native oysters per year from the historic oyster beds around Cork Harbour between 1995 – 2001, suggesting that very large oyster beds (in this case 13 million oysters) enable evolution of resistance.

Invasive Non-Native Species (INNS) affect native oysters' habitat and inshore habitats more generally. INNS which are known to affect oysters include the invasive Carpet Sea Squirt (*Didemnum vexillium*) which has been identified in an oyster farm based at the Loch Creran SAC with subsequent intensive biocontainment methods involving 70 stakeholders (Cottier-Cook, et al., 2019). Slipper limpets (*Crespidula fornicata*) infest the whole of the North Sea's oyster and mussel beds (GB Non Native Species Secretariat, 2019). A further threat, *Schizoporella japonica*, has been identified at more than one quarter of Scottish ports, and unusually appears to be spreading from the north by "hitch-hiking" on ship hulls (Loxton et al., 2017)).

Unlawful gathering: SNH's Commissioned Report on *Ostrea edulis* in Scotland (UMBS, 2007)) noted the extent of unlawful gathering on Scotland's remnant west coast oyster beds. This continues today, with an effective "line" of native oysters just at the point where they cannot be gathered by a person reaching with a pole (*personal communication*).

Other challenges include:

Pollution and sediments: Survival and reproduction of mollusc are severely affected by legacy tributyltin (TBT) contamination from antifouling paints (Héral, 1989) and from other metal and chemical contaminants.

Disturbance: A key requirement for oyster bed recovery is lack of disturbance; bottom disturbance may remove oysters, increase sediment, and disturb spatting and settlement. Projects which are part of the Native Oyster Restoration Alliance uniformly sited their projects where bottom disturbance was likely to be minimal, or sought protected areas for the oysters (see e.g. the Ehat project, Essex (Native Oyster Restoration Alliance (ENORI), 2019). Despite these issues, SNH's Commissioned Report (Mazic et al., 2015) concludes that:

"Based on the amount known about these specific bottlenecks for this species, the willingness of public and private sectors to the management and recovery of this species and its availability for translocation from other areas, the overall potential for recovery of this species appears high".

Established restoration techniques are tried and tested for each of the three bottlenecks and are sufficiently advanced so that they can be applied with some certainty of success. Given ideal conditions, site-scale recovery should be possible 6 – 12 years. (ibid, p49)".

2.1.4 Ecosystem services of restored native oyster reefs

In the USA, the bioengineering properties of both oyster aquaculture and oyster reefs have long been recognised for improving water quality, preventing coastal erosion, and improving fisheries. The key multi-year project which demonstrate water quality benefits is the Chesapeake Bay Programme (Figure 2).

Chesapeake Bay is a substantial estuary in the Eastern United States, with a catchment area of 65,000 square miles (over twice the area of Scotland). The Bay itself is 200 miles long and up to 30 miles wide. Since colonial times,

[2] https://essexnativeoyster.com/#recovery

[3] http://www.oie.int/index.php?id=2439&L=0&htmfile=chapitre_bonamia_ostreae.htm

the Chesapeake has lost more than 98 percent of its native oysters, *Crassostrea virginica*. Historically, oyster reefs posed navigational hazards to Chesapeake Bay explorers and watermen harvested 17 million bushels of oysters each year. Maryland and Virginia watermen and the seafood industry have lost $4 billion in income in the past 30 years alone.

After a devastating bout with disease in the late 1980s combined with decades of overharvesting, habitat destruction, and water pollution, the population of the oyster declined significantly to less than one percent of historic levels. The severity of this decline can be illustrated in terms of its impact on water quality: in the late nineteenth century, the Bay's oysters could filter a volume of water equal to that of the entire Bay in three or four days; today's population takes nearly a year to filter this same amount. In the *Chesapeake Bay Watershed Agreement*, the Chesapeake Bay Program set a goal to restore reefs and populations in ten rivers by 2025 (Chesapeake Bay Foundation, 2014), to contribute to its Strategic Themes including a Sustainable Fisheries Goal and a Water Quality Goal.

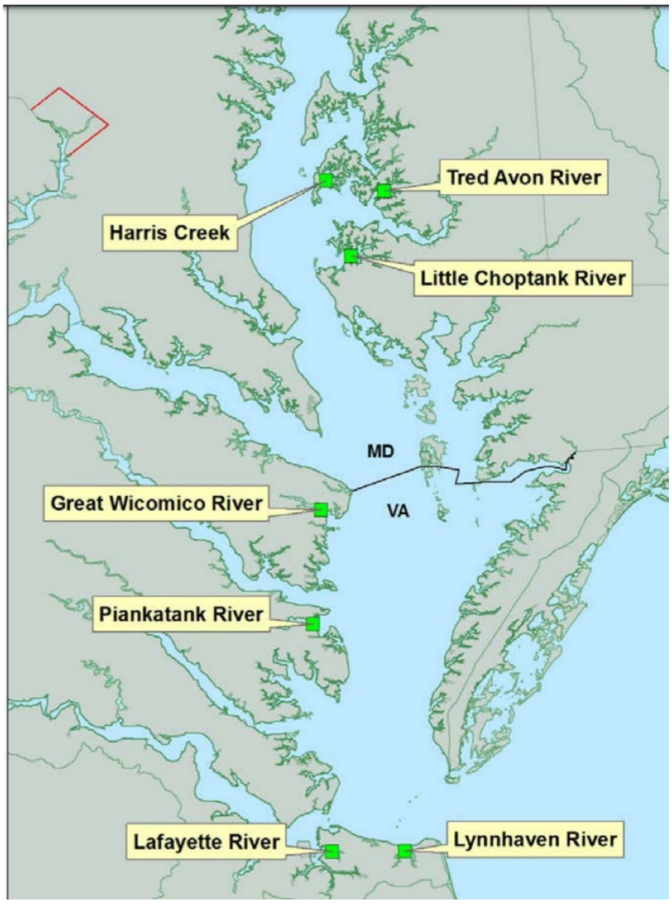

Figure 2 Diagram of Chesapeake Bay Oyster Reef Ecosystems Projects
Source: Bruce, 2018.

The importance of *C. virginica* and its restoration has pulled together stakeholders to agree to the Chesapeake Bay Watershed Agreement. The "wicked" problem of water quality and in particular of non-point pollution requires to be met with a solution based on a "common ground" that motivates a wide range of actions. For Chesapeake Bay, the restoration of its historic oyster beds – and with them, the restoration of the potential economic and social benefits that are still within the living memories of the inhabitants of the area –provided a catalyst to a much broader programme for cleaner water.

The EPA has been a significant funder of the Chesapeake Bay programme. Unlike Scotland, where water quality monitoring, terrestrial habitat quality and marine habitat quality are split between agencies, the US Environmental Protection Agency (EPA) regulates all three.

The EPA regulates discharges to the catchment of the Bay through a mechanism known as the Total Maximum Daily Load (TMDL) for Nitrogen, Phosphorus and Sediment (Environmental Protection Agency, 2010). In 2010, after a lengthy multi-stakeholder consultation process, the EPA set Bay watershed TMDL limits requiring a 25% reduction in nitrogen, 24% reduction in phosphorus and 20% reduction in sediment. The TDML was then set for each catchment area, to allow for regulation of both point and non-point pollution. The Chesapeake Clean Water Blueprint sets out the TDML and the state-specific implementation plans designed to achieve those limits. EPA and the Bay jurisdictions agreed to implement Best Management Practices to achieve 60 percent of the necessary pollution reductions by 2017, and 100 percent of those practices in place by 2025.

Achieving the Blueprint requires an extensive range of land-based and water-based measures. The Chesapeake Bay Foundation commissioned a Report on the economic benefits of implementing the Blueprint (Chesapeake Bay Foundation, 2014).

The Report estimated that in 2009 (before the Blueprint), the land and waters of the Chesapeake Bay region provided economic benefits totaling $107.2 billion annually. These benefits include air and water filtration, agricultural and seafood production, property valuation, and flood and hurricane protection. The Report found that the value of these same benefits would increase by $22.5 billion to $129.7 billion every year if the Blueprint is fully implemented.

The costs of implementing the Blueprint were cited in the Report as between $5bn and $6bn annually; a clear economic surplus of $14bn to $15bn annually.

The Report converted ecosystem service productivity per unit of land or water to a value of dollars per year using a dataset drawn from the Earth Economics' Ecosystem Valuation Toolkit (Briceno, 2014). This Toolkit attempted to move economic valuation from a "service provision" viewpoint to a "benefits and outcomes" view. While this

[4] Information in this section is extracted from the website of the Chesapeake Bay Program https://www.chesapeakebay.net unless otherwise cited.

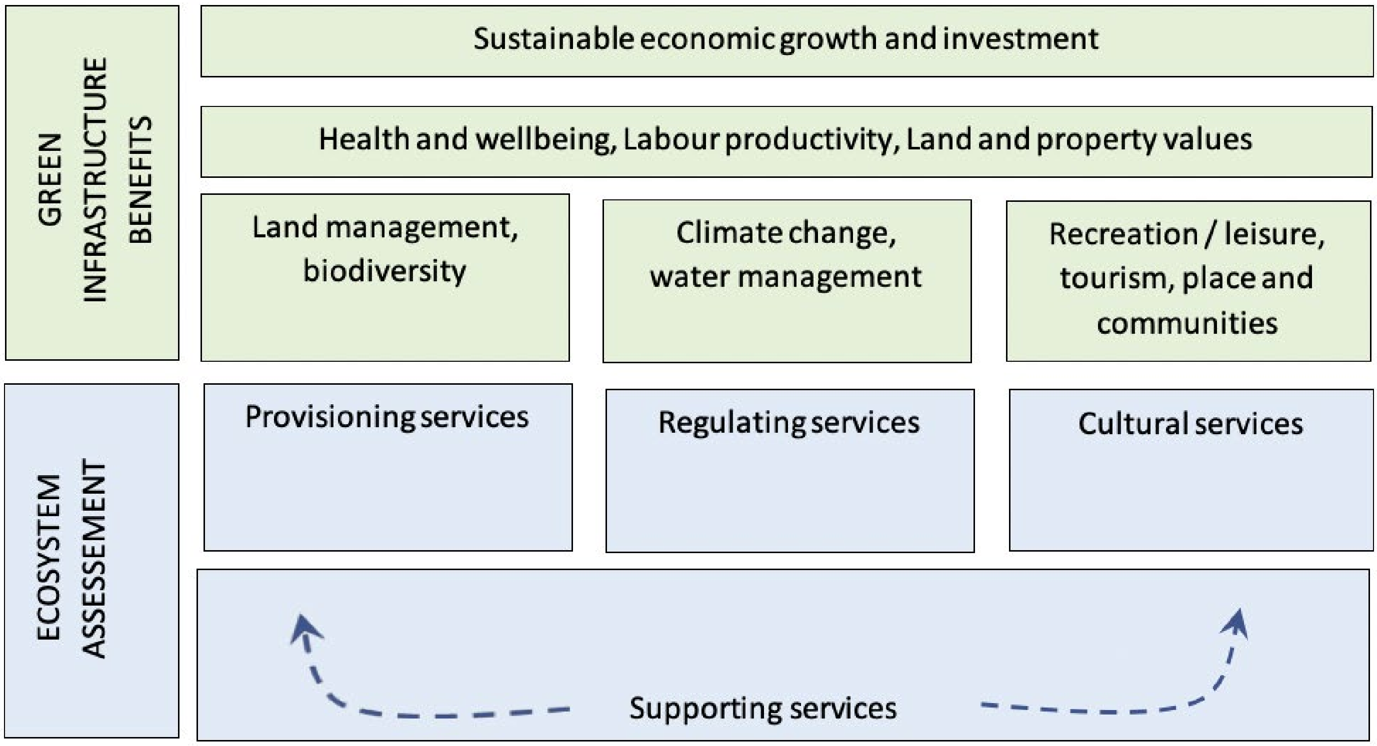

Figure 3 Green infrastructure benefit groups: comparison to "service provision approach"

Source: Building natural value for sustainable economic development: The green infrastructure valuation toolkit user guide (Green Infrastructure Valuation Network, 2011)

Toolkit has drawbacks, (see e.g. (Natural England, 2013), it has the advantage of valuing a range of benefits in a wide range of ecosystems (Figure 3).

The Report concludes, "*Natural capital, as the basis for ecosystem service flows, is an important contributor to the Chesapeake Bay region's economy and quality of life. As these study results suggest, implementing the Chesapeake Clean Water Blueprint could result in important economic benefits relative to today's conditions and relative to conditions that would be expected to prevail if no further action is taken to reduce pollution of the Chesapeake Bay. These benefits accrue both due to changes in the pattern of land conversion in the region and due to adoption of best management practices that result in reductions of pollutant loads. Both types of change would improve ecosystem service productivity and, assuming stable values for those services, increases in the economic output of the region's natural capital.*"

The provisioning and value of oysters as an iconic species, while providing the initial catalyst for the Chesapeake Bay programme, is not the major source of economic benefit from the Blueprint identified in the Report. While restoration of oyster fisheries and the impacts of oysters for use as water filtration and resource re-use are identified in the report as benefits and as delivering the Blueprint, other habitats re-created by the Blueprint such as wetlands and underwater grasses are also significant providers of these services. Overall, the Report finds that of the $22.5bn increase in economic value, $1.2bn is from food services – of which oysters are only a part; and $4.3bn is from waste- water treatment, again of which oysters are only a part. It not possible to estimate what proportion of these service values oysters were assessed as providing without accessing the detailed Toolkit calculations.

This finding proposed that the direct and indirect economic impacts of oyster restoration per se are a small component of the value of improving the ecological impact of land-use and land management to obtain cleaner water in which the oyster reefs will grow or be farmed.

Choptank River Complex – valuation of commercial fishery services

The Chesapeake Bay Foundation commissioned a more detailed, productive services economic impact assessment on an area of the Chesapeake Bay, the Choptank

River Complex (Knoche, 2018). This work required the development of an ecological model and the linking of the model's outputs to a regional economic impact model to estimate the increase in commercial seafood production and allied change in key economic measures associated with oyster reef restoration. The findings were that retaining mature oyster reefs as sanctuaries would result in an 80% increase in associated shellfish harvests; a 650% increase in finfish harvests; leading to an annual Gross Value Added of $13.3m and 319 jobs – against a cost to restore of a forecast $72million.

Chesapeake Bay pollution management: economic benefits of water quality services

While oysters deliver ecosystem benefits with an imputed economic value, conversely there are potential cost-reduction benefits to the implementation of the Blueprint from *C. virginica* restoration. The EPA has undertaken an extensive research programme with its academic partners into the extent of the oyster population and the impacts of that population on water quality. By 2018, 1,200 acres (485ha) of oyster reef were reported as restored[5]. The EPA's mid-point monitoring (EPA, 2018) of the Chesapeake Bay Blueprint in 2017 found that the highest estimates of water quality standards had been attained in more than 30 years. While the 60 percent goals for reducing phosphorus and sediment as measured under the current suite of modelling tools were exceeded, the goal for reducing nitrogen was not met, and pollution control strategies would be amended for the future.

The EPA has now taken the filtration and denitrification impacts of oyster aquaculture and oyster reefs into account in determining the TMDL of one part of the Chesapeake Bay ecosystem, Harris Creek.

By 2017, the Chesapeake Bay Programme reported (Maryland Oyster Restoration Interagency Workgroup, 2018) that Harris Creek had 351 acres (142ha) under restoration through seeding with over 2 billion juvenile oysters and 42,000 tons of cultch, of which 192 acres (78ha) were complete i.e. had met biomass targets of 15 oysters per m2 and biomass 15g dry weight per m2. Using results from the Chesapeake Bay monitoring programme, Kellogg et al., (2014) initially created a model to compute the volume of water filtered, removal of phytoplankton, suspended solids, and associated nutrients via filtration, recycling of nutrients and consumption of oxygen by oyster respiration, production of faeces, N and P accumulation in oyster tissues and shell, oyster-enhanced denitrification, and N and P burial associated with restored reefs. Further work was then done to enhance the model, including taking into account key species present on oyster reefs, such as mussels and tunicates (Kellogg et al., 2018).

The study (Maryland Oyster Restoration Interagency Workgroup, 2018) found that the restored reefs, while only 10% of the extent surveyed in 1913, are able to filter the full volume of Harris Creek in less than ten days during summer months. The restored reefs have the potential to remove one million pounds of nitrogen (over 450,000kg) from the Chesapeake Bay over a decade. The water filtration benefits of the reef are provided by more than the oysters. Mussels and tunicates living on the oyster reefs contribute more than 40% of the total filtration.

Based on these findings, the Chesapeake Bay Program is developing measures for in-situ, permanent removal of sediment, nitrogen, and phosphorus pollutants from the estuarine water column via oyster filtration. This would allow oyster aquaculture and oyster reefs to be included as a Best Management Practice mechanism for nitrate, phosphorus, algae and sediment removal under the Clean Water Act, allowing the EPA to use this information to amend the TMDL requirements for those parts of the ecosystem ameliorated by oysters. The work is being carried out by an Oyster Best Management Practice Expert Panel.

Their first report (Oyster Best Management Practice Expert Panel, 2016) proposed default reduction effectiveness estimates for aquaculture oysters. The second report (Oyster BMP Expert Panel, 2018) will propose default measure for oyster reefs.

The Chesapeake Bay Programme's proposals for oysters as a Best Management Practice would provide one of the world's largest recognition of oysters' bio-engineering functions in catchment management. It would also provide additional incentive for the Programme partners to continue to promote oyster restoration, as a lower cost and less contested alternative to other land-based best practice management measures.

Long Island Sound: alternative cost value of nitrogen extraction by oyster reefs

Bricker et al., (2018) considered the potential use of shellfish aquaculture to supplement nutrient management in urban estuaries which require nutrient reductions and also support shellfish populations. Long Island Sound has higher nitrogen loads and chlorophyll, and lower dissolved oxygen concentrations than the median of U.S. estuaries. The researchers note that Long Island Sound is representative of urban estuaries in the European Union, which have these same characteristics. Ecosystem service values were estimated using ecosystem-scale models for nitrogen extraction and valued using an avoided costs valuation. The ecological modelling estimated that 1.3% of the current Sound input of nutrients of 50,000 tonnes per year could be removed by the existing 2,120 ha of reefs – almost 200,000 person-equivalent quantities. Conventional management wastewater treatments for this amount of pollution would require annual investment of between $8.5million and $230 million per year.

The wide variation in the "alternative cost" model demonstrates the need to link the known impact of oyster reefs and the costs of establishing these, with the infrastructure investment decisions being taken by water management organisations.

