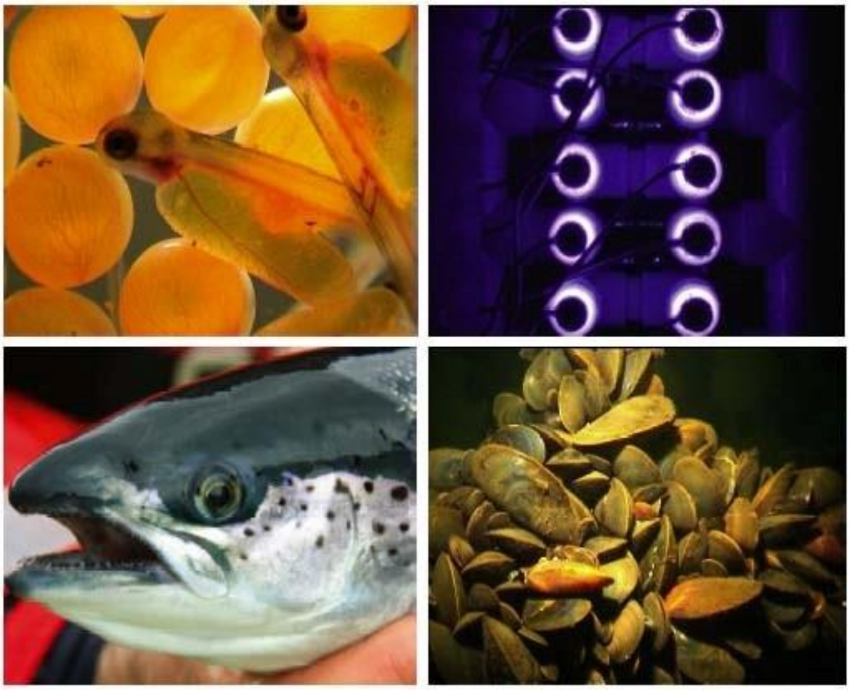
Scottish Aquaculture Research Forum

SARF096

New Approaches to Mussel Seedstock Acquisition



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NEW APPROACHES TO MUSSEL SEEDSTOCK ACQUISITION

Mussel seed on pegged dropper, Shetland (photo: authors)

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Table of Contents

List of Acronyms

AFBI	Agri-Food and Biosciences Institute
APB	Aquaculture Production Business
ASSG	Association of Scottish Shellfish Growers
BIM	Bord Iascaigh Mhara
CEC	Crown Estate Commissioners
DARD	Department of Agriculture & Rural Development
EC	European Commission
EMFF	European Maritime & Fisheries Fund
FAO	Food and Agriculture Organisation (of the United Nations)
FHI	Fish Health Inspectorate
FTE	Full time equivalent
INNS	Invasive & Non-Native Species
MLS	Minimum Landing Size
MSS	Marine Scotland Science
MZI	Mossel ZaadInvang installatie
NAFC	North Atlantic Fisheries College
NGO	Non-governmental organisation
NK2	Natura 2000
NWIFCA	North West Inshore Fisheries & Conservation Authority
PEI	Prince Edward Island
RTD	Research & Technology Development
SAC	Special Area of Conservation
SAGB	Shellfish Association of Great Britain
SAMS	Scottish Association for Marine Science
SARDI	South Australian Research and Development Institute
SARF	Scottish Aquaculture Research Forum
SEPA	Scottish Environment Protection Agency
SPA	Special Protection Area
TAC	Total Allowable Catch

Executive Summary

Introduction

The Scottish cultivated mussel sector has expanded considerably over the past decade, from 2000 tonnes in 2000 to 7,200 tonnes of marketable production in 2010. 2011 saw a minor decline to 7,000 tons with a further decline to 6,300 tonnes in 2012.

Production is distributed around the west coast mainland, the Western Isles and Shetland. Shetland is the dominant producing area with some 70% of production in 2012. The industry is socio-economically important providing both full-time and part-time employment, estimated at some 200 FTE's overall directly in production, with further jobs in up- and down-stream activities.

There are aspirations to grow the industry by 100% by 2020.