[5] https://www.chesapeakebay.net

The Baltic: economic benefit of shellfish in water quality management

The Chesapeake Bay Programme's proposal for oyster restoration as mitigation for water pollution may be the world's largest but it is not the first. Peterson et al., (2019) explains that. "Traditional measures utilized to reduce nutrient loading to the marine environment are land based. These are directed either towards point sources like sewage treatment plants, or diffuse emissions mainly from cultivated land. Abatement measures for diffuse sources comprise a long list; including restrictions in fertilisation, restriction in the periods where fertilisation is allowed, requirements for catch crops and winter green fields, wetland restoration and wetland reconstruction, afforestation, and fallowing of intensively cultivated fields. With increasing marginal costs for implementing traditional land- based abatement measures (Hasler, 2014), it is appealing to look for alternatives, such as mitigation measures in the recipient water bodies.

"Strategies less costly than traditional abatement measures are attractive in coastal zones where population densities are low. Finally, internal loading from sediments in areas that have been affected by decades of excess nutrient loading is a problem for water quality that can only be dealt with by marine mitigation measures."

The countries surrounding the Baltic Sea are looking for alternative ways to address the eutrophication prevalent in these waters, with a Forum[6] now established to cooperate on research and findings, including through nitrate and phosphorous recycling using shellfish; in this case, mussel farming. The Interreg programme 'Baltic Blue Growth'[7], begun in May 2016, has implemented several pilot mussel farms in the Baltic Sea and explored under which biological and financial conditions mussel farming for nutrient recycling is possible, and the extent of that nutrient recycling. The project proposes to use mussel harvesting for proteins in animal feed, thus cycling the nitrogen and phosphorus back onto land with the aim that the prices paid for this feed will create a viable market for the mussels and may allow governmental payments to mussel farmers for environmental services.

The interim paper on the economic evaluation of mussel farming for nutrient uptake (Schultz-Zehden, 2019) considered the costs of mussel farming against direct economic benefits, against "willingness to pay" approaches to economic valuation undertaken elsewhere, and against the alternative costs of measures for nutrient reduction.

An extensive study on willingness to pay for the benefits generated by reduced eutrophication is the "Baltic Sea survey on use and non-use values" (Swedish Environmental Protection Agency Report Series, 2010). The study looks at the willingness to pay for different scenarios for 2050, based on the Biodiversity Strategy and Action Plan and report. People's willingness to pay corresponded to their direct experiences of the scenarios described. According to the study, algae blooms (59% of respondents), fish species composition (51%) and turbidity (47%) were the ecological consequences that respondents were most worried about and most willing to pay to mitigate.

The paper found that the balance between costs of production and any of these measures was contingent on a number of factors, including the costs of production; the costs of alternative measures already undertaken, (which increase per kg of pollutant extracted as the water quality is closer to target). For willingness to pay, the amount offered varied depending on the economic status of the region of the respondents – the wealthier the region, the more they were "willing to pay"; and their general level of awareness of environmental issues.

In short, the efficacy of shellfish as a mitigation for nitrate and phosphorous pollution was well-accepted; the issue was at what stage in pollution mitigation of a water body was the use of this method more effective than other methods; who should pay (polluters, people who benefit from pollution, or government to deliver social and economic benefits); and how much. As the authors point out, however, it is the only method being considered which is marine and not land-based, and therefore the only method available to remove pollution once it is in the marine waterbody.

These case studies demonstrate that shellfish are already being valued economically as bioengineers for water purification, over very large marine areas and in significantly polluted waters, demonstrating their regulatory service value. The Chesapeake Bay provides case studies that demonstrate the calculable economic benefits of long-term investment at a catchment scale and for measurable pollution mitigation benefits. It also demonstrates how the measurable regulation services provided by oyster aquaculture and oyster reefs can be taken into account in water quality decision-making.

The Choptank River Complex considers the valuation of oysters on the basis of the alternative costs of treatments but requires to be aligned with proposed investment decisions to reduce the wide variation in value.

The Baltic example considers a narrower economic methodology based solely on the value of clean water as perceived by the beneficiaries of that water, while

[6] https://strategyforum2019.eu/10th-annual-forum-of-the-eusbsr

[7] https://www.submariner-network.eu/projects/balticbluegrowth

acknowledging that shellfish have a wider ecological and social value in terms of ecosystem services. It investigates how the concept of shellfish for pollution treatment has been be applied in a European regulation context, particularly focusing on shellfish farming's value as an alternative or as additional remediation treatment.

2.2 DEEP: innovation, benefits and impacts

2.2.1 Overcoming challenges through innovation

Rationale for the project

The whisky industry wishes to ensure that it is a good corporate citizen; its brand and the brand of the companies producing whisky, emphasizes the history, purity, simplicity and mystery of production, and therefore the unique taste of the product. Whisky is one of Scotland's great export success stories, albeit that the profits from the product most often accrue to overseas multinationals, with 55% of whisky production owned by 3 multinationals based overseas.

The whisky industry is keen to demonstrate its environmental credentials, with a Scotch Whisky Environmental Strategy published in 2009 and refreshed in 2016; and a SEPA Scotch Whisky Sector Plan in 2018. The Environmental Strategy focussed on renewable energy and energy management; reduced and recycled packaging; zero waste to landfill; and responsible water use. In 2018 the industry reported significant progress towards its 2020 targets, including a 29% reduction in water usage by 2018 compared to the 2012 base year (Scotch Whisky Association, 2018). Whisky production was at that time reported as requiring 11 litre of water per 1 litre of finished product (Zero Waste Scotland, 2016). The Environmental Strategy is silent on the issue of reduction of volumes of outfall water. The whisky industry invested heavily to ensure compliance with the Urban Waste Water Treatment Directive 91/271/EC – regulating ouflows from the industry, for which compliance was required by 2000; and the Water Framework Directive (WFD) 2000/60/EC which regulates abstraction of water from the environment, for which compliance was required by 2012.

The SEPA Sector Plan stated that the whisky sector had an "excellent" 95% compliance record overall for these two Directives, with "isolated" incidents of pollution which were "dealt with quickly".

The SEPA Sector Plan includes commitments to working with the sector to explore the possible alternative options for disposing of or extracting value from distillery effluents and continuing to encourage the sector to address River Basin Management Plan pressures associated with their operations relating to historic and regulated discharges to river water from inland distilleries as soon as practically and economically possible.

The DEEP project is driven by, and funded through, LVMH's corporate social responsibility agenda. The Glenmorangie Distillery near Tain, Ross-shire, has operated for over 170 years. While fully in compliance with all required legislation, including discharge regulations, the Distillery was the single greatest generator of high Biological Oxygen

Demand (BOD) out flows in the LVMH group of companies. LVMH made an investment of £6million in an Anaerobic Digestion Plan to reduce its BOD outflows by up to 95% (Glenmorangie Company, 2019). This also generates sufficient recycled heat to reduce the Distillery's use of fuel by 15% (Glenmorangie Company, 2019), creating financial payback within 7 years.

Project aims and outcomes

The DEEP project is a partnership between Glenmorangie Company, Heriot-Watt University, and the Marine Conservation Society. It aims to reintroduce the native oyster, *Ostrea edulis*, into the Dornoch Firth, Ross and Cromarty, an ecosystem where it once flourished. The DEEP project has two related aims; increased biodiversity and improved water quality. Heriot-Watt researchers have calculated that absorbing the amount of nutrient-rich outflow from the Distillery will require 4 million oysters, spread over a 40ha bed, at a density of 10 oysters per square metre (Table 1).

Table 1. Oyster Capacity for Nutrient Fixing

	Distillery Outflow nutrients	DEEP Oyster fixing capacity
Particulate Matter (BOD)	22 tonnes per year	718 tonnes per year
Nitrogen	14.6 tonnes per 5 years	12 tonnes per first 5 years 28 tonnes per next 5 years
Phosphorus	n/a	0.1 – 0.6 tonnes per year

Source: Heriot-Watt University, The Dornoch Environmental Enhancement Project (DEEP); Heriot-Watt University Research Packages (2019, unpublished)

The proposed oyster bed is planned create more than enough biological capacity to absorb the remaining outflow nutrients from the Distillery. The DEEP project plans ongoing monitoring of water quality from the 2016 baseline to assess the impact of the developing oyster bed.

The oysters' own potential to uptake nitrogen, phosphorus and particulates provides a significant potential social, environmental and economic benefit, and is explored in section 9 below.

Oysters and Biodiversity: Due to the early stages of oyster restoration projects and the extirpation of native oyster beds across most of its range, there are no comparative whole-habitat studies of biodiversity in European oyster beds. Similar horse mussel beds have been found to have between 250 and 300 other species associated with them and up to 22,900 individual organisms per square meter (Rees et al., 2008; Sanderson et al., 2008): the most species rich habitats sampled in whole sea areas (Robinson et al., 2012). These kinds of structurally complex habitats are increasingly found to be important for the growth and survival of juvenile fish and shellfish (Heck et al., 2003); Bejarano et al., 2011). In a study of whelk catches in the Irish Sea, Kent et al., (2016) found that shellfish reef was 'Essential Fish Habitat': sustaining double the catch rates and smaller size classes of the common whelk, Buccinum undatum, compared to other habitats.

This potential to increase biodiversity provides a significant potential environmental and economic benefit and is explored in Section 9 below.

The DEEP project also plans to assist in restoration of the adjacent mussel bed. The Royal Burgh of Tain has a Royal Charter granted by James I and VI to fish mussels in an area of the Dornoch Firth, where fishing was closed by Highland Council in 2016 due to overexploitation and collapse of the fishery.

Overcoming the challenges to restoration

While this is not the only Ostrea edulis restoration project in the UK or in Europe, this project is using a unique methodology for its restoration which increases both social and economic impacts.

In 2017, the project placed 300 mature oysters purchased from one of the UK's few remaining wild oyster fisheries at Loch Ryan, Dumfries and Galloway, and confirmed that the animals could survive in the current ecosystems in the Dornoch Firth. In late 2018, the project placed a further 20,000 "on-grown" oysters into the Firth, having previously placed the cultch, for which they used ex-food industry waste shell. The project plans to place a further 200,000 oysters in 2020, ramping up to a million per year to reach the target numbers.

The DEEP project used the native oyster aquaculture supply chain to provide the animals for mass deployment of native oysters. To do so, the project partners and regulators have had to overcome supply-chain bottlenecks and regulatory requirements which have been well-documented e.g. Laing et al (2005) as challenges to expanding native oyster aquaculture.

Supply of cultch: this project has identified old mollusc shells as the preferred settling medium or cultch. By repurposing old shells for this use, 1,200 tonnes of shells will be diverted from the waste streams of the shellfish industries. Use of these shells requires both regulatory changes and a biosecurity mechanism. Currently the shells are classed as "animal waste" because of the remnant biology on the shells after processing. This status requires shell processors to carry out additional and costly work to manage the waste stream and dispose or confine the shells– a significant economic burden on what is a small-margin business (personal communication, West Coast Sea Products, Scottish Shellfish Marketing Group).

Supply of spat: the oyster larvae that has gone through physiological changes to commence its growing cycle. Spat supply has long been considered the major challenge to the successful restoration and aquaculture of the native oyster, with spat management programmes dating back to Roman times. More widely, a multi-species hatchery has been long identified as necessary for assisting the growth of the aquaculture sector in Scotland and the UK e.g. (Kaspar, 2014; Adamson, 2018). More recently, one of the key findings to date from all NORA project monitoring is that spatfall – the amount of spat available within the oyster restoration area – is extremely variable year on year, with some years having none and others having very significant spatfall (Native Oyster Restoration Alliance, 2019). This was identified during the NORA 2019 conference as an area for further research and has a direct bearing on how the DEEP project was designed.

The project is working with micro-enterprise partners Morecambe Bay Oysters and Orkney Shellfish Hatchery to improve survival rates of spat and to ensure biologically clean product. The Heriot-Watt researchers led by Professor William Sanderson propose to submit a Knowledge Transfer Partnership grant application to investigate challenges to increasing spat yields and ensuring single-species spat at hatcheries. The pilot hatchery now operating as part of the Netherlands project "Programme towards a Rich Wadden Sea" (Native Oyster Restoration Alliance, 2019) indicated that it can achieve 80% survival rates; this compares very favourably to reported spat survival rates of 20 – 30% by native oyster aquaculture. Depending on the hatchery cost requirements, this has the potential both to reduce hatchery costs per spat and to increase the number of spat available for on-growing.

Supply of "on-grown" oysters: oysters that are around 10 grams. Unlike most other restoration programmes which rely on mature oysters reproducing, this project uses smaller oysters as restock. This allows placing of oysters in volume, overcoming the limited mature oyster supply. Using on-grown oysters aims to reduce predation by crabs and other predators which will eat spat and smaller oysters but cannot break into larger oyster's shells. Using half-grown oysters still creates a spatting source – *Ostrea edulis* will produce spat at this size and age, but much less than a mature of 70 – 80 ml (Laing et al., 2005). The project is working with micro-enterprise aquaculture businesses at Loch Ryan Oysters, Lochnell Oysters, and start-up Maorach Beag to obtain both mature broodstock and on-grown oysters. There are necessarily biosecurity issues with on-grown oysters as they are currently grown in Little Loch Broom and Loch Nell. Both waters are currently certified as free from diseases and free from invasive non-native species, and are protected by designation under the Water Framework Directive and subsidiary regulations as Shellfish Waters

Biosecurity: the introduction of shellfish and other diseases, and of invasive non-native species, is a risk to all UK waters, and translocation increases that risk. The project has agreed a stringent biosecurity plan for translocation with SNH and Marine Scotland, including chemical cleaning and quarantine, to ensure close to zero risk of such introductions. This is currently an intensive process involving manually scrubbing each oyster twice, and the project are seeking alternative and more efficient ways of ensuring biosecurity. This may include an on-shore on-growing facility at Inver, on the Dornoch Firth.

Location: Regulatory permissions: shellfish in the UK are, in legislative terms, either grown for food and regulated as aquaculture; or an existing protected species through habitat and species conservation legislation. There is no single regulatory process for reintroduction of a marine species for conservation reasons. Reintroductions in Scotland are regulated by Scottish Natural Heritage and must follow the Scottish Code for Conservation Translocations, which requires the appropriate licensing and permissions. Further, the Dornoch has two Nature Conservation Orders in place, protecting 3 bird species of European importance and as a wetland of international importance under the Habitats Directive 79/409/EEC.

The Dornoch Firth is not designated as native oyster habitat. Designations were made over sites where habitat and populations were extant at the time of the designation and not, as in the Dornoch, where they had been extirpated. The DEEP project carried out archaeological and historic research to demonstrate the presence of the native oyster at that site (Farinas-Franco, et al., 2018).

To progress to its current stage, the project obtained planning permission, authorisation for an Aquaculture Production Business, a Marine License, Crown Estate Scotland lease, and resolution of objections from SNH and Marine Scotland following approval of the Biosecurity Plan for translocations. The current planning conditions are that all equipment must be removed from the site by 31 December 2021, including oyster cages and cultch.

To proceed to mass deployment over a larger site, the project will have to apply for all the relevant permissions, and for a permanent installation. This will test the current regulatory processes, as they were not designed to manage permanent reintroductions.

Regulatory exclusions: To succeed, the project will have to ensure that the developing oyster bed remains undisturbed. The DEEP project may require a Several Order, which gives its grantee an exclusive right to manage the species named in the Order, in the specified area and for a specified limit of time. An Order may restrict other fishing practices within its area in order to protect the specified shellfish stock. In Scotland, there are five such Orders currently in place, all relating to scallops (Marine Scotland Science, 2018).

In summary, the DEEP project is addressing and finding solutions to many of the challenges that have prevented and continue to prevent both wider restoration projects. One of the key solutions being implemented with the investment from the DEEP project is strengthening the aquaculture supply chain, which will benefit other restoration projects by creating a supply of disease and Invasive Non-Native Species (INNS) -free oysters, spat, on-grown and broodstock; and benefit native oyster aquaculture by improving methodologies for hatchery and for on-growing.

[8] Water Environment (Shellfish Water Protected Areas: Designation) (Scotland) Order 2013

Table 2. DEEP: Addressing Challenges to Native Oyster Restoration	
Challenge	**DEEP response**
Limited broodstock numbers	Identifying and connecting a Scottish supply chain Supporting supply chain development by working capital investment and certification Joint research with new Orkney hatchery to decrease mortality rates (currently around 80%) and ensure biosecurity
Lack of suitable substrate	Research evidence of favourable substrate Catalysing re-use of 1,200 tonnes shell waste from other Scottish industries; working with regulators to ensure appropriate application of regulations to this waste which will benefit the shellfish industry more widely
Diseases and pests	Rigorous, zero-risk, biosecurity process for introduction of shell and of juvenile native oysters, with further research to allow "scaling up" of this effort
Invasive non-native species	As above: also, visual inspection to ensure no cross-contamination with Pacific oysters; working with new Orkney-based hatchery to support biosecure spat (oyster larvae) and juveniles
Pollution	Restoration in regulated shellfish waters Researching and monitoring the water quality impacts of the developing oyster reefs
Disturbance	Working with regulators to identify methods for exclusive use of sea-beds using existing legal instruments
Regulation	Providing proof of prior existence of native oysters in an area not designated as existing habitat Working with government agencies and regulatory bodies to ensure compliance and create a mechanism for licensing for re-introduction This work may provide a methodology for future restoration in other areas
Investment	Glenmorangie plans to invest £6.4m, recognising the brand value of the DEEP project as promoting corporate social responsibility goals through inherent valuation of the ecosystem and cultural / social services provided by native oysters
Leadership	Glenmorangie have provided leadership in this restoration effort, working with multiple government and regulatory bodies, academic institutions, the shellfish industry, and the community to help ensure successful restoration.

2.2.2. Strengthening the supply chain

DEEP is in the process of investing £1.5million into the supply chain to obtain production of spat and on-grown oysters. This will have a substantial impact on a sector which operates on low margins, poor cash flow, is regarded as risky by banks, and therefore generally has low levels of capital investment e.g. (Crown Estate, 2015, p. 42). The DEEP project is enabling access to markets, providing an alternative market for native oysters earlier than food markets, and assisting in increasing productivity of both hatcheries and on-growers.

Loch Ryan

The Loch Ryan Oyster Company, locally owned and run in Stranraer, manage the last remaining wild fishery for oysters in Scotland, protected by a Royal Charter granting sole rights to the oyster beds dating to 1701. The beds are managed by boat dredging using a specialised net for mature oysters and replacing both empty shells (for cultch) all oysters that are either too small or too large for the market – the perfect oyster is between 75g and 85g, around 8 years old. Loch Ryan land around 500 oysters per day (selling around 200,000 oysters in a year) – around 1.5% of the population – except in the breeding season between May and September to allow the oysters to reproduce and the spat to attach to cultch. There was an estimated population of 1 million oysters in 1996, the last time it was surveyed. The Loch is fished by time limits, allowing 4 years for each bed to recover and produce more oysters before being re-fished.

The Loch Ryan Oyster Company depurates (purifies) its oysters before delivering them live either via web sales, the restaurant trade in London, or exports to Asia.

Loch Ryan Oyster Company provides 2 full time jobs in oyster shellfishery management, and 4 jobs in depuration, sales, and administration.

The DEEP project provided an alternative market for Loch Ryan Oyster Company, purchasing 3,000 mature oysters for its initial "survivability" trial. DEEP is now providing advice to the Company to assist in its management of the stock, including additional surveys of the Loch to determine whether there are other oyster beds in the Loch, their extent and condition. DEEP are also offering advice in the larval dispersion in the Loch, to find out where the young larvae prefer to settle out and on what type of cultch. This will help the Company to determine the current size of the population, its sustainable take, and confirm or otherwise its current management practices – all to assist in maintaining financial and ecological sustainability of this unique fishery."

Community Development: The Stranraer Development Trust, formed in 2016, promotes the town through the Stranraer Oyster Festival which headlines on "wild native oysters from Loch Ryan". More than 10,000 visitors enjoyed the first Stranraer Oyster Festival in 2017, with the numbers increasing to 14,000 for the 2018 festival. 125 local businesses engaged in the Festival, 90 youths dedicated their time and energy to volunteer and over £1m was generated for the local economy. Scientists from the DEEP project attended the Festival, providing information on the native oyster, the need for restoration, and encouraging people to observe and pick up live oysters.

Lochnell Oysters

Lochnell Oysters is a family-owned micro-enterprise close to Oban. Lochnell Oysters lease three bays on the south shore of north Loch Linnhe, owned by the Lochnell Estate, to grow both Pacific and native oysters. John Hamilton re-created and self -tested a process for aquaculture of the native oysters, based on previous research material, the experience of other farmers in the UK and his own experience; this involves growing native oysters in "baskets" attached to lines in subtidal waters. He started in 2007, collecting and purchasing broodstock oysters from a variety of disease-free sites. He then persuaded Morecambe Bay Oysters, to produce spat from his broodstock in the hatchery before on-growing at his site.

Lochnell Oysters currently buy around 1 million spat per year, of which around 20 – 25% survive through the hatchery process and their first year. Oysters are on-grown in the sub-tidal area and take 3 – 4 years to maturity, growing faster than Loch Ryan oysters due to what appear to be perfect growing conditions. Lochnell Oysters sell small batches of mature oysters on-line, by phone order, and in markets. Lochnell Oysters currently have more demand than they can meet.

The DEEP project has worked with Lochnell Oysters, purchasing broodstock and purchasing on-grown smaller oysters, improving the cash flow of the business and enabling the business to expand operations, more than doubling output. For Lochnell Oysters to become a supplier to the Glenmorangie Company required that it met stringent procurement requirements including policies and procedures, and Lochnell – as with the other suppliers to the Glenmorangie Company has been assisted to meet these compliance requirements, increasing its ability to sell into other supply chains.

The DEEP project has also sourced a method of laser etching for the broodstock oysters, allowing oysters to be marked with their original source as the reference for a planned Knowledge Transfer Partnership for genetic sampling and selective breeding.

Citizen Science: Lochnell Oysters is supporting CROMACH community group to introduce a thousand juvenile native oysters in cages near Ardfern on the shoreline of Loch Craignish to help restore this essential keystone species

to a sea-loch where it was once abundant. The project, funded by Sea-Changers, and supported by Scottish Natural Heritage, is the first community-led native oyster restoration project in Scotland. Very early efforts by school pupils to identify native oysters have led to the recording of potential invasive non-native species, an aspect of citizen science that could help identify and therefore contain these invaders.

Maorach Beag

Maorach Beag is a recent start-up and again a family business, currently being run part-time as family members have paid employment elsewhere. The business received all the relevant permissions in 2015 and has continued to both build infrastructure and to farm Pacific and native oysters. The long-term goal of the business is to focus solely on the production of Native oysters; Pacific oysters are being grown in the short term to provide cash flow to support the build out of the business.

The first commercial seed, sourced from Guernsey Sea Farms (Pacifics) and Morecambe Bay Oysters (Natives), was placed on the farm in July 2017. Installation of the farm has been entirely self-funded, as lending finance is not available for aquaculture – another barrier preventing expansion and growth of the sector. For example, grading of oysters is done by a self-built grader to avoid the need for expensive infrastructure.

Maorach Beag was able to grow native oysters to commercial size in just three growing seasons, having had a warm summer. It supplied native oysters to the DEEP project in 2019 – again, supported to be compliant with the requirements of the Glenmorangie Company's procurement process – helping its first cash flows in after almost four years of expenditure. Maorach Beag sees a business opportunity to supply clean, disease-free on-grown and broodstock native oysters to the growing restoration projects across Europe. In the longer term, they also see a significant opportunity in the table market, delivering a high value quality product that can be framed and supported by Scottish provenance.

As with Loch Ryan Oysters and Lochnell Oysters, Maorach Beag participated in the NORA 2019 conference, connecting with restoration projects across Europe.

Orkney Shellfish Hatchery (OSH)

OSH is a Scottish company with North American private equity funding whose vision is to run a biosecure, modern dual species hatchery to produce lobster juveniles (*Homarus gammarus*) and native oyster spat (*Ostrea edulis*) in Orkney. OSH has invested heavily in modern algal production techniques, bio-secure systems, skilled staff and global aquaculture hatchery accreditation to produce a facility that, together with educational partners (Heriot- Watt) and sister company (Shellfish Hatchery Systems), is able to provide a test bed for industry advancement alongside the production of species for restoration and maintenance of shellfish populations.

OSH uses an innovative technology system to ensure that the process is biosecure and programmed to meet the needs of each spat larval type. OSH is owned by the Cadman Capital Group, a USA-based multinational private equity group specialising in alternative investments.

DEEP are interested in working with OSH as part of the supply chain due to the biosecurity aspect of the hatchery. Existing hatcheries that produce both Pacific and native oysters are not able to ensure that the native oyster spat is not commingled with Pacific oyster spat; Pacific oysters are listed as an invasive non-native species (GB Non-Native Species Secretariat, 2019). While commingling can be addressed on farms that are licensed for both Pacific and native oysters, the species must not be introduced to the DEEP or other restoration sites.

OSH are now investigating diversification into on-growing in addition to hatchery work, and are in discussions with Lochnell, Maorach Beag, and seeking a third on-grower to provide independently certified on-grown oysters for sale into restoration markets and food markets. OSH's and this third on-grower would be planned to be based in the Orkney archipelago. Given the regulatory requirements, this may take two years to become reality and will require an estimated £350,000 investment.

DEEP and OSH are working on a joint proposal for a Knowledge Transfer Partnership through Innovate UK to investigate optimal hatchery techniques for the native oyster, including potential differentiation between native oysters for the table market (for which a thin shell and more meat is required) and for the restoration market, which may require different characteristics to ensure long term survival and breeding success. Success in this research will assist OSH to have a European-wide lead in hatchery aquaculture for the native oyster, meeting the market needs of the extensive restoration network.

Shellfish processors: Scottish Shellfish Marketing Group and West Coast Sea Products

The DEEP project requires 4,500 m^3 – approximately 2,250 tonnes – of shell cultch to settle in the Dornoch Firth to create oyster habitat. After discussions with SEPA and other regulators, it has identified waste mussel and scallop shell from these fisheries as a potential source, working with the Scottish Shellfish Marketing Group (SSMG) and the West Coast Sea Products (WCSP).

SSMG is a cooperative of mussel and Pacific oyster growers. Its members produce shellfish along the entire Western seaboard of Scotland and Shetland. SSMG owns and operates a centralised packing, processing, and dispatch facility in Lanarkshire. The company has diversified into a range of "ready meal" products, resulting in a waste stream of shells which have been through a cooking process and are therefore biologically inert. SSMG generate around 500 tonnes of shells per year.

WCSP create around 4,000 tonnes of shell annually, primarily from scallops fished in UK waters. WCSP have found some alternative markets for this shell, but it is currently regulated as a low-risk Level 3 Animal By-Product waste, which requires containment requiring additional plant and buildings to transport and store the waste. WCSP have found animal food markets for all residual biology on the shell, leaving only a very small amount which is currently weathered out.

Mussel and scallop shells are suitable cultch for oysters and for assisting with restoration projects, including DEEP. The Glenmorangie Company wishes to use the shell as cultch and has identified a biosecure process and transport for the shell waste using windfarm aggregates distribution by barge. Success depends on SEPA being satisfied that the shell waste does not contravene regulatory requirements; this discussion is on-going between the processors and SEPA, catalysed by the DEEP process.

Should the waste be reclassified, this will reduce a costly regulatory burden on these community-based companies, helping ensure that their products remain competitive, the companies are more financially sustainable, and enabling recovery of a waste stream for a further purpose.

2.2.3 Summary: present social and economic impacts of DEEP

The above sets out how DEEP is already impacting our most remote and rural economies, summaries below.

Table 3. Summary of DEEP social and economic benefits to date

Direct social and economic benefits of DEEP

- Safeguarded three SMEs by providing additional markets for their product and by assisting in access to new supply chains, helping protect 11 existing jobs in economically fragile areas;
- Enabled these three SMEs to develop expansion plans for increasing production and investment, now being further developed by Highlands and Islands Enterprise;
- Assisted in the development of a Scottish multi-species hatchery, long identified as necessary for assisting the growth of the aquaculture sector in Scotland and the UK;
- Provided four knowledge transfer and partnership working with SMEs, including surveying wild populations, providing insights into hatchery methods, and providing knowledge of native oyster growth and production methods:
  - investigating optimal hatchery techniques
  - investigating optimal on-growing systems and processes
  - investigating genetic selection for optimal oyster characteristics
  - as a follow up from an existing PhD, investigating spatfall distribution from the restored reef.

3 Helping deliver Ambition 2030: opportunities and barriers to growth

3.1 Opportunities for Growth: the food market

The Scottish Government published "A Trading Nation" in April 2019 (Scottish Government, 2019), re-stating its commitment that exports could, and should, contribute more to the goal of sustainable, inclusive economic growth. Scotland's food and drink sector has long been successful in exporting, with an increase in exports between 2013 to 2018 from £5.4 billion to £6.3 billion, making up 20% of Scotland's international exports (Scottish Government, 2019). The Scotland Food and Drink Partnership of industry, government and its agencies, published "Export 2.0: Delivering today, planning for tomorrow" in June 2019, an update to its 2014 strategy for growth "Ambition 2030" (Scotland Food and Drink Partnership, 2017) to double the food and drink sector's turnover to £30billion to 2030. This includes a strong focus on exports.

The industry-led strategy for aquaculture, "Aquaculture Growth to 2030: A Strategic Plan for farming Scotland's seas" (Scotland Food & Drink Partnership, 2016), set out the ambition to double the contribution of Scotland's aquaculture to the economy from £1.8 billion to £3.6 billion by 2030. It noted that the sector contributes 8,800 FTE jobs[9], many in remote and rural areas, and sustains the economic and social fabric of the Highlands and Islands (p2). This value increase would include increasing mussel production to 21,000 tonnes per annum (the strategy is silent on the contribution of other shellfish).

Native oysters do not have a significant role in these strategies. Farmed salmon accounted for 86% of employment, earnings, and Gross Value Added of the aquaculture sector in Scotland in 2015; shellfish for just under 9% (Westbrook et al., 2017). Of the shellfish aquaculture sector in 2018, mussels accounted for 95% of 7,200 tonnes of shellfish table production and native oysters just 0.2%, very similar to previous years' proportions (Figure 4).

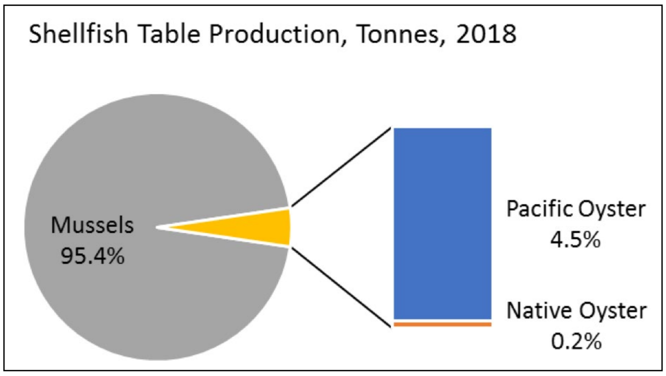

Figure 4 Shellfish Production in 2018

Source: (Marine Scotland Science, 2018)

Note that this does not include the output from wild fisheries, that is, the Loch Ryan Oyster Company; including this output would not make a significant difference to the findings.

Although the native oyster is a very minor part of both current production and of strategies for growth, it does have unique selling points which may enable it to contribute disproportionately to growth plans.

Ambition 2030 (Scotland Food and Drink Partnership, 2017) set out the success factors to achieve the planned doubling of the sector by 2030. These included:

- Collaboration across industry, government and its agencies
- Reputation, based on provenance and quality
- Diversity of product.

In terms of the market and consumer trends, Ambition 2030 (Scotland Food and Drink Partnership, 2017) set out key factors supporting the growth of the Scottish sector, including the increasing world population, experiences around food and drink, a strong wellbeing agenda related to food, and a focus on social and environmental benefits in making food and drink choices.

[9] Note that these 2016 figures were recalculated by Westbrook et al (2017) as a GVA of £0.6billion and jobs of 12-22 FTEs.

The brand messaging is set out as below:

"In developing the 'Scotland, A Land of Food and Drink' brand we have showcased our talented people, world-class products and iconic landscapes synonymous with heritage, tradition and our natural larder. We will continue to build this element of the brand and project it to our existing and emerging markets. We will develop our brand values around responsibility and trust. This goes much deeper than marketing – it's about a renewed commitment to, and defining a culture around, our stewardship of the environment and resource management, our investment in the workforce and our ability and willingness to contribute to the wellbeing of our nation.

Businesses of all sizes and in all key markets will benefit from an enhanced Scottish food and drink brand to create trust, build emotional connections with customers and consumers, raise expectations of quality and strengthen loyalty." (ibid, p5).

Scottish native oysters are uniquely placed to meet this brand description and therefore to create both brand value and command a higher price. This proposition has already been tested by the Loch Ryan Oyster Company, who trialled exports into China, and who report a significant premium on live Scottish Native oysters into that market[10]. They report that this market requires higher volumes and good reliability of supply for the regulatory challenges to be worth the effort.

Chinese aquaculture, including its shellfish, is suffering as a result of poor environmental protection resulting in water contamination and disease; as with the Chinese economy more generally, there is an increasing shortage of cheap labour as the population ages (Rabobank, 2018). The impacts of this have already been felt by crab fisheries in UK waters. Seafish, the Non-Departmental Public Body established by the UK government to support the £10 billion UK seafood industry, reports that *"from 2010 – 2017, [farmed and fished] shellfish exports by value to the EU have increased by 8% but to non-EU markets by 146%. Much of this improvement in non-EU markets trade has been from a small base and much has been driven by increased brown crab exports particularly to China"* (Seafish, 2019). In 2017, 76,000 liveweight tonnes (£267m) were exported to EU countries, while 8.5 tonnes (£32m) were exported to non-EU markets (Seafish, 2019).

There are already links into overseas markets with Pacific oysters, including the UAE, Taiwan, China, Japan, Singapore (Figure 5). These trade links and existing distribution networks and systems provide a firm foothold into these markets, creating a basis for further development.

Technological developments which support expansion include improved transportation of live shellfish. Both the Irish and English markets are using advanced depuration systems during transport to overseas and particularly Far Eastern markets (commercial information in confidence).

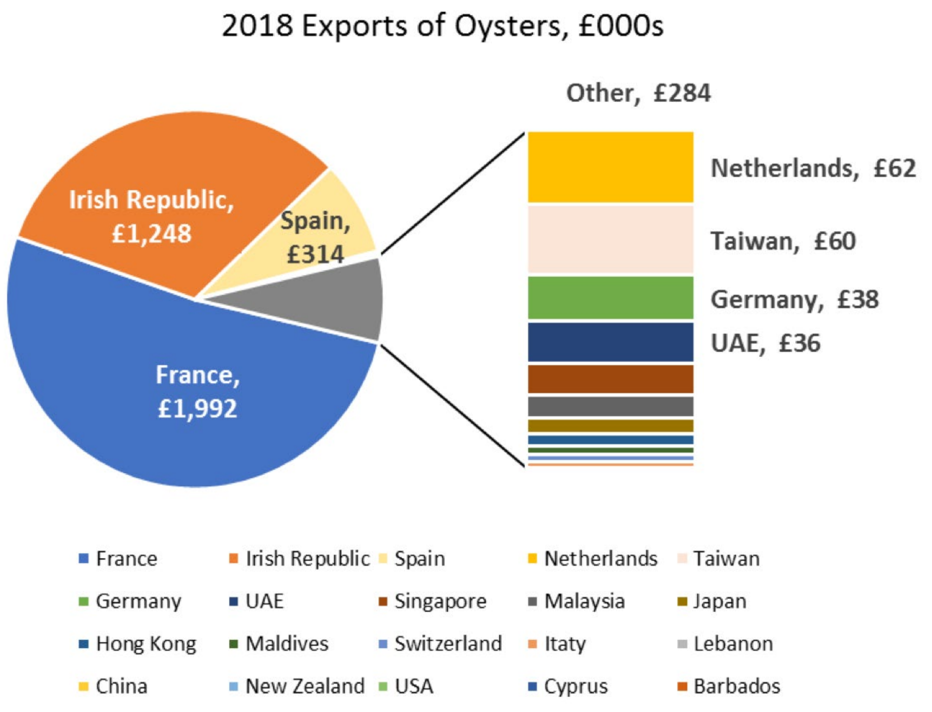

Figure 5 UK exports of live Pacific oysters, 2018. Source: HMRC Fish Exports 2018

[10] China is the world's largest producer and consumer of shellfish. The Food and Agriculture Organisation of the United Nations (FAO) published "The State of World Fisheries and Aquaculture" in 2018 (FAO, 2018) stated that *"China, by far the major producer of farmed food fish [including shellfish], has produced more than the rest of the world combined every year since 1991."* In 2016, world production of farmed molluscs was 17.1 million tonnes (*ibid*, p 5); a growth of 14 million tonnes since 1990; of these, 15.8 million tonnes were produced in Asia (*ibid* p20). Of worldwide production of 17.1million tonnes, 5.6 million tonnes were various species of oysters including 0.6 million tonnes of Pacific oysters (*ibid* p24).

Scottish native oysters, with their cultural history, a strong environmental story of restoration and recovery, backed by a Scottish brand and grown in Class A disease-free shellfish waters, provide a clear proposition to the middle Eastern and Asian market. The size of the market means that native oysters will be a very small proportion of a growing market.

3.2 Opportunities for Growth: the restoration market

There are significant funds from a variety of sources being invested in native oyster restoration in across the UK and Europe.