There is a perception that natural settlement of mussel spat is decreasing in recent years and this is having significant consequences for the rope growing industry in Scotland, which relies wholly on this source for seed stock. This is thought to be the main factor behind recent production declines.

In addition, some strategically important licensed production areas, such as Loch Etive, have been severely impacted by the occurrence of a damaging invasive species of mussel, *Mytilus trossulus*

Against this background, the Shellfish Forum felt it was desirable to undertake a thorough review of alternatives to current practices of relying on natural spatfall. SARF thus acted on requests to fund a study which reviewed the situation inside and outside Scotland and examined possible alternatives methods of seed acquisition, both conceptually and where possible through business cases.

The study objectives requested by SARF are thus as follows:

1. Global Review of literature on mussel seed supply
2. Assess status and trends of seed availability in Scotland
3. Propose novel approaches to seed supply in Scotland
4. Recommend preferred future approaches through business cases as appropriate.

The study was undertaken by Homarus Ltd, a niche advisory firm in fisheries, aquaculture and the marine environment, between May and November 2013, with oversight from a Steering Group drawn from a mix of aquaculture regulatory and industry interests.

International situation

At a global level the farmed mussel industry produced some 1.8 million tonnes of mussel in 2011. Almost all of this production relies on natural spatfall. Major producers (>100,000 tonnes per year) are China, Chile, Spain and New Zealand.

Variability in spatfall has resulted in production fluctuation and business uncertainty problems in many countries. In the majority, no measures are taken to overcome this and fluctuation is tolerated.

In some countries, various interventions are used to try to better understand mussel settlement patterns and to optimise use of the resource. These include, in order of sophistication

- Studies and surveys of mussel larvae and seed beds (Chile, Canada, USA, Netherlands, UK, Ireland)
- Use of dedicated spat collection sites (Chile, Canada, USA, Netherlands, UK, Ireland, France, New Zealand,)
- Novel collection devices (Netherlands, Norway)
- Controlled reproduction in hatcheries (Canada, USA, France, Netherlands, Australia, New Zealand)

In some countries there is significant disaggregation of the industry and trade between specialist spat suppliers and on-growers (Chile, Canada, Spain, New Zealand).

The availability, size and cost of spat is also intrinsically linked to the farmers' practices in grow-out. Where spat is collected at a very small stage and/ or it is deemed expensive, the part-grown crop is stripped and resocked at lower densities to gain better overall yields. Galicia (Spain) and New Zealand are particular examples of this.

The novel collectors (MZI) initiative in the Netherlands is driven by changing regulation. It appears to be meeting the demand of the industry in part, though with a significant cost and, in the short term at least, economics are confused by variable wild supplies.

The role of hatcheries appears niche at present. There are several examples of hatcheries being associated with public sector R&D activities (west coast USA, Canada, South Australia, New Zealand).

The BLUESEED (EC Framework 6) and REPOSEED (EC Framework 7) projects were undertaken from mid 2000's by a number of R&D and commercial partners across Europe and generally concluded that mussel production in hatcheries was technically possible but not economically viable.

There seem to be only 2-3 fully commercial hatcheries, two in west coast USA which are precursors for a relatively small production industry. There is one hatchery in Tasmania which appears to be providing for the needs of one on-growing business.

New Zealand have been undertaking R&D for some 15 years in to mussel hatchery techniques. There is no public domain data on economics of hatchery production. Joint research/commercial hatcheries are under development and the government has recently committed to further R&D for another seven years and value some £13m, along with industry partners. This appears to be a result of a deeply supportive government who see their mussel industry as a valuable component to New Zealand's strong primary production sector, coupled with some large, well-funded production companies who feel very exposed to reliance on a single and variable source of spat.

Status in Scotland

Two recent surveys, one by MSS and one within this study, confirm the general perception that natural spatfall is declining.

It appears to be at about 50% of optimal requirements overall in 2012, compared to about 80% in 2007. The position is considerably worse in Highland than Shetland and Western Isles, although there is also significant local scale variation. On this basis production could double and meet growth aspirations if spat supply were to become continually optimal.