These amounts have been gathered from a range of sources, as there is no collective for the total of funds available; and some projects are currently bidding for funds. These projects have been able to source funds from European habitat and research funds; national funds; and private trusts and foundations. Projects are members of the Native Oyster Network in the UK and Ireland (NONUI), set up and led by the Zoological Society of London and Portsmouth University in 2018, and funded by the John Ellerman Foundation. The NONUI represents a wide range of partners including universities and research institutes, fishermen and fishery regulators, harbour authorities, regulatory and other government agencies, and includes 17 projects of varying sizes (Native Oyster Network UK & Ireland, 2019) The Native Oyster Restoration Alliance (NORA) is an alliance of European-wide projects set up in 2017 with an active programme to restore or reintroduce this key ecosystem. Network members are representatives of nature conservation agencies, science, non-governmental organizations (NGOs) as well as oyster farmers (Native Oyster Restoration Alliance , 2019) and include a further 7 projects. The Alliance is funded by the German Federal Agency for Nature Conservation.

The projects to date are focusing on available broodstock for spat regeneration; exclusion of any oyster fishing or sea-bottom disturbing activities; spatting and growth of spat; and carrying out research on spatting recruitment, spat settlement, and cultch.

The DEEP project has taken a different approach, based on the available science from long-established restoration projects at Chesapeake Bay. DEEP, is using on-grown oysters to help establish the population and overcome predation issues. The Solent project, which previously proposed to rely on spatting from broodstock, has placed its first order for on-grown oysters from Scottish sources as it now has monitoring evidence that predation of spat is likely to prove a challenge to achieving its objectives.

Significant oyster restoration projects in the UK, Ireland, and Europe which are currently using the methodology of broodstock oysters and spat recruitment are listed below. These projects range in size from tens of hectares (as with DEEP) up to entire estuaries and areas of hundreds of square kilometres (as in the 287 km^2 being addressed by the Essex Native Oyster Restoration Initiative). Project summaries for the project below are available on the NORA website https://noraeurope.eu/:

- Essex Native Oyster Restoration Initiative - conservation and fishery management
- Solent Oyster Restoration Project - conservation and fishery management
- Chichester Harbour Oyster Partnership Initiative - conservation and fishery management
- Lough Foyle Native Oyster conservation and fishery management
- Loch Swilly Oyster Society conservation and fishery management
- Cuan Beo native oyster conservation and fishery management
- Native Oyster Reef Restoration Ireland (NORRI)
- Loch Ryan Oyster conservation and fishery management
- RESTORE reintroduction for ecological restoration, Germany
- Voordelta reintroduction for ecological restoration, Netherlands
- "Towards a Rich Wadden Sea", Wadden Sea reintroduction for ecological restoration, Netherlands
- Borkam Reef Pilot reintroduction for ecological restoration, Netherlands
- Gemini Windfarm Pilot reintroduction for ecological restoration and bioengineering of windfarm infrastructure, Netherlands

There are significant sums being invested in these projects, many from non-governmental sources. The DEEP project has a published budget of £6.4 million investing in supply chain and research and plans to introduce 4 million "restoration" size oysters; the Solent project has a published budget of £2million from the Blue Marine Foundation and is considering whether to proceed with 250,000 restoration oysters in its next phase; the Voordelta project €8.5million from the Post Code Lottery Netherlands. Other projects have not published their total budgets, but a conservative estimate is €50 - €60 million over the next 3 years. Some element of this will be spent on the supply chain. DEEP is planning to spend 23% of its funds on the supply chain; information is not available on how much of the investment in restoration projects elsewhere will be so invested.

The potential for windfarm bioengineering is of particular interest. 'The Rich North Sea' project has undertaken a pilot project within Eneco's Luchterduinen to contribute to a blueprint for underwater nature restoration at all offshore wind farms. Numerous and substantial new wind farms are planned for the Dutch sector of the North Sea in the coming years. The project aims to show that nature conservation and sustainable energy generation can be mutually beneficial. Fishing along the seabed is not permitted within wind farms, which enables marine features – including oyster reefs - to develop undisturbed. The project has placed an artificial reef at a depth of 20 meters including reef balls and cages containing adult oysters. In the course of 2019, more cages will be positioned with different types of materials to which spat can attach. The aim is to determine whether the oysters grow and reproduce sufficiently, and whether their larvae establish themselves in the vicinity and form a reef. This makes it possible to investigate the ideal conditions for the development of oyster beds within a wind farm. Currently the project is using oysters supplied from Norwegian wild managed stocks; it is looking for a replacement to provide sustainable stocks not taken from the wild, and the disease-free broodstock from Scottish native oyster suppliers are of great interest.

The oysters will not only contribute to the ecosystem, but also provide bioengineering. Scour at the base of windfarms caused by sea currents is of significant concern, as the infrastructure is intended to last at least 20 years The project is seeking to demonstrate that oysters and other reef-inhabiting molluscs could provide a self-sustaining bioengineering solution, creating a protective reef at the base of the windfarms (Kamermans, 2018).

Mitsubishi have expressed an interest in applying this methodology for the planned 950 MW Moray East offshore windfarm; this is being explored with the DEEP project.

The total market for these restoration oysters can only be surmised at this point in time. Estimates have been provided confidentially of an estimated 50 – 150 million oysters over the next 5 – 10 years; a market for disease-free, biosecure "restoration" and mature broodstock oysters which currently have a very limited source of supply, and where Scotland's nascent aquaculture is a market leader.

Achieving this level of increase in the supply of oysters will require ongoing investment to develop the supply chain.

3.3 Delivering growth: the opportunities

There is a significant market overseas for a niche "Scottish brand" oyster – a market that is already in development and has established infrastructure for delivery (8.1 above). This market is constrained only by supply and by its inclusion in an existing UK and Scottish Strategy for seafood exports. There is also a restoration market for disease-free, biosecure "restoration" size (20gr) and broodstock (80gr) oysters in the UK and in Europe which is already at 2 million per annum and has the potential to at least maintain that level from existing projects.

The significance of the restoration market is that it reduces the need for working capital for native oysters. The current period from purchase of hatchery product to market is three to four years; and can be as long as five years in poor weather conditions for growth. Restoration oysters reach the required size one to two growth seasons after purchase; in a good growth summer, this can be just one year.

Although the cash returns are smaller – prices for restoration oysters have been quoted at approximately one-third the "farm gate" price for a table oyster – it is sufficient to allow the oyster farmer to re-invest in hatchery product earlier, and to help reduce a significant barrier to growth.

The two oyster farm license holders already have permissions and available loch space to increase production to 8 million oysters (confidential communication), from the current 200,000 oysters. Increasing this by 2 more on- growing farms, as is planned as a result of the DEEP project at the same relatively small level of production would provide at least 50 times the current volume of native oysters; this is before improvements in productivity as a result of on-going research into spat recruitment and on-growing methods. Increasing current spat and juvenile oyster viability – which has already been done at the hatchery scale by the Roem van Yerseke experimental hatchery in the Netherlands (Roem Hatchery, 2018), with survival rates as high as 80% compared to 25% experienced in the UK currently – would allow 100 times the current volume of native oysters to market.

The current levels of production from aquaculture from one farm are around 200,000 native oysters on average over the last 4 years (Marine Scotland Science, 2018, p. 3) of table oysters. An increase to an average annual production of 8 million shells in 5 years' time is within current and currently planned farm space capacities. This depends on other barriers to production being overcome, particularly the need for funding and investment to allow oyster farms both to invest in the necessary equipment and for medium-term working capital.

At 8 million table (mature) oysters per annum, the output from this sector would equal that of the current Pacific Oyster sector which has averaged 8 million shells (table and on-grown) over the last 3 years (*ibid*), and would reach 5% of the total Scottish shellfish aquaculture sector.

Growth above the 8 million oysters per year will depend on other challenges being met, including productivity; available space; marketing; and investment.

3.3.1 Potential economic benefits from native oyster aquaculture and restoration

The aquaculture sector is of key economic importance for Scotland and the Highlands and Islands, providing significant direct and indirect employment opportunities in remote and fragile communities. Highlands & Islands Enterprise (HIE) and Marine Scotland (MS) commissioned an impact study in 2017 (Westbrook , 201) to understand the composition of the aquaculture sector in Scotland and consider the opportunities and challenges facing the growth of the sector as set out in "Aquaculture Growth to 2030" and its wider supply chain up to 2030. The Westbrook 2017 study illustrated the impacts that might be achieved by the growth scenario set out and considered other, more conservative, scenarios. The impact study considered the findings of an earlier study, "An Assessment of the Benefits to Scotland of Aquaculture" (Imani Development, 2014), commissioned by HIE and MS in 2014 to demonstrate the sector's social and economic impacts.

As with the strategies for growth (section 8.1 above), native oysters do not feature in the Westbrook study or in the findings, due to the current micro size of production. That said, the findings for the impact of growth in the native oyster sector specifically can be inferred from the Westbrook (2017) study, and the findings on the potential for growth and the barriers to growth are of direct relevance to potential economic and community benefits of a larger native oyster industry.

3.3.2 Employment and Gross Value Added

Westbrook (2017, p. 57) calculated that every full-time equivalent job in shellfish aquaculture added £68,600 value at 2015 prices (Table 4).

Table 4. Gross value added per sectoral employee per year

Employment	Earnings
1 FTE direct employment	£24,500
0.4 FTE indirect and induced employment	£9.800
Total employment impact	£34,300
Gross Value Added – 100%	£68,600

Source: Westbrook (2017, p. 57)

The mussel aquaculture industry has a higher GVA per direct FTE as it also includes processing jobs; it is assumed here that the market will be for live product. The shellfish industry has a higher GVA per direct FTE as it includes jobs in transport; it is assumed here that native oysters will use established transport methods and links. The above analysis therefore assumes that no additional jobs will be created in processing or in transport.

Current employment in aquaculture in Scotland in native oysters is assessed at 1 FTE in part time jobs, based on discussion with producers: at this level of employment, there is an assessed Gross Value Added of around £100,000 per year.

The margins on native oyster production are very low, and natives are currently farmed as part of a multi-species production, with Pacific oysters and with other shellfish. There is no current excess productive capacity in the labour force to absorb any increases in production. Productivity is likely to increase as research drives more effective and efficient production, and it is reasonable to assume a relatively high level of productivity growth as findings are incorporated into the sector.

Estimates of employment earnings and gross value added on a range of productivity scenarios, from 10% increase in productivity per annum down to 2% per annum are shown in Table 5.

Table 5. Gross Value Added from Growth in Native Oyster Aquaculture Production					
	2015 3-year average		2024 values @ 2015 prices		
Oysters (Shells) (000s)		200	3,600	3,600	3,600
Productivity gain per year			8,000	8,000	8,000
Cumulative productivity gain over 5 years			10%	5%	2%
Employment		Earnings	61%	28%	10%
FTE direct employment	1	£24,500	16	29	36
FTE indirect and induced employment	0.4	£9,800	6	12	14
Total FTEs	1.4		22	41	50
Total employment impact £000s		£34.3	£748	£1,390	£1,721
Gross Value Added £000s		£68.6	£1,496	£2,780	£3,442

Based on growth to 8 million shells per year, and depending on the level of productivity gains from R&D and knowledge transfer, native oyster aquaculture production could create between 22 and 50 new FTE jobs and add between £1.5m and £3.4m value added to Scotland's rural economy, annually.

There are likely to be additional value-added benefits as the oyster farms gear up and invest in capital – lines, buoys, trestles, oyster cages, and (depending on the production method used) boats. Further work is being undertaken in the industry to identify the most productive method for on-growing, and this will have a significant increase on value added.

3.3.3 Community and social benefits

While a mid-point of 41 FTE new jobs may seem a relatively small benefit, these are jobs in some of the Highlands, Islands, and Argyll's most fragile economies. Westbrook (2017, pp. 58-59) considered his own work providing evidence of the following social and community impacts of aquaculture – in this case, salmon - in remote and rural parts of the Highlands and Islands:

- A mixture of employment provided for existing residents (generally relatively young) and new residents when new farms have been established;
- Long employment duration – reflecting the lack of alternative or more attractive employment, relatively high pay in the local context, and on and off the job training provided by employers to develop employees' skills.
- Company and employee expenditure that has helped to sustain local businesses and avert closures due to otherwise insufficient annual demand from residents and visitors. Businesses supported include hotels and other accommodation and catering establishments (which also provide for site visitors), fuel supply, hardware supply, divers, house building and maintenance, leisure boat moorings, and those providing repair and maintenance services to company operations, access roads and sites, etc.
- Local primary schools whose rolls have been increased through attendance by the children of aquaculture employees, which can be important in keeping schools open where rolls are small and reducing.
- The important work that can be carried out in local areas by the partners of aquaculture employees, e.g. school teaching, nursing, etc.
- The roles that aquaculture staff play in local voluntary coastguard, fire, etc. services – with their marine experience relevant.
- Use of company berthing facilities by other commercial and leisure boats, with company boats potentially available in emergencies.

3.3.4 Oysters and tourism

The focus above has been on the production of native oysters for the food market. Native oysters are also a significant tourist attraction, providing added value to regional economies. New Zealand[11] has a well-established "oyster trails"; Nova Scotia has a "seafood trail"[12].

The Stranraer Oyster Festival 2018 contributed £1.1 million to the local economy[13]. This festival is branded through an association with Native Oyster of Loch Ryan and brought 14,000 visitors to a town in an area which has been in

[11] https://media.newzealand.com/en/story-ideas/discover-the-new-zealand-oyster-trail/

[12] https://www.novascotia.com/eat-drink/nova-scotia-seafood-trail

[13] http://www.stranraerdevelopmenttrust.co.uk/2019/02/03/stranraer-oyster-festival-worth-1m/

economic decline for some time and particularly since the new ferry terminal was built outside the town in 2011.

In Croatia, the area of Mali Ston Bay farms Ostrea edulis on a rope and line system, capturing young wild oysters and cementing them onto a rope which is harvested after two years. The system harvests around 1,000 tonnes of oysters a year from small local associations and cooperatives, almost all consumed in the restaurants around Mali Ston Bay[14]. There is significant potential to expand production here, but again production is limited by reliance on wild juvenile oysters. The potential for aquaculture to contribute to economic growth in the region is recognised by the Croatian government as part of their aquaculture. The University of Dubrovnik recently opened a shellfish hatchery to help overcome this specific issue (University of Dubrovnik, 2019). These tours are well advertised and have an international reputation, with economic impact studies of the areas where they are occur (New Zealand Institute of Economic Research, 2017), (Nova Scotia Fisheries Sector Council, 2005) alluding to a significant impact on the local economies. Quantified impacts of these seafood tourism sectors are not available as the impacts are included within broader tourism sectors.

3.4 Summary: Wider economic impact potential of Native Oyster Aquaculture

In summary, investing in the existing potential for native oyster farming would deliver to current strategies for the development of Scottish Aquaculture, (Table 6).

Table 6. Wider economic impact potential from developing current production sites

Towards Aquaculture Growth to 2030 and Ambition 2030
- Developing a supply chain capable of delivering a 5% growth increase to the Scottish aquaculture sector, a size comparable to the current Pacific oyster market, in the next 5 years;
- Generating an estimated 41 FTE jobs and add £2.8million GVA annually to some of Scotland's most fragile rural economies; strengthening their social resilience
- Developing a base for rural tourism, boosting FTEs and GVA in our coastal areas using the approach developed in New Zealand and elsewhere

3.5 Barriers to growth

The "Aquaculture Growth to 2030" (Scotland Food & Drink Partnership, 2016) strategy sets out six inter-related strategic priorities to achieve this growth (Figure 6), each of which has a directly application to the growth of native oyster aquaculture – and where DEEP is already making an impact.

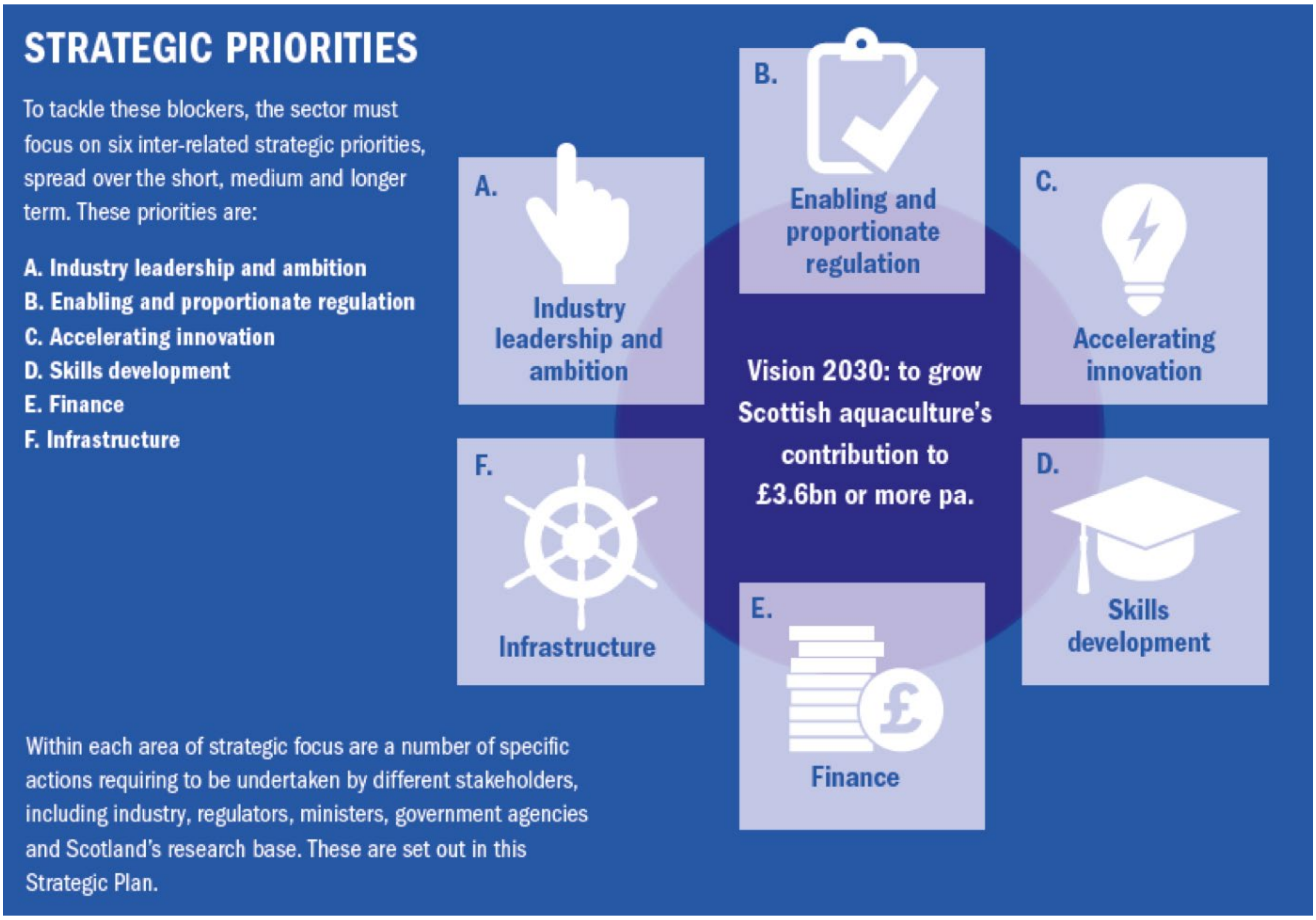

Figure 6 Aquaculture Growth to 2030: Strategic Priorities
Source: Scotland Food and Drink, "Aquaculture Growth to 2030: A Strategic Plan for farming Scotland's seas" p3.

[14] https://www.seafoodsource.com/features/croatian-flat-oyster-hatchery-planned

Assessing these challenges for native oysters as a growth area (letters refer to the diagram above):

A. The Glenmorangie Company is providing both leadership and ambition to the development of native oysters, and this is helping draw together a micro-sector of the aquaculture industry.

B. The regulatory aspects of DEEP relating to restoration are proving complex to address. However, the general issues for aquaculture permitting have been highlighted by the aquaculture industry. In 2015 Marine Scotland and The Crown Estate jointly commissioned an independent review of the consenting process for aquaculture. These recommendations are being progressed (Scottish Government, 2019). Conversely, lack of regulation or at least lack of enforcement may also be a threat because of the risk of diseases and invasive non-native species. While aquaculture businesses are required to have a biosecurity plan which must be available to Fish Health inspectors, there are many difficulties for regulators to enforce compliance in a sector where there are many small dispersed actors and many potential sources of pollution. Even eDNA techniques could not identify the source of the non-native species present at the oyster farm in Loch Creran (Cottier-Cook et al., 2019).

C. DEEP is accelerating innovation within the native oyster aquaculture industry. Its knowledge transfer and other partnership are helping build skills in the hatchery and aquacultures sectors.

D. For growth to happen, aquaculture will have to overcome the barrier of skills and interest in working in the industry – a problem across the fish and aquaculture sector. Seafish has put a strategy in place to address this issue sector-wide. (Seafish, 2017).

E. Infrastructure in this instance refers to transport infrastructure and to broadband infrastructure. These issues are mentioned in the context of the much larger salmon industry who are implementing technology-based solutions to feed and monitoring; none of the shellfish industry groups raised these as a significant barrier to growth.

F. Finance is the single biggest challenge remaining to deliver significant growth in aquaculture and in restoration.

3.6 Finance and investment in the supply chain and restoration

Native oyster aquaculture suffers, as does existing shellfish aquaculture, from an inability to attract traditional or even alternative market lending. There are no fundable assets on the balance sheet for the shellfish before they are marketable. A shellfish farm's assets are the Crown Estate or other lease, the farm licenses and permissions, short-life assets such as buoy, nets, anchors and baskets, and possibly a boat (potentially involving a boat mortgage). Attracting finance is one of the biggest hurdles to new entrants and to expansion in the shellfish aquaculture industry, given expenditure required in the order of £600,000 over 5 years before significant income materialises (estimates provided commercially in confidence). Attempts to create a lending model e.g. by lending on the expected value of the harvest, undertaken on behalf to the sector by Seafish, have had no success to date (Seafish, personal communication). Shetland's mussel farms reportedly overcame this issue with a local combination of private lending and enterprise sector lending.

DEEP is providing finance to a sector by paying for native oyster stock in advance, providing up-front cash flow to a sector that has seen very little external investment in productive capacity, and by so doing, increasing capacity for investment in infrastructure. However, this will not be sufficient income to enable capital investment and working capital for expansion. It will aid working capital flows but can only provide a much smaller amount of net profit or surplus cash towards capital investment. Growing the aquaculture sector in Scotland will require government and social capital intervention where the lending market cannot underwrite the risks.

Creating a "story" around this iconic species allows for other sources of capital, such as crowdfunding, which are more willing to take a longer view and take a higher risk for ecosystem benefits, including cultural and social value. DEEP is creating – and marketing - much wider awareness of the ecological value of the native oyster as a restoration objective and its cultural and social history in coastal regions. Generation of value – and through this, restoration funding has been successful where the purpose is restoration of a wild fishery, shoreline protection, or restoration for conservation. For example, the Blue Marine project in the Solent (aimed at restoration of a wild fishery and restoration of the ecosystem) is majority funded through corporate social responsibility money. DEEP is an ecological restoration project and a water quality project funded through Glenmorangie's corporate social responsibility funds. The windfarm oyster projects in the Netherlands are also funded through corporate social responsibility funds to improve the environmental impact of new windfarm construction.

These funds are having an impact on oyster aquaculture in terms of creating a market for hatcheries and potentially grown-on oysters, but they are not providing investment into that supply chain. To realise the benefits of an expanded native oyster aquaculture supply chain which can exploit the restoration market and provide a basis for an international market expansion, funding will have to be made available through non-market channels for infrastructure improvements.

Historically grant funding has been available through the European Maritime Fisheries Fund to enable set up and growth of aquaculture. It may be that future funding schemes will be available through the UK and Scottish Governments following Brexit, or through regional development agency funds.

4 Towards an ecosystem value

4.1 Wider applications of the DEEP approach

Government bodies and other non-financial markets may invest in oyster restoration – including in oyster on-growers - if they perceive that the benefits exceed the costs. Such decisions are made based on political, economic, and social drivers which differ in priority based on the objectives of the funder.

The European Marine Board's Future Science Brief (Austen et al., 2019) examined the current methodologies for valuing marine ecosystems, explaining that, "Valuation of the direct and indirect benefits (for either societal welfare, health and economic activities) stemming from marine ecosystem services can help to assess the long-term sustainability of blue growth, support policy development and marine management decisions, and raise awareness of the importance of the marine environment to society and in the economy". This examination focussed on the most widely used method of assessment, the "services" provided by the ecosystem (Figure 7).

It is outside this study's brief to consider a full ecosystem valuation assessment of oyster restoration, particularly given the extensive modelling data and assumptions required for that valuation which are not yet available. However, it is valid to use the approach above in considering case studies undertaken elsewhere on oyster restoration valuation and other shellfish production for water quality management, and to consider why oysters have attracted Corporate Social Responsibility capital for projects such as the Solent Oyster Restoration Project, the Hudson Bay Billion Oyster Project, the Chesapeake Bay project, or indeed DEEP rather than an existing shellfish in that environment. For Northern Europe, as in the Baltic example, this would be blue mussels – which are much better established as a production source with a known methodology for reproduction.

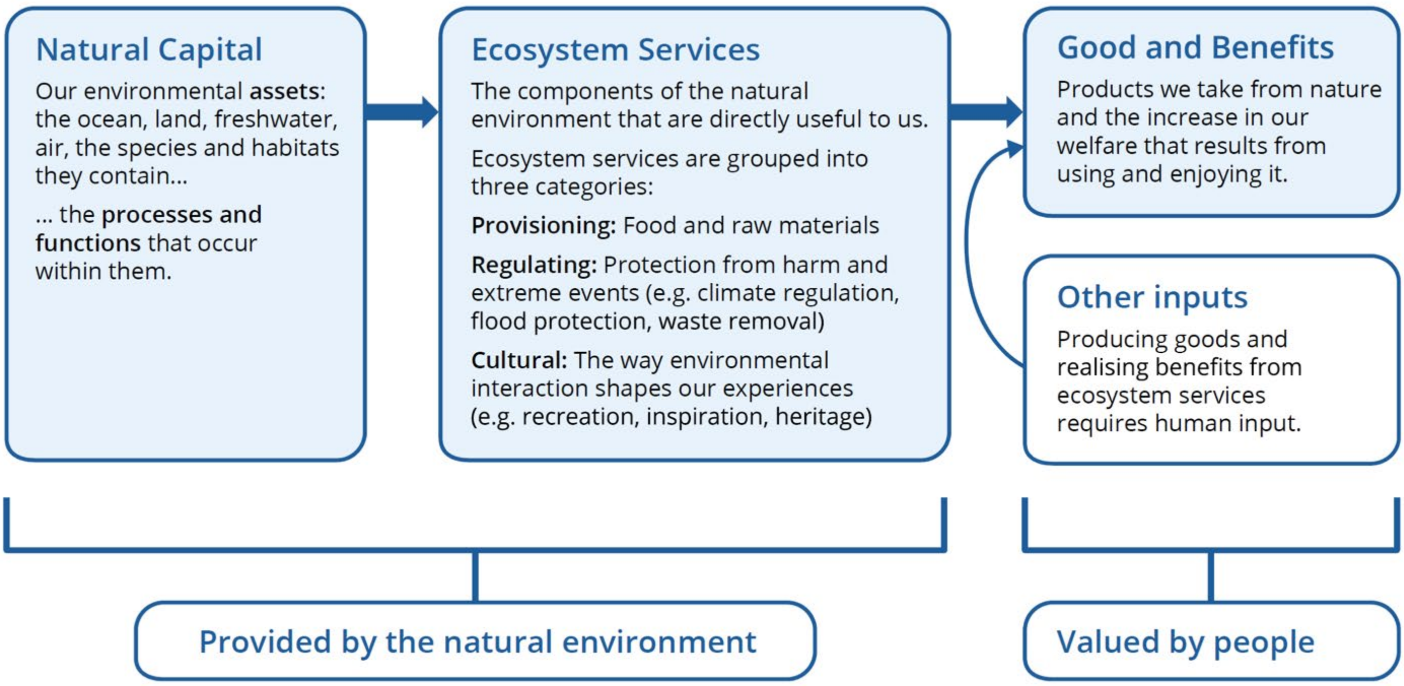

Figure 7 Ecosystem valuation: a services and benefits approach
Source: Austen et al (2019)

4.2 DEEP – imputed value of cultural and social services

Glenmorangie's approach to the circular economy at its site in Tain has enabled re-use of 95% of its liquid waste organic content as a renewable energy co-product, reducing its reliance on fossil fuels by 7% per year. The purpose of the DEEP project is two-fold; to improve water quality by ensuring removal of the final 5% of organic waste at end-of-pipe; and by so doing to restore an endangered species; creating an environmental and ecological benefit. The investing company, Glenmorangie, benefits by adding value to its brand; a significant driver in an industry where competition is based on brand values. The economic value of the oysters themselves as a potential wild fishery resource - a "provisioning service" in the terminology of ecosystem valuation - is not part of the impact investment decision. It is the "cultural and social service" – the perception that Glenmorangie is carry out an ecologically responsible restoration which has historic and cultural resonance – which creates brand value and translates into a willingness to pay for the Glenmorangie product.

4.3 The native oyster USP: cultural and social values

The incentive to invest in oyster restoration depends on matching costs of restoration with the benefits from restoration. A significant proportion of the current investment in oyster restoration is through Corporate Social Responsibility funding.

The single advantage that the native oyster has over other shellfish with more established production (for example the common mussel, *Mytilus edulis*) is in its ecological, cultural and social value. Unlike the Pacific Oyster *C. gigas, Ostrea edulis* is a native and therefore its restoration is likely to enhance, and not to damage, ecosystems. It has a history of human exploitation which has been demonstrated through archaeological records to have commenced with early human occupation of the British Isles, with recent history in its over-exploitation in the 19th centuries. Emotionally, it has a popular appeal as a missing ecosystem from Scotland's coastal waters. The Glenmorangie, Essex Oyster, and Solent projects have all promoted restoration of a missing and historic ecosystem, increasing the native oyster's social value as demonstrated by "citizen science" projects such as CROMACH. Social value is a significant injector of funds into conservation and restoration, from corporate investors such as Glenmorangie monetising that value through brand, to, for example, individual subscriptions from members who value bird protection and monetise this through membership of a multi-million pound conservation organisation such as the RSPB[15].

In the context of economic valuation of ecosystems set out in Figure 5 above, *Ostrea edulis* demonstrably has a significantly higher inspiration and heritage value than other shellfish. The issue is how to monetise that value and link the benefits to the costs. As with all the current efforts at restoration, this is likely to include a wide range of central and local government agencies, regulatory bodies, third sector organisations with a focus on water quality or marine conservation, industry, and communities directly impacted by or co-located with restoration efforts. One of the advantages of such a wide range of stakeholder involvement in a common objective is that each stakeholder will value a different range of benefits. Investments by the Zoological Society of London, Blue Marine Foundation, and Glenmorangie demonstrate that in the UK, as in Chesapeake Bay and the Hudson River, it is possible for stakeholders with wider social values based around cleaner water, ecosystem restoration and cultural history to provide leadership in restoration projects, monetising that social value.

In summary, there are case studies of applied ecosystem valuations and implied social and cultural valuations for the wider ecosystem values of oyster restoration, which consider not only the production values but also the regulatory and social values. These valuations have been used to justify and encourage cooperation and funding from a wide range of stakeholders to a single objective, restoration of the local native oyster.

The next section considers how these value methodologies might be applied to supporting delivery of Scottish Government policy objectives in Scotland.

5 Native Oyster Restoration

5.1 Opportunities to deliver policy objectives

Government regulation, policy, and its investment decisions will have a significant impact on the potential for native oyster restoration, either as enablers or as part-funders alongside other sources of investment. This section summarises briefly the available policies and plans which impact government-enabled into restoration, other than through its heritage conservation agencies (SNH and the conservation remit of Marine Scotland).

[15] While there have recently been economic valuations of the provisioning and regulating services provided by birds – see e.g. (Whelan, 2015), £82m (RSPB Audited Accounts 2019) of subscriptions and legacies pre-date and are independent of any such valuations.

The Scottish Government's alignment around its Strategic Objectives since 2007 - a Scotland that is Wealthier and Fairer, Smarter, Healthier, Safer and Stronger and Greener – has been the focus for its policies and regulations since 2007.

The Scottish Government are committed to making Scotland a 'Hydro Nation' where water resources are developed so as to bring the maximum benefit to the Scottish economy. The Hydro Nation Strategy (Scottish Government, 2012) includes encouraging all water users, including Scottish Water, to use innovative approaches to the use, storage, resource extraction, and management of wastes including outfalls to the sea. The Hydro Nation Strategy includes the aim to *"Deliver Economic Gain to Scotland. Utilising Scottish expertise to maximise the economic benefit of our abundant water resources within a sound ecological context"*. The Hydro Nation strategy was assisted by the Water Resources Scotland) Act 2013 which set out a Duty for Ministers to manage the value, including the economic, social, and environmental value, of Scotland's waters, which include coastal waters. The Act also expanded Scottish Water's powers to engage in any activity which supports this Duty.

SEPA set out its regulatory strategy, "One Planet Prosperity" (Scottish Environment Protection Agency, 2014), with two-fold aims; ensuring that all those regulated met their legal obligation and reach compliance, using new enforcement powers under the Act; and helping as many regulated entities as possible move 'beyond compliance'. SEPA are working with a range of stakeholders and influencers to achieve these aims, recognising the influence of third sector organisations and consumers on organisational behaviour.

5.2 River Basin Management – a role for Ostrea edulis?

SEPA leads the River Basin Management Planning process in consultation with a range of stakeholders, which produces RBMPs every 6 years. The third RBMP is in preparation, with consultation responses highlighting the need for increased integration with other plans including biodiversity strategies[16].

The River Basin Management Plan for Scotland's River Basin 2015-2027 (Scottish Government, 2015) was based on an assessment of the current quality of Scotland's designated coastal waters and of its surface and ground waters.

That Plan stated that the main pressures on water quality are rural diffuse pollution and wastewater discharges – both of which have a significant investment budget for remediation (Figure 8).

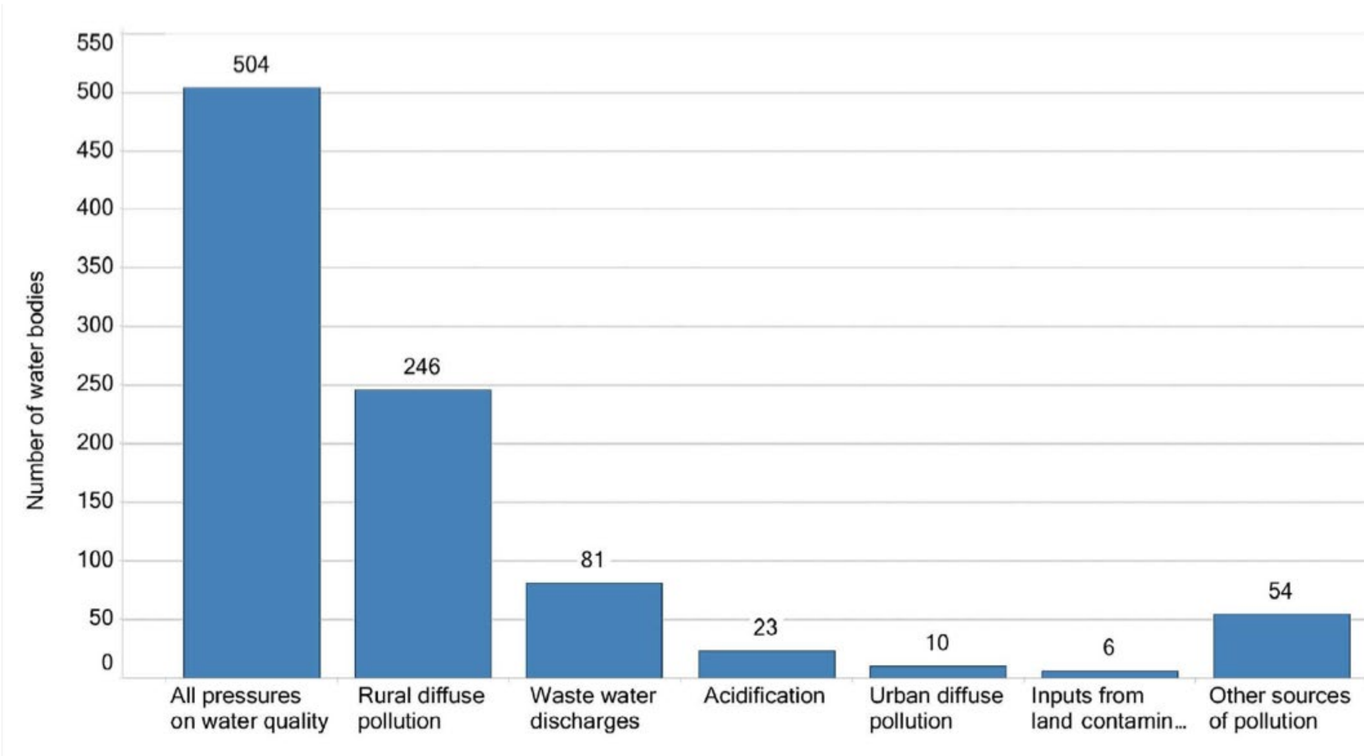

Figure 8 Pressures on water quality on water bodies in Scotland. Many water bodies are subject to multiple pressures and may feature in several of the bars in the figure. Source: (Scottish Government, 2015)

[16] https://www.sepa.org.uk/media/426912/sos_digest_scotland.pdf

To deliver these “One Planet Prosperity” aims, and to help ensure that key regulated sectors go “beyond compliance, SEPA is working with the regulated sectors in a series of Sector Plans, aiming to complete these by 2021. The Scotch Whisky Sector Plan was one of the first three to be completed in 2018 (Scottish Environment Protection Agency, 2018); the Water Supply and Waste Water Sector Plan (Scottish Environment Protection Agency, 2019) was completed in 2019. Plans for agricultural sectors are under development.