Additional measures to combat shortage of supply have been undertaken by a minority of producers so far and include:

- Thinning and re-socking of their own seed
- Buying in seed
- Contracting with specialist seed sites

This third measure is also apparent from the MSS annual surveys with a growing number of sites dedicated to spat production, as is commonplace in some other countries.

Novel approaches to seed stock supply in Scotland

Regulatory backdrop

The regulatory framework in Scotland relating to new developments or adaptations to existing practices are divided into those which involve the physical nature of the farm and those which manage the impact on the environment.

Although onerous, neither group of legislative requirements rule out any of the possible novel approaches to seedstock acquisition considered within this study

Genetic backdrop

Mussels studied in various areas of Scotland differ from one another in terms of proportions of species and hybrids within the population.

Some of the possible solutions to seed supply discussed below may involve moving seed from one place to another, both short and long distance. Clearly long distance movement could potentially involve introduction of undesirable traits and particularly the invasive *M.trossulus*. It also goes against the Code of Good Practice followed by ASSG.

More investigations on genetic make-up of possible source seedstock should be undertaken and there is a possible route through which legislation could be applied.

Adaptations of existing practice

More information could be gained on the distribution of mussel larvae in time and space at several levels. This could be

- Monitoring undertaken by growers at the individual business level.
- Routine monitoring in all production areas by MSS or others as a service for industry, based on the Prince Edward Island model
- Dedicated scientific study on factors affecting mussel larval abundance and dispersal

Under-utilised sites could be brought into use as spat collection sites, should study prove them to be promising. Various mutual arrangements between growers would be possible to facilitate this potential and share risks of doing so.

Hand gathered seed

Hand gathered seed is the least capitally intensive way of providing for seed needs.

Within the wider UK where occasionally large 'ephemeral' beds of seed mussel can accumulate inside intertidal coastal areas, such as the Solway Firth, Morecambe Bay and the Burry Inlet.

Significant effort would be needed to secure permissions for exploitation and organise (usually local) labour to do the picking. Once collected, seed from such sources would need to be transported to the farmer's jetty, transhipped to work boats and then re-socked onto growing ropes.

Mussel seed beds

Large accumulations of mussel seed in the sub-tidal occur in various locations around England and Wales.

This study has not been able to firmly determine indications of seabed settlements within wider Scottish waters – the process of surveying potential settlement areas is not developed beyond the anecdotal as there has been little economic interest shown in any such resource to date.

Previous reviews have produced very little additional understanding beyond the settlements which are evident within the Dornoch and wider Moray Firth systems. Discussions with some North Irish based mussel companies suggest the possibility of some such areas off the Clyde and the wider Argyll coastline.

Gathering of mussels from the shoreline or seabed in Scottish waters has been considered as a right of *Regalia Minora* in that the Crown estate has expressed some management over the utilisation of any such fishery.

Should the sector wish to buy in seed mussel, there are a number of potential source locations to consider – including the Solway Firth, along the Argyll shoreline and Dornoch Firth in Scotland, with well understood and reasonably geographically close ephemeral intertidal and sub-tidal seed mussel beds known to occur along the Cumbrian and Lancashire Foreshore (Siloth, Beckford Flats, Morecambe Bay).

Exploitation needs specialist and expensive dredgers which would need to be purchased or contracted with. Transport and resocking would produce similar logistical challenges to those for inter-tidal seed.

Stand alone mussel collection sites

Globally there are two major families of spat collector deployed: the more established long line rope material which are strategically deployed in appropriate locations at appropriate times of year, and the more recent purpose built floating net systems, known as MZIs.

Rope systems

New sites dedicated for spat collection would be subject to the same Planning controls as regular ongrowing sites.

The Scottish industry already uses a variety of collector rope types, (conventional pegged rope, ladders, Spanish collector rope, New Zealand continuous loops). This technology could be applied on a larger and wider scale.

Logistics of moving / trading / resocking between spat collection and ongrowing sites would be moderate and easier than buying in and resocking spat from inter-tidal or sub-tidal areas.

MZI systems

These more recent systems have been developed in the Netherlands and various designs have been tested. Most now comprise of floating buoyancy pipe and tensioned netting hanging below as settling medium.