Pending delivery of the agricultural sector plans, actions to address rural diffuse pollution – including nitrates, phosphorus, faecal indicator organisms, pesticides and sediment - are set out in the Rural Diffuse Pollution Plan for Scotland (2015-2021) (Scottish Government, 2015), overseen by the Scottish Government’s Diffuse Pollution Management Advisory Group. This Plan set out the ambition to improve from 62% of water bodies in Scotland at good status to 88% by 2027, and 93% in the longer term. The highest priority for action was given to those areas with the greatest impact on human health including catchments draining to bathing waters, where applications for funding

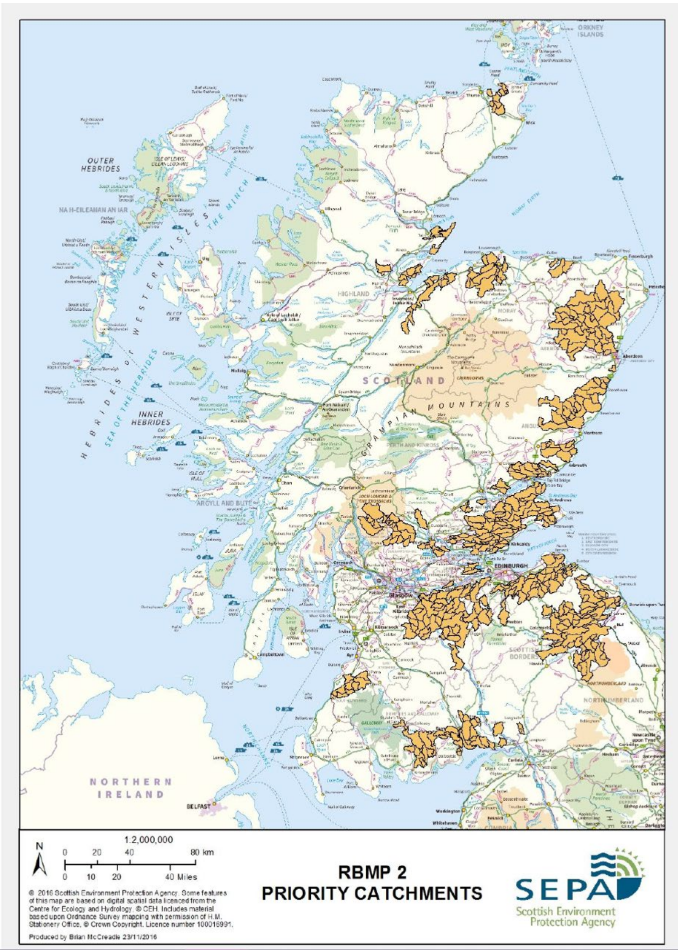

Figure 9 Priority areas for rural diffuse pollution
Source: (Scottish Government, 2015)

to the Scottish Rural Development Programme for mitigation methods by farmers are encouraged. £150 million was made available from 2015 to 2018[17]; exact figures of the proportion of this spent on water quality improvement measures compared to other agri- environmental are not available. As can be seen from the map below (Figure 9), all such areas are close to the coast, and many coastal outflows are proximate to the historic extent of oyster beds as shown in Figure 1 above.

Actions to address waste water pollution are set out in SEPA’s Water supply and waste water sector plan (Scottish Environment Protection Agency, 2019) , which underpins its “One Planet Prosperity” strategy and contributes towards UN Sustainable Development Goals. This sets SEPA’s objectives to work with regulated businesses to maximise products and services, and to minimise energy use into, and waste and emissions from, water use. SEPA’s overall goals and objectives for sewer networks include minimising sewage losses resulting from spills or storm water causing overflow directly into the water environment, particularly through combined sewer overflows. SEPA’s proposed actions for all those involved in waste management is to take action to reduce both blockages and storm water overflows, as shown in Figure 10 below.

Scotland's Centre of Expertise for Waters (CREW), a Scottish Government funded partnership between the James Hutton Institute and Scottish Universities, investigated the economics of resource recovery from the water cycle in the context of the circular economy (Dionisi et al., 2017). The report recommended expansion the current full-scale installations of heat pumps (for raw waters and wastewaters) and anaerobic digesters (for wastewaters and solid waste). It called for further Investigation of the feasibility of these technologies in Scotland at a commercial scale, looking at their optimisation, costs and practical implementation.

While these heat pumps and anaerobic digesters will allow for a significant recovery of heat and potentially a reduction in fossil fuel use, there remains the issue of the remaining outflows into coastal waters. DEEP have reduced their BOD content by 95% using an anaerobic digester and allied plant, and seek to remove the final 5% via bioengineering by native oysters. DEEP have the benefit of being able to control the inputs into the AD system through variation of their production – a benefit not available to wastewater companies who must cope with a significant variation in water load.

[17] https://www.ruralpayments.org/publicsite/futures/news-events/environmentally-friendly-farming-news-release/

Scottish Water, as the statutory corporation that provides water and sewerage services across Scotland, is responsible for almost all the sewerage and waste infrastructure.

Between 2015-21, Scottish Water planned (Scottish Water, 2015) to spend £296million to improve all known discharges that are confirmed as being non-compliant with the Urban Waste Water Treatment Directive and the Water Framework Directive: £35million on treatment to comply with the Bathing Water Directive; and no further investment in to comply with the Shellfish Water Quality Directive "until all other impacts are understood" (Scottish Water, 2015, p. 20). Scottish Water explain that £134million of the £296million will be spent on treatments to reduce flooding from sewers: this refers to terrestrial flooding from sewers, and not storm-induced floodwaters overwhelming the 4,000 combined sewer overflows[18] resulting in discharges to Scotland's waters. They present a new future for sewer networks (Figure 10).

In planning infrastructure investment for 2021-2027, Scottish Water is required by its regulator, The Water Industry Commission for Scotland, "to improve its efficiency and, where appropriate, take advantage of innovation to ensure that prices are kept as low as is consistent with a sustainable industry for future generations" (Water Industry Commission for Scotland, 2018).

Scottish Water set three requirements for investments in environmental improvements, including coastal water quality (Scottish Water, 2015, p. 18):

- There is robust scientific evidence that our discharges are having an impact on the water environment;
- There will be a clear benefit from the proposed investment; and
- Investing in our assets is the most sustainable way of achieving the required environmental outcome.

Scottish Water has also stated that, "We can no longer rely solely on traditional engineered solutions, such as making our sewers and tanks bigger. These methods are costly, disruptive, carbon intensive and use significant resources, while delivering only limited additional capacity."[19]

The Chesapeake Bay and Baltic examples have provided evidence that uptake of nitrates, phosphorus, and sediment by shellfish can be modelled such that it provides a method for addressing pollution once it has reached the marine environment. A sufficiently sized biomass of shellfish can provide a rapid response to such pollution (Section 2.1.4, Harris Creek), although the biomass requirement is dependent on the quantity of pollution to be filtered.

Oysters are not only being used to address non-point pollution from agricultural sources. In the Hudson Bay Billion Oyster Project, oysters are being reintroduced specifically as a mechanism for addressing urban and wastewater pollution overflows.

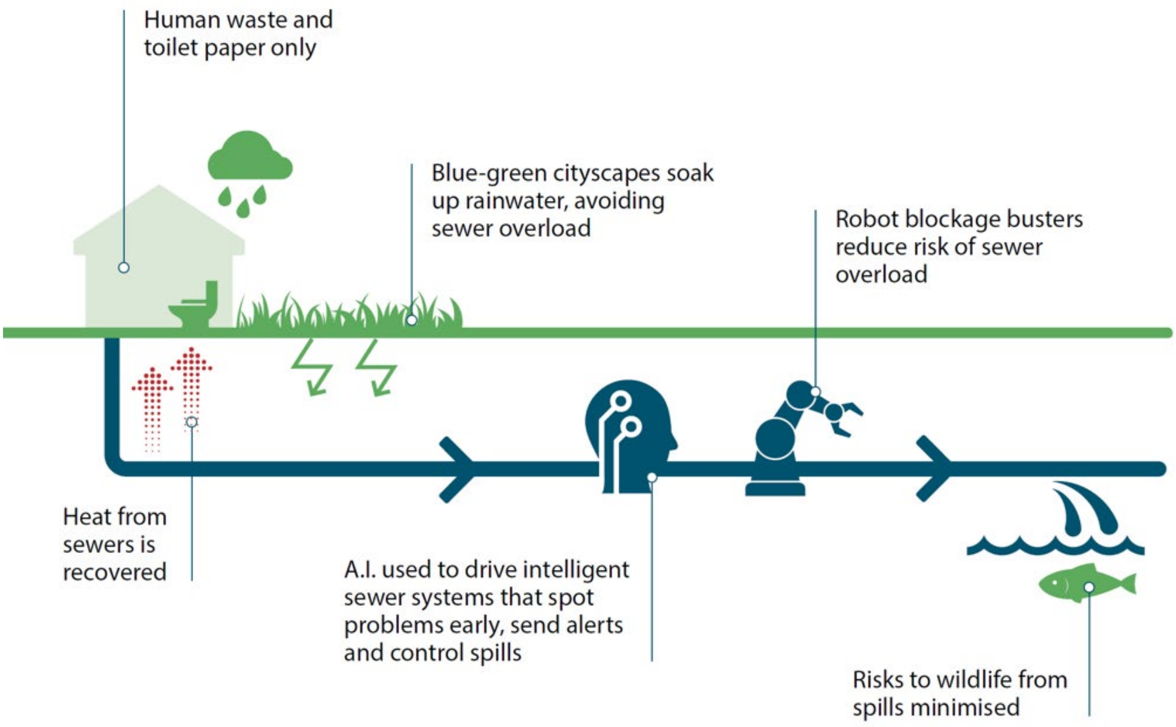

Figure 10 What might future sewer networks look like?
Source: (Scottish Environment Protection Agency, 2019)

[18] http://marine.gov.scot/information/location-and-type-waste-water-treatment-plants-2010-2012

[19] https://www.yourwater.scot/our-ambitions/ambition-three/resilient-water-waste-network/

The Hudson Estuary receives outflows from 44 waste treatment works, with required investments totalling billions of dollars to maintain or replace infrastructure that is over 60 years old[20]. The Hudson Estuary has been closed to commercial oyster aquaculture for a century due to over-extraction and pollution. The Billion Oyster Project[21] (Figure 11), and its allied Oyster Restoration Research Programme have demonstrated that C. virginica, once re-introduced, can survive and reproduce in these waters and provide an effective filtration service (McFarland, 2018) (Zarnoch, 2014). A study on stakeholder perception demonstrated that the perception of ecological benefits and the risks (Figure 12) to public health and the economy predicted stakeholder support for the programme, and that these perceptions did not vary between commercial fisheries and Programme volunteers (Holley, 2018). The Project uses shells collected from local restaurants, diverting this from landfill.

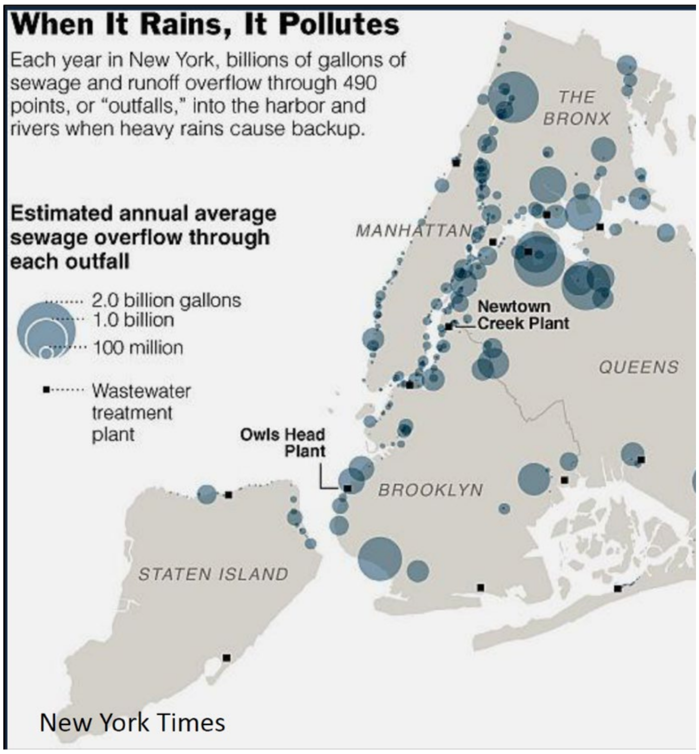

Figure 12 Hudson Bay Estuary: Pollution Infographic
Source: New York Times November 22, 2009

The Hudson Estuary receives outflows from 44 waste treatment works, with required investments totalling billions of dollars to maintain or replace infrastructure that is over 60 years old[20]. The Hudson Estuary has been closed to commercial oyster aquaculture for a century due to over-extraction and pollution. The Billion Oyster Project[21] (Figure 11), and its allied Oyster Restoration Research Programme have demonstrated that C. virginica, once re-introduced, can survive and reproduce in these waters and provide an effective filtration service (McFarland, 2018) (Zarnoch, 2014). A study on stakeholder perception demonstrated that the perception of ecological benefits and the risks (Figure 12) to public health and the economy predicted stakeholder support for the programme, and that these perceptions did not vary between commercial fisheries and Programme volunteers (Holley, 2018). The Project uses shells collected from local restaurants, diverting this from landfill.

A more widespread use of oysters (or other shellfish) as pollutant mitigation at particular sites in Scotland requires specific local application of existing research on ecosystem service modelling, assessment of impact on water flows, habitat availability, and resolution of potential conflicts with other users. This will enable a response to whether the cost of the investment in restored oyster reefs is greater or less than the benefits that each stakeholder anticipates in provisioning, regulatory and social values.

For water infrastructure investments and for diffuse pollution investments, the costs are significant and the benefits in terms of cost avoidance compared with the alternative therefore also significant. In addition, applying native oysters for pollution management would allow Scottish Water and other regulators to demonstrate a commitment to wider environmental and social values as required by the Scottish Government's Hydro Nation Strategy.

Increasing public awareness of diffuse plastic pollution in the marine environment may also provide a continuing driver for more awareness of, and the need to mitigate and

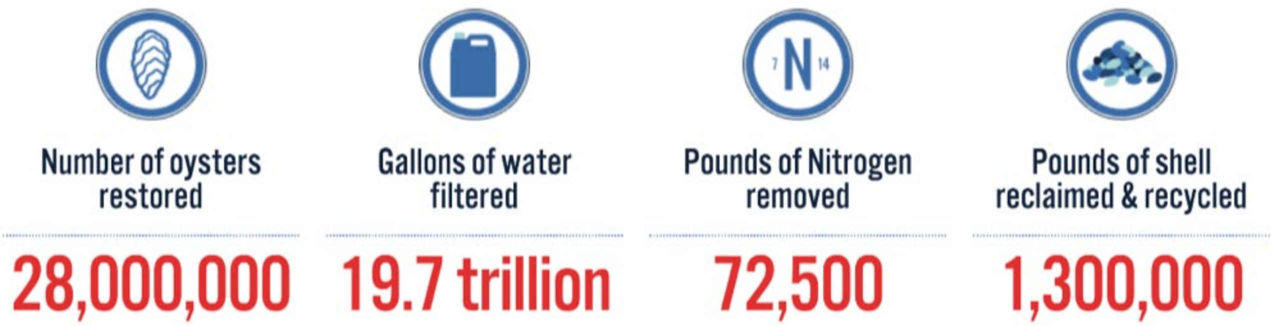

Figure 11 Infographic: The Billion Oyster Project 2010 – 2018 impact
Source: https://billionoysterproject.org/about/our-story/

[20] https://www.riverkeeper.org/water-quality/testing/
[21] https://billionoysterproject.org/

manage, wider issues on the health of our coastal waters in addition to bathing and shellfish waters. The "Blue Planet" effect has demonstrated that social support for clean seas is much more widespread than only in vocal third sector organisations such as Surfers Against Sewage[22] and the Marine Conservation Society[23]. Use of native oysters as part of the pollution solution would gain citizen support based on their social values.

Use of marine filter feeders, including oysters, as a pollution mitigation mechanism would require a change in regulations for the introduction – or re-introduction – of oysters or other shellfish. Currently, as with DEEP, the regulatory system is focussed on shellfish farming – where shellfish are assumed to be produced for human consumption. The Shellfish Directive requires that water quality meet specific standards, particularly in relation to bacteria carried by faecal matter. As with other aspects of the value of oysters as an ecosystem benefit, DEEP is working with SEPA and other regulators to address this issue.

5.3 Towards Zero Waste: Scotch Whisky industry reusing co-products in circular economies

The whisky industry is working in partnership with regulators including SEPA to demonstrate "beyond compliance" approaches, setting environmental targets in its Scotch Whisky Environmental Strategy. The industry continues to invest in a range of methods for managing and re-using co-products.

Whisky co-products have several advantages in the design of circular economies. Distilleries are single point waste producers; generate a consistent output from a single production process; and the liquid wastes contain relatively simple and substantially organic wastes which due to their copper content are classified as urban wastewater and therefore regulated. The industry is highly profitable, has a culture of a decades-long view on investments and returns, and has brand value in Corporate Social Responsibility and improving environmental and social performance. The industry has the financial resilience to support long-term investments; half of Scottish malt and grain whisky distilleries are owned by two multinational corporations, Diageo and Pernod Ricard; a further three companies make up the next 20%, William Grant and Sons, the Edrington Group, and Bacardi (Whisky Invest Direct, 2019).

The other key aspect of whisky industry investment is that brand value is central to its business model. Glenmorangie have demonstrated enhancement of brand value through recognising the wider value of oysters as an ecosystem.

While Glenmorangie's investment in the AD plant is of significant environmental benefit in reducing fossil-fuel energy use, it has a much narrower social appeal and therefore much lower brand value. Bioengineering provides a far more appealing story than grey infrastructure.

There is considerable potential for the industry more generally to adopt such an approach. The sector study from Zero Waste Scotland (Zero Waste Scotland, 2016) identified underutilised value streams for the industry, with over 2 million tonnes being disposed of to sea and land, and 684,000 tonnes being used as animal feed. Outflows and uses were summarized in Figure 13 below.