Many of the systems require very specific machinery to harvest off the seed, (such as seed brushing systems), which are often expensive.

MZIs would be new to Scotland, but the technology involved is not complex, (apart from possibly harvest machines). Floatation pipes are the same as those in common use for salmon farms and anchoring systems will also be similar to those currently used for mussel long lines. Visual impact is very low which may aid planning issues if potential sites are in sensitive locations.

As with stand-alone rope systems, potential locations for, and timing of, deployment of MZIs locations would ideally be guided by significantly better understanding of larval distribution.

Hatcheries

Hatchery production is an integral part of some species of bivalves. In the UK, (including Guernsey), there are four commercial hatcheries in operation, all principally involved in growing *C.gigas* for the UK and further afield. None, to date, have commercialised assets toward the production of mussel spat. This situation is mirrored across Europe.

Marine Scotland have expressed support for the development of an economically viable shellfish hatchery in Scotland. While strategically interesting, such a facility would require significant capital investment and need to be able to cover operating, capital servicing and depreciation costs when supplying a market that was variable, depending on natural spat fall available to growers.

Hatcheries have several potential advantages:

- more reliable seed supply
- possibility of bringing "all-season" mussels to the market
- Potential to produce sterile (3n) animals which will retain good meat condition all year

Likely costs of production extrapolated from a variety of sources are very high at present and are unlikely to be viable in spite of the advantages mentioned.

Economic aspects

Cost of each option for improving seed supply have been researched and presented.

They have been tested for viability at the unit weight level (cost per tonne harvested) and potential outcomes compared at the whole industry level.

Unit weight

Existing simple cost models suggest an approximate overall margin of some £200 per tonne

Buying in seed: £100 per tonne – viable

Dedicated collector sites: £100 per tonne – viable if sites located

MZIs: £150-200 per tonne – marginal, need trials and development

Hatchery £5,000 - £30,000 – non-viable

Whole industry

Simple costs models and industry feedback suggest the bounds within which tolerable costs of optimised seed supply lie is perhaps £300,000 to £600,000 per year, on an industry-wide basis.

Results from a survey of industry which included estimates of tolerable costs, provided a higher figure of £750,000, but based on a small sample

Outcomes of assumed expenditure of the total potentially tolerable costs of £600,000:

Buying in seed: 7,000 tonnes additional production

Dedicated collector sites: 6,000 tonnes additional production if sufficient sites located

MZIs: 4,000 tonnes additional production if sufficient sites located

Hatchery: 200 to 1,200 tonnes additional production, (estimate includes a 10-fold efficiency savings compared to R&D derived costs currently)

Benefits of improved larval monitoring and scientific research could be significant but are not quantifiable.

Next steps

The least cost / least risk business case for the industry appears to be to buy in seed, accepting the proviso that it is genetically and physiologically suitable and there was no significant risk in introducing unwanted pests.

This would at least buy time while further studies were carried out by both industry and research bodies to better understand spat settlement patterns and hopefully deploy rope collectors or MZIs in under-utilised sites or new dedicated spat collection sites with good characteristics.

The hatchery issue, whilst being strategically interesting for both the sector and the government, is troubled by questions of cost and wider viability. However, with new approaches and techniques becoming established, it could perhaps be re-visited in around 10 years' time and production technologies and costs reassessed.

These figures used to arrive at these conclusions are indicative only and are more use for comparing to each other than in prediction of absolute outcomes. There also have to be some significant "reality checks" to take account of the actual position of many businesses currently. These will significantly influence ability and likelihood of taking forward both the least costs / least risk option, as well as further apparently attractive options. Issues which need to be considered and addressed where possible are identified as:

- Business liquidity and viability
- Logistical issues with transporting and resocking
- Genetics and INNS
- Monitoring and research
- Collector sites and novel device development

1 Introduction

This report covers work undertaken on a study commissioned by the Scottish Aquaculture Research Forum (SARF) entitled: "NEW APPROACHES TO MUSSEL SEEDSTOCK ACQUISITION".

The study was undertaken by Homarus Ltd, a niche advisory firm in fisheries, aquaculture and the marine environment. It was managed by a Steering Group drawn from a mix of aquaculture regulatory and industry interests.