The industry's focus on Corporate Social Responsibility and public reporting of impacts allows insight into their performance and demonstrates how the industry is implementing innovative and effective solutions to address issues of energy usage, resource use, and waste. For example, Diageo, the world's second largest distiller and the largest Scotch whisky producer, operates 28 whisky distilleries in Scotland and has made a commitment to send zero waste to landfill by 2020. The company does not have published targets for going "beyond compliance" in tonnes of BOD emitted to the oceans. Diageo reported (Diageo, 2018) that worldwide in 2018 it produced 17.8 million m^3 of wastewater, containing 23,584 tonnes of Biological Oxygen Demand; that almost 100% of this was created in Europe and Turkey; and that 99.7% of this BOD was discharged under permit into the sea[22].

Diageo is considering an investment in an anaerobic digestion plant in partnership with other distilleries to re-use whisky co-product on Islay, helping reduce carbon footprint and reduce BOD output from current licensed outfalls.

[22] Coastal distilleries in Scotland have historically discharged waste into coastal waters, and are now regulated and monitored by SEPA under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR) arising from the European Water Framework Directive to discharge pot ale and spent lees out into coastal waters. The discharge levels enforced through CARs are based on the principle of dilution of the initial discharge plume by outfall into fast-moving waters, supported by work carried out by SEPA in Loch Harport in 1999/2000.

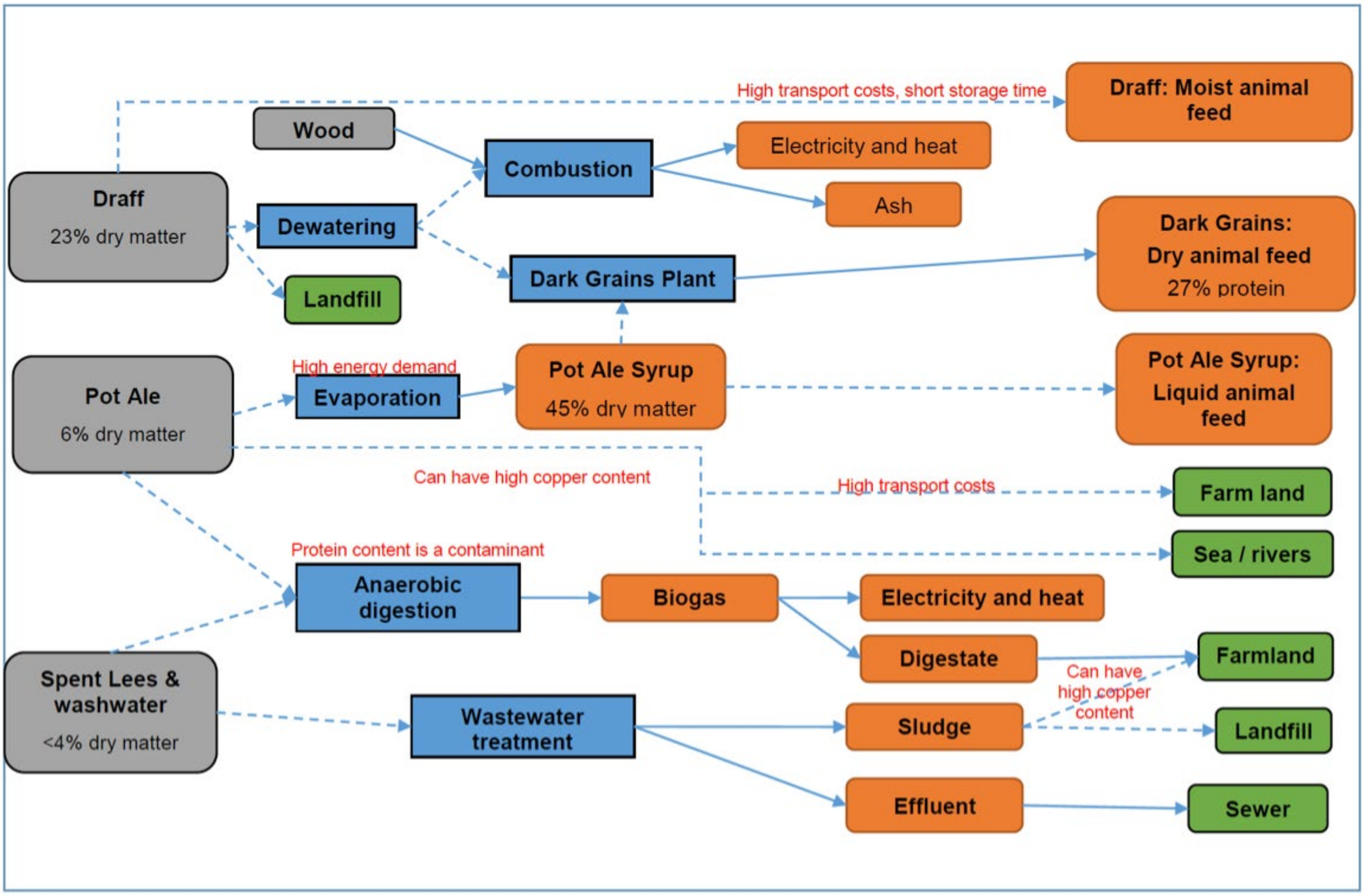

Figure 13 Current uses for Whisky By-products in Scotland. Source: (Zero Waste Scotland, 2016)

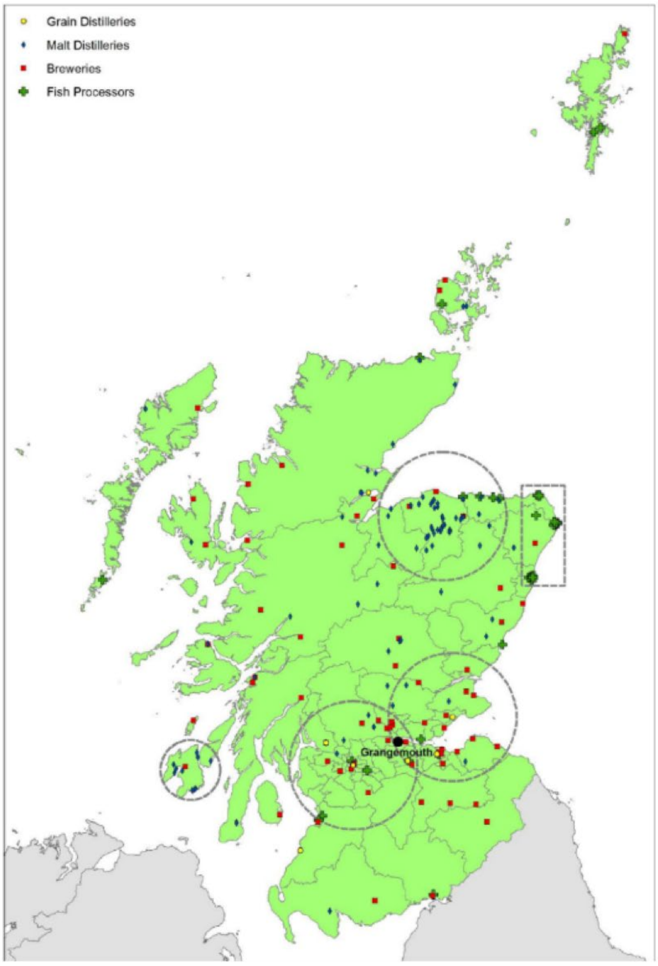

Figure 14 "Hotspots" for resource recovery in the Beer, Whisky and Fish industries. Source: Zero Waste Scotland (2016)

The 8 whisky distilleries on Islay, owned by 6 different companies[23] produce around 16 million litres of whisky annually (Duguid, 2015), which is approximately 10% of the total Scottish whisky output of 160 million litres (Zero Waste Scotland, 2016) – and therefore produces approximately 10% of the total industry output of 1.6 billion litres of pot ale (Zero Waste Scotland, 2016), much of which is currently discharged to sea under license[24]. Islay is one of the potential "hotspots" identified in the Zero Waste Scotland Study on Beer, Whisky and Fish (Zero Waste Scotland, 2016) which proposed as an action, detailed bioresource mapping for specific wastes and by-products. The Zero Waste Scotland (2016) report set out the map of hotspots for these sectors, positing these areas as a basis for further investigation (Figure 14)

The coastal hotspots on the Moray Firth, the Firth of Forth, and the West Coast align to areas known historically to have supported large oyster populations (Figure 1; (Mazik, 2015)).

The DEEP approach of using native oysters for bio-engineering is not currently perceived as a "resource recovery" in the terms of a Zero Waste Circular Economy. The studies discussed above demonstrate that oyster aquaculture and particularly oyster reefs elsewhere have been shown to have an economic value based not only on provisioning (food) benefits, but also on regulatory

[23] Beam Suntory, Diageo, Distell, Kilchoman Distillery Co. Ltd, LVMH, Rémy Cointreau
[24] Bruichladdich installed an AD plant in 2011 which removed 95% of the BOD and copper from its liquid waste streams, generating heat and FITs and ending its previous practice of tankering spent lees and pot ale to outfalls. This rerouted energy to heat water and to heat its visitor centre, bottling hall and meeting rooms. It now plans to use the energy to malt barley on-site rather than sending it to Inverness.

(waste management) benefits, cultural and social benefits. Recognising these benefits within a circular economy model would require a broader view of such models than the current emphasis on re-extraction of resources for human re-use. The development of a full economic value for ecosystem services would help recognise bio engineering as part of the circular economy.

5.4 Summary: Benefits of the DEEP approach to the Hydro Nation Strategy

Wider applications of the DEEP approach to pollution reduction and clean water may benefit the Scottish Government's Hydro Nation Strategy and Scottish Environment Protection Agency's (SEPA) One Planet Prosperity ambitions, delivering a value-added and cost- effective addition to existing methods based on the ecosystem value of native oysters for regulation and for cultural benefits.

Table 7. Summary: Benefits of native oyster restoration to water quality management
Native oyster restoration delivers significant economic value through ecosystem benefits, with a role demonstrated world-wide as:
- A measurable method for addressing non-point eutrophic and waste-water pollution, accepted by water quality regulators – "regulatory services" - An iconic keystone species with implied ecosystem, cultural and social benefits, levering in corporate social responsibility and impact investments - setting it apart from other shellfish species used for water quality purposes
Recognition of the economic regulatory value and ecosystem value in oyster restoration would enable:
- Achievement of Water Quality and River Basin Management goals through pollution management in the water body rather than on land; - Cost reduction for non-point pollution and wastewater treatment; - Use of oysters for bioengineering in waste recovery as part of the Circular Economy - Opportunities to engage citizens and communities in recognising the value of clean coastal water, hence assisting compliance e.g. through Regional Marine Plans and investment e.g. through impact investment

These benefits have been realised in large water body volume case studies in the USA and in pilot studies in the Baltic Sea. To achieve these benefits, there requires to be closer policy integration and working between government agencies and delivery bodies to develop a collective policy approach for integrating ecosystem benefits and their multiple values into Hydro Nation, Circular Economy, and Zero Waste strategies and applications. This would include the development of a regulatory framework for oysters and other shellfish as non-food bioengineers, rather than the current regulatory approach based on the food provision of oysters.

The application of this approach to particular waste recovery or pollution management issues will depend on the cost-benefit approach to each locality. This will require detailed locality modelling of potential take-up of nitrogen, phosphorus, and faecal indicator organisms, pesticides and sediments in catchment basins. The extent to which the approach is "worth" the investment in native oyster restoration depends on the benefits to the range of involved and investing stakeholders requiring a locality ecosystem valuation of the provisioning, regulatory, and cultural / social values of the native oyster including cost avoidance. Matching the costs of the investment to the wider ecosystem benefits from it will require development of impact investment or other trading or compensatory models.

The benefit of using native oysters for resolving the "wicked problem" of waste management and recovery is that it provides a single solution with evidenced multiple benefits. As in Chesapeake Bay, oysters become both the result of ecosystem recovery, supported by a wide range of stakeholders; and part of the contribution to that recovery.

[28] Beam Suntory, Diageo, Distell, Kilchoman Distillery Co. Ltd, LVMH, Rémy Cointreau

[29] Bruichladdich installed an AD plant in 2011 which removed 95% of the BOD and copper from its liquid waste streams, generating heat and FITs and ending its previous practice of tankering spent lees and pot ale to outfalls. This rerouted energy to heat water and to heat its visitor centre, bottling hall and meeting rooms. It now plans to use the energy to malt barley on-site rather than sending it to Inverness.

6 Summary

Native oyster beds (*Ostrea edulis*) are one of the most endangered marine habitats in Europe, with associated population losses of over 95%, mainly due to overfishing in the 19th and early 20th century. The loss of this keystone species has also meant a loss of oyster reef habitat for other shell and fin fish, and a loss of key ecosystem services for filtration and sequestration of pollutants. Difficulties and costs of native oyster aquaculture means that for the last 30 years, commercial oyster aquaculture in the UK has focused on the faster-growing non-native Pacific oyster (*Crassostrea gigas*).

The DEEP project plans to restore 40 hectares of native oyster reef off the shore at Dornoch, to provide a bioengineering solution to the last 5% of biological oxygen demand pollutants from the Glenmorangie Distillery at Tain. The DEEP project plans to spend £1.5 million on sourcing native oysters, and this spend has already helped to overcome both known challenges to aquaculture of native oysters and identified barriers to setting up a shellfish supply chain. The process so far has already created measurable economic benefits including safeguarding three SMEs by providing additional markets for their product and assisting in access to new supply chains thus helping protect 11 existing jobs in economically fragile areas; enabling these three SMEs to develop expansion plans for increasing production and investment; and assisting in the development of a Scottish multi-species hatchery; and providing four knowledge transfer and partnership working with SMEs.

The supply chain created for DEEP has the USP of producing disease-free native oysters in high quality shellfish waters under the Scottish "brand". The Scottish supply chain has a current advantage in that its on-growing production are ahead of almost all European production. This creates an immediate potential to supply both into the growing European restoration market and also into an existing, but currently very small, world-wide market for native oysters. Supply chain capacity increases to meet the restoration market would help provide working capital funding to reach existing markets for high-quality shellfish with a Scottish provenance, particularly in the Middle East and Asia. The DEEP research being undertaken is supporting innovative methods in this supply chain to increase efficiency and productivity, reducing cost and increasing production levels. The supply chain thus created could enable economic activity from native oyster cultivation to equal the current Scottish levels for Pacific Oysters within 5 years, adding 5% growth to the overall Scottish aquaculture sector and helping deliver Ambition 2030. This has the potential to create up to 50 FTE jobs and £3.5m gross value added. These jobs would be in the most fragile rural communities, helping sustain some of the most economically marginal areas of the Western and Northern Highlands and Islands, bringing not only economic but social value to areas depopulated by migration and struggling with an aging demographic.

The DEEP project has added to the evidence for the UK cultural and social value of native oysters; the history of native oyster fisheries and the role of the native oyster in the ecosystem have been marketed to appeal to wide audience, resonating with developing social values on the environment, community, and the sea. These social and cultural values do not attach to blue mussels, horse mussels, or Pacific Oysters which do not combine production values, ecosystem services, and rarity / extirpation-related social values. Native oysters are an iconic species for restoration of coastal waters. The use of oysters' cultural values to drive ecosystem restoration and increased production – and to attract social capital - has been well demonstrated for over a decade in the Chesapeake Bay Programme in the USA where oyster restoration has driven improved water quality management across 800,000 hectares of water fed by a 65,000 hectares catchment, in a multi-stakeholder partnership, resulting in measurable production, restoration and social economic benefits which exceeded restoration costs annually by a factor of 2 ($15 billion net surplus annually).

Native oyster restoration projects across the UK and Europe emphasise social value as a significant part of the incentive for restoration, attracting millions in corporate and social funding – such as the Blue Marine Foundation's investment in the Solent Native Oyster Restoration Initiative. These projects include the use of oyster reefs for bioengineering in windfarms, and have an estimated demand for 40 – 50 million native oysters with a total project investment value, including research, of between €50 - €60 million over the next 3 years. The Scottish supply chain currently is in advance of all other EU supply chains to deliver disease-free native oysters from regulated waters and managed stock to that restoration market.

The original driver for DEEP, the bioengineering functions of native oysters in extracting pollutants, particularly those implicated in non-point pollution, have been studied extensively. These ecosystem models have been applied to non-point pollution management in Chesapeake Bay, enabling oyster aquaculture and reef restoration to become recognised as a "best practice method" for reducing pollution in the marine environment by the regulating body. This is a cost-effective addition to measures being taken on land and helps address the risk of non-compliance in landowners and managers. Similar approaches were trialled in the Baltic Sea; in those cases, the ecosystem modelling was accepted as part of measures to attain companies with EU water quality directives.

This paper considered these wider applications of the DEEP approach for delivery of Scottish Government key objectives. Scottish Government has set out the Hydro Nation Strategy for Scotland with accompanying legislation which required Ministers to manage the economic, social and environmental value of Scotland's waters. SEPA is contributing to this through its "One Planet Prosperity" strategy, aiming to move regulated bodes beyond compliance. Its two key challenges to Scotland's water quality, including its coastal waters, are rural diffuse pollution and waste-water treatment discharges. Many of the priority catchments for rural diffuse pollution drain into coastal waters which were historically native oyster fishing areas; the Chesapeake Bay Programme has provided extensive evidence of the use of oysters to mitigate run-off pollution. For waste-water treatment, oysters are being used in the Hudson Bay Billion Oyster Project in the USA to help clean this highly-polluted and massive estuarine system, demonstrating that oysters can survive and reproduce in such conditions and provide an effective bioengineering filtration service.

For this approach to be applied in Scotland, investment in native oyster restoration for bioengineering must meet with Scottish Water's criteria for investment. Scottish Water is required by its regulator, The Water Industry Commission for Scotland, to innovate to ensure cost-effective delivery of a sustainable service. The previous 6 years' investment included almost £300 million on waste-water treatment and this amount is unlikely to reduce for the 6-year plan 2021-2027. CREW have recommended investment in AD plants as a key method for cost-effective resource recovery from waste-water. Bioengineering could, as with DEEP, provide a modelled treatment both for the "last 5%" and also provide a rapid response management tool for one-off effluent discharges which otherwise require a significant grey infrastructure investment.

As European grants for terrestrial management of rural pollution will change after Brexit, and as water infrastructure costs continue to rise, bioengineering could provide significant cost savings benefit and deliver wider ecosystems services including social and cultural values. Ecosystems models would be required to demonstrate how the treatment would meet the required standard; these models would have to be accepted by the SEPA and other regulatory bodies. This modelling would be locality-dependent and would have to consider the benefits and costs of conventional and bioengineering for that locality against the potential pollution load, together with the habitat requirement of the shellfish. The advantage of the native oyster for this use compared to e.g blue mussels is in terms of the latter's reef-building habits and the resulting potential for greater nitrification and denitrification from a self-sustaining, three dimensional oyster reef which can be established on a wider range of habitat than e.g. blue mussels.

The Scottish Government is driving forward policies on the Circular Economy, through Zero Waste Scotland. For the whisky and beer sector, ZWS have focussed on resource re-use with a direct provisioning value, such as re-use of organic matter for fertiliser and for energy and is promoting research into other innovative resource extraction. The use of bioengineering to restore natural habitats could also be considered in circular economy models where it delivers demonstrable impacts for wider ecosystem provisioning, regulatory and social benefits. These impacts will encourage investment from non-traditional finance, for example Corporate Social Responsibility and Impact investment funds, quantifying the social value of these ecosystems and monetizing that value into native oyster restoration.

Actions identified in this Report which are required to achieve these benefits are set out below.

Creating native oyster aquaculture capacity to supply European-wide restoration markets

- Regulatory change to permit DEEP to continue to expand restoration of native oysters for non-aquaculture purposes
- Continuing support for research into efficient and effective hatchery and on-growing techniques
- Capital and set-up investment in native oyster aquaculture
- Completion of existing government agency actions to simplify regulations for new shellfish aquaculture sites
- Continuing enforcement and awareness-raising of disease and non-native species exclusion from Scottish waters and specifically potential oyster restoration / aquaculture sites

Supporting native oyster aquaculture capacity to supply world-wide Scottish Shellfish markets

- Industry collective action for branding, marketing and selling
- Support for branding and marketing of native oysters into Asian and Middle Eastern markets as part of Ambition 2030
- Continuing dialogue on the standards for Scottish Shellfish Waters and their monitoring and protection
- Access to working capital support for native oyster aquaculture

Use of native oysters for Bioengineering in Water Quality Management

- Closer policy integration and working between government agencies and delivery bodies to develop a collective policy approach for integrating ecosystem benefits and their multiple values into Hydro Nation, Circular Economy, and Zero Waste strategies and applications
- Development of a regulatory framework for oysters and other shellfish as non-food bioengineers
- Detailed locality modelling of potential take-up of nitrogen, phosphorus, and faecal indicator organisms, pesticides and sediments in catchment basins
- Locality ecosystem valuation of the provisioning, regulatory, and cultural / social values of the native oyster including cost avoidance
- Development of impact investment or other trading or compensatory models to match costs and ecosystem benefits

7 References

Adamson, E. S. (2018). *Shellfish Seed Supply for Aquaculture in the UK: Report on Views Collected from the Industry in 2017.* London: The Fishmongers' Company.

Austen, M. C.,et al. (2019). *Valuing Marine Ecosystems - Taking into account the value of ecosystem benefits in the Blue Economy,.* Ostend, Belgium: Future Science Brief 5 of the European Marine Board.

Beaumont, A., Garcia, M., Honig, S., & Low, P. (2006). Genetics of Scottish populations of native oyster Ostrea edulis, human intervention and conservation. *Aquatic living Resources*, pp. 389-402.

Briceno, T. K. (2014, March). Ecosystem Valuation Toolkit: Custom Data Pull for the Chesapeake Bay Region. *Earth Economics 18.*

Bricker, S. B. (2018). The Role of shellfish aquaculture in reduction of eutrophication in an urban estuary. *Environmental Science and Technology 52(1), 173-183*, p. https://doi.org/10.1021/acs.est.7b03970.

Bruce, D. (2018). *A Summary of Chesapeake Bay Ecosystem Services*. Retrieved from Chesapeake Bay: https://www. chesapeakebay.net/channel_files/25674/8_2017_fish_git_-david_bruce_-_assessing_ecosystem_services_provided_by_ chesapeake_bay_oyster_restoration_12152017.pdf

Chesapeake Bay Foundation. (2014). *The Economic Benefits of Cleaning Up the Chesapeake: Implementing the Chesapeake Clean Water Blueprint.*

Chesapeake Bay Foundation. (2014). *What Guides Us*. Retrieved from Chesapeake Bay: https://www. chesapeakebay.net/what/ what_guides_us/watershed_agreement

Cottier-Cook, E., M. D., Giesler, R., Graham, J., Mogg, A., Sayer, M., & Matejusova, I. (2019). Biosecurity implications of the highly invasive carpet sea-squirt Didemnum vexillum Kott, 2002 for a protected area of global significance. *Management of Biological Invasions Volume 10, Issue 2*, pp. 311-323

Crown Estate. (2015). *Shellfish Site Leases - Rent Review.* Crown Estate.

Diageo. (2018). *Sustainability & Responsibility Performance Addendum to the Annual Report 2018.* Retrieved from Diageo: https://www.diageo.com/PR1346/aws/media/7452/diageo_sr_2018_final_final.pdf

Dionisi, D., Geris, J., & Bolaji, I. (2017, CRW2017-17). *Water and the circular economy -where is the greatest sustainable economic benefit for waste recovery in the water cycle?* Retrieved from CREW: www.crew. ac.uk/publications.

Duguid. (2015). *Sustainable Energy using Anaerobic Digestion of By-Products: Islay Whisky Industry Case Study, Unpublished MSc Thesis.* University of Strathclyde Department of Engineering .

Environmental Protection Agency. (2010, December). *Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment.* Retrieved from https://www.epa.gov/sites/production/files/2014-12/ documents/cbay_final_tmdl_exec_ sum_section_1_through_3_final_0.pdf

EPA. (2018). *EPA Oversight of Watershed Implementation Plans (WIPs) and Milestones in the Chesapeake Bay Watershed.* Retrieved from EPA: https://www.epa.gov/chesapeake-bay-tmdl/epa-oversight-watershed-implementation-plans-wips- and-milestones-chesapeake-bay

FAO. (2009). *Cultured Aquatic Species Fact Sheets - Ostrea edulis.* Retrieved from FAO: http://www.fao.org/ tempref/FI/ DOCUMENT/aquaculture/CulturedSpecies/file/en/en_europeanflatoyster.htm

FAO. (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals.* Rome: FAO.

Farinas-Franco, J., et al., (2018). Missing native oyster (Ostrea edulis L.) beds in a European Marine Protected Area: Should there be widespread restorative management? *Biological Conservation 231*, pp. 293-311.

GB Non Native Species Secretariat. (2019, June). *Slipper Limpet*. Retrieved from www.nonnativespecies.org.

GB Non-Native Species Secretariat. (2019, 6). *Pacific oyster*. Retrieved from www.nonnativespecies.org: http:// www. nonnativespecies.org/factsheet/factsheet.cfm?speciesId=1013

Glenmorangie Company. (2019). *About Us: DEEP.* Retrieved from www.theglenmorangiecompany.com.

GN Non-Native Species Secretariat. (2019, June). *Sargassam muticum*. Retrieved from www.nonnativespecies.org.

Green Infrastructure Valuation Network. (2011). *Green Infrastructure Valuation Toolkit.* Retrieved from Ecosystems Knowledge: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val

Hasler B, S. J.-W. (2014). *Regional cost-effectiveness in transboundary water quality management for the North Sea.* Retrieved from Research Gate: https://www.researchgate.net/publication/262196604_Hydro-economic_modelling_of_cost- effective_transboundary_water_quality_management_in_the_Baltic_Sea

Héral M., A. C.-P. (1989). Effect of organotin compounds (TBT) used in antifouling paints on cultured marine molluscs. A littérature study. In b. N. Edit, *Aquaculture. A biotechnology in progress* (pp. 1081-1089). Bredene: European Aquaculture Society.

Holley J.R., M. K. (2018). Troubled waters: Risk perception and the case of oyster restoration in the closed waters of the Hudson-Raritan Estuary. *Marine Policy 91 pp104-112*, https://doi.org/10.1016/j.marpol.2018.01.024.

Imani Development. (2014). *An Assessment of the Benefits to Scotland of Aquaculture.* Retrieved from Scottish Government: https://www2.gov.scot/Topics/marine/Publications/publicationslatest/farmedfish/AqBenefits

Kamerman, P. B. (2018). Offshore Wind Farms as Potential Locations for Flat Oyster (Ostrea edulis) Restoration in the Dutch North Sea. *Sustainability 10*, www.mdpi.com/journal/sustainability.

Kaspar, H. (2014). *A multi-species shellfish hatchery as a key asset for the development of Scotland's shellfish aquaculture industry and the restoration of native oyster reefs*. Retrieved from MASTS : https://www.masts.ac.uk/media/35906/ henry-kaspar-tce-fellowship-report-shellfish-hatchery-assessment.pdf

Kellogg, M. B. (2018). *An updated model for estimating the TMDL related benefits of oyster reef restoration.* Retrieved from Conservation Gateway:https://www.conservationgateway.org/Documents/Harris_Creek_Model_and_Oyster_Reef_ Restoration_Benefits.pdf

Kellogg, M. S. (2014, December). Use of oysters to mitigate eutrophication in coastal waters. *Estuarine, Coastal and Shelf Science*, pp. 156-168.

Knoche, S. I. (2018). *Estimating Ecological Benefits and Socio-Economic Impacts from Oyster Reef Restoration in the Choptank River Complex, Chesapeake Bay.* Morgan State University.

Laing, I. S. (2006). *Bivalve cultivation: criteria for selecting a site.* http://www.cefas.co.uk/publications/techrep/techrep136. pdf: CEFAS Technical Report 136.

Laing, I., Walker, P., & Areal, F. (2005). *A feasibility study of native oyster (Ostrea edulis) stock regeneration in the United Kingdom.* CARD Project FC1016: CEFAS.

Loxton, J. W. (2017, August). Distribution of the invasive bryozoan Schizoporella japonica in Great Britain and Ireland and a review of its European distribution. *Biological Invasions, 19, 8*, pp. 2225–2235.

Marine Scotland. (2017, October). Regulating and Several Order for Shellfish. Retrieved from National Marine Plan interactive. Marine Scotland Science. (2018). Scottish Shellfish Farm Production Survey . Scottish Government.

Maryland Oyster Restoration Interagency Workgroup. (2018). *2017 Maryland Oyster Restoration Update.* Retrieved from Chesapeake Bay Programme: https://chesapeakebay.noaa.gov/images/stories/pdf/2017marylandoysterimplementationupdate.pdf

Mazik, K. S. (2015). *A review of the recovery potential and influencing factors of relevance to the management of habitats and species within Marine Protected Areas around Scotland.* Scottish Natural Heritage Commissioned Report No. 771.

McFarland, K. H. (2018). Restoring oysters to urban estuaries: Redefining habitat quality for eastern oyster performance near New York City. *PLoS ONE 13(11):*, https://doi.org/10.1371/journal.pone.0207368.

Native Oyster Network UK & Ireland. (2019, June). *Restoration Project Partnerships*. Retrieved from Native Oyster Network UK & Ireland: https://nativeoysternetwork.org/restoration-projects-partnerships/

Native Oyster Restoration Alliance . (2019, June). *restoration-projects*. Retrieved from www.noraeurope.eu.

Natural England. (2013). *Commissioned Report NECR126 Green Infrastructure – Valuation Tools Assessment.* Retrieved from Natural England: http://publications.naturalengland.org.uk/publication/6264318517575680

New Zealand Institute of Economic Research. (2017). *The economic contribution of marine farming in the Thames-Coromandel District.* Aquaculture New Zealand.

Nova Scotia Fisheries Sector Council. (2005). *Economic Value of the Nova Scotia Ocean Sector.* Government of Canada.

OSPAR Commission. (2011). Report of the OSPAR / MFSD workshop on approaches to determining GES for biodiversity. *Biodivers. Ser. 56*.

Oyster Best Management Practice Expert Panel. (2016). —*Recommendations on the Oyster BMP Reduction Effectiveness Determination Decision Framework and Nitrogen and Phosphorus Assimilation in Oyster Tissue Reduction Effectiveness for Oyster Aquaculture Practices.* Retrieved from Oyster Recovery: https://oysterrecovery.org/wp- content/uploads/2017/01/Presentation_Oyster-BMP-Panel_1st-Report_WQGIT_Approval_12-19-16_Final_1.pdf

Oyster BMP Expert Panel. (2018). *Oyster BMP Expert Panel Update: Reduction Effectiveness Strategies of Oyster BMPs in Secnd Report.* Retrieved from Chesapeake Bay: https://www.chesapeakebay.net/channel_files/30431/cornwell_ oyster_bmp_panel_update_fisheries_git_draft.pdf

Petersen, J. H. (2019). Nutrient Extraction Through Bivalves. In J. H. Petersen, *Goods and Services of Marine Bivalves* (pp. 179- 208). DOI: 10.1007/978-3-319-96776-9_10.

Pogoda, B. (2019, January). Current Status of European Oyster Decline and Restoration in Germany. *Humanities 2019, 8, 9*.

Rabobank. (2018). *China's Changing Tides: Shifting Consumption and Trade Position of Chinese Seafood.* Rabobank.

Roem Hatchery. (2018). *Investigations*. Retrieved from Roem Hatchery: https://roemhatchery.nl/onderzoek/

Schultz-Zehden, A. S. (2019). *Baltic Blue Gowth Publications.* Retrieved from Submariner Network: https://www.submariner- network.eu/images/BalticBlueGrowth_Deliverables/wp3/BBG_GoA53_Ecosystem_services_20190423.pdf

Scotch Whisky Association. (2018, April). *2018 Environmental Strategy Report*. Retrieved from scotchwhisky.org.uk: https:// www.scotch-whisky.org.uk/media/1294/final_2018_environmental_strategy_report.pdf

Scotland Food & Drink Partnership. (2016). *Aquaculture Growth to 2030: A Strategic Plan for farming Scotland's seas.* Scotland Food & Drink .

Scotland Food and Drink Partnership. (2017). *Ambition 2030: a growth strategy for farming, fishing, food and drink.*

Scottish Aquaculture Research Forum . (2014). *Overcoming Bottlenecks in the Intensive Commercial Production of Native oyster (Ostrea Edulis) spat.* February.

Scottish Environment Protection Agency. (2014). *One Planet Prosperity - Our Regulatory Strategy.* SEPA.

Scottish Environment Protection Agency. (2018). *Scotch Whisky Sector Plan.* Retrieved from SEPA: https://sectors.sepa.org.uk/ scotch-whisky-sector-plan/

Scottish Environment Protection Agency. (2019). *Water supply and waste water Sector Plan.* Retrieved from SEPA: https:// sectors.sepa.org.uk/water-supply-and-waste-water-sector-plan/

Scottish Government . (2015). *The river basin management plan for the Scotland river basin district 2015 – 2027.* Retrieved from SEPA: https://www.sepa.org.uk/media/163445/the-river-basin-management-plan-for-the-scotland-river-basin- district-2015-2027.pdf

Scottish Government. (2012). *Scotland The Hydro Nation: Propectus and Proposals for Legislation* . Retrieved from Hydro Nation : https://www.hydronationscholars.scot/documents/Hydro_Nation_Prospectus.pdf

Scottish Government. (2015). *Rural Diffuse Pollution Plan for Scotland (2015-2021).* Scotttish Government

Scottish Government. (2016). *Making Things Last - A Circular Economy Strategy for Scotland.* Scottish Government.

Scottish Government. (2019). *A Trading Nation - a plan for growing Scotland's exports.* The Scottish Government.

Scottish Government. (2019, June). *Food and drink*. Retrieved from Trading nation: https://tradingnation.mygov.scot/sectors/ food-and-drink/

Scottish Government. (2019, June). *guidance/report-serious-fish-or-shellfish-diseases*. Retrieved from https://www.gov.uk/.

Scottish Government. (2019, June). *Topics: Marine and Fisheries: Aquaaculture: Fishfarm Consents*. Retrieved from Scottish Government: https://www2.gov.scot/Topics/marine/Fish-Shellfish/18716/ICR-Table?refresh=0.018792055462430235

Scottish Parliament Debates. (2001, May 2). Retrieved from www.theyworkforyou.com.

Scottish Water. (2015). *Business Plan: Delivery Plan 2015 - 2021.* Retrieved from Scottish Water: https://www.scottishwater. co.uk/en/Help%20and%20Resources/Document%20Hub/Key%20Publications/Delivery%20and%20Business%20 Plans

Seafish. (2017). *The World is your Oyster: Attracting young people to the seafood sector.*

Seafish. (2019). *UK export trade and markets for selected shellfish species 2017.* Seafish.

SeafoodSource. (2018, July 12). *Croatian flat oyster hatchery planned.* Retrieved from www.seafoodsource.com.

Swedish Environmental Protection Agency Report Series. (2010, October). *Report 6348 Baltic Survey - A survey study in the Baltic Sea countries on people´s attitudes and use of the sea.* Retrieved from Stockhold Resilience Centre, Stockholm University : https://www.stockholmresilience.org/research/research-programmes-and-projects/balticstern/publications/ balticstern-publications/2016-02-03-baltic-survey---a-survey-study-in-the-baltic-sea-countries-on-people%C2%B4s- attitudes-and-use-of-the-sea---report-on

The Source Magazine. (2017, November). *New-Energy*. Retrieved from The Source Magazine: https://www.thesourcemagazine. org/whisky-distillery-turns-co-products-renewable-energy/

University Marine Biological Station Millport. (2007). *Conservation of the Native Oyster Ostrea edulis in Scotland.* Scottish Natural Heritage Commissioned Report 251.

University of Dubrovnik. (2019). Retrieved from Unica Network EU: http://www.unica-network.eu/sites/default/files/Dr.%20 Jug-Dujakovic%20Mari-BIC%20aquaculture%20business%20center.pdf

Water Industry Commission for Scotland. (2018). *Strategic Review of Charges 2021-2027: 2018 Decision Paper 3: Investment planning and prioritisation.* Retrieved from www.watercommisson.co.uk.

Westbrook, S., & Development, I. (2017). *The Value of Aquaculture to Scotland.* HIE.

Whelan, C. S. (2015 , 227-238.). Why Birds Matter: From Economic Ornithology to Ecosystem Services. *Journal of Ornithology. 156*, p. https://www.researchgate.net/publication/274961065_Why_Birds_Matter_From_Economic_Ornithology_to_ Ecosystem_Services.

Whisky Invest Direct, sourced from: Ronde, Ingvar. Malt Whisky Yearbook 2019; Gray, Alan S. Scotch Whisky Industry Review 2018. (2019, June). *About Whisky*. Retrieved from Whisky Invest : https://www.whiskyinvestdirect.com/about-whisky/ malt-whisky-distilleries-in-scotland#

Zarnoch, C. H. (2014, Vol. 24, No. 2 pp 271-286). Effect of eastern oysters (Crassostrea virginica) on sediment carbon and nitrogen dynamics in an urban estuary. *Ecological Applications Vol 24, No. 2*, p. https://www.jstor.org/ stable/24432145.

Zero Waste Scotland. (2016). *Sector study on beer, whisky and fish.* Retrieved from Zero Waste Scotland: https://www. zerowastescotland.org.uk/BeerWhiskyFish

CREW Facilitation Team

Hydro Nation International Centre

James Hutton Institute

Craigiebuckler

Aberdeen AB15 8QH

Scotland UK

Tel: +44 (0)1224 395 395

Email: enquiries@crew.ac.uk

www.crew.ac.uk

CREW is a Scottish Government funded partnership between
the James Hutton Institute and Scottish Universities.