1.1 Study Background and Rationale

The Scottish cultivated mussel sector has expanded in size and production considerably over the past decade, from 2000 tonnes in 2000 to 7,200 tonnes of marketable production in 2010. 2011 saw a minor decline to 7,000 tons with a further decline to 6,300 tonnes in 2012[1].

Production is distributed around the west coast mainland, the Western Isles and Shetland. Shetland is the dominant producing area with some 70% of production in 2012. As with other forms of aquaculture, scale of production has been increasing. For example the proportion of mussel farming businesses producing over 100 tonnes per year has increased from 29% of the industry in 2007 to 38% in 2012. Mussel farming is a useful part-time and full-time employer within the production areas. No data is available for employment disaggregated by cultivated species. Using the MSS survey data there are some 249 FTE's involved in shellfish production in Scotland[2]. Assuming, very crudely, that employment growing any given species correlates directly with its first sales value, and using the value data in the 2012 MSS survey, employment in mussel farming is some 214 FTE's. In reality the mussel industry is likely to be more productive per person than oysters, so actual direct employment is perhaps 175 to 200 FTE's. Mussel farming also generates employment upstream in supply activities and downstream in processing, sales and distribution, mostly in Scotland but also within the wider UK.

One of the critical components in ensuring that this production is not only sustained but increases to meet the industry's aspiration for growth of 100% increase by 2020, a target supported by Scottish Government, is the development of more reliable access to mussel seed. This sits inside the overarching framework as described within a Fresh Start[3], for *"Scotland should have sustainable, growing, diverse, market-led and profitable farmed fish and shellfish industries, which promote best practice and provide significant economic and social benefits for their people, while respecting the marine and freshwater environment. The industries will contribute to the overall vision for Scotland's marine environment of "clean, healthy, safe, productive and biologically diverse seas managed to meet the long-term needs of nature and people".*

However recent years have seen a series, possibly developing trend, of less than optimal spat settlement on the conventional mussel seed collectors deployed across widespread areas utilised by

[1] Scottish Shellfish Farm Production Survey 2012 Report – Marine Scotland Science (May 2013) LA Munro, IS Wallace and AS Mayes. ISBN 978-1-78256-575-8 / ISSN 1363 - 5867
[2] Assumes 1 FTE = 2 part-time, or 4 casual employees
[3] A Fresh Start – the Renewed strategic framework for Scottish aquaculture. Scottish Government May 2009 ISBN 978 07559 8019 2

the Scottish aquaculture sector. This has been the subject of much concern and comment. Yet whilst there is no clear indication as to why the collection of spat from seed collector ropes over these years has been so disappointing, it is clear that without settlements of sufficient size occurring, in the absence of alternative sources of mussel seed, there will be an adverse impact on production of mussels in Scotland. This factor is believed to be a major contributor to the 10% decline in production seen between 2011 and 2012.

In combination with the partial failure of the spat collection, some strategically important licensed production areas, such as Loch Etive, have been severely impacted by the occurrence of a damaging invasive species of mussel, *Mytilus trossulus*[4]. This is the subject of SARF report 064. The consequences of the establishment of a population of *M trossulus* in Loch Etive have been severe, with all production in the area (which had been in excess of 1,000 tonnes per year) currently extinguished as remedial measures are applied to the Loch in an attempt to biologically eradicate the species ([5]).

Against this background, the Shellfish Forum felt it was desirable to undertake a thorough review of alternatives to current practices of relying on natural spatfall. SARF thus acted on requests to fund a study which reviewed the situation inside and outside Scotland and examined possible alternatives methods of seed acquisition, both conceptually and where possible through business cases.

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4. Recommend preferred future approaches through business cases as appropriate.

1.2 Study implementation and report structure

The study commenced in late April 2013 with a start-up Steering Group meeting in Edinburgh. A short progress report was produced in July with an update in September. The draft final report was completed in November 2013 and circulated to the Steering Group. This report is the final version.

The study team comprised of Patrick Franklin and James Wilson. Their brief profiles are as follows:

Patrick Franklin: Managing Director, Homarus Ltd. Senior and established consultant in the fisheries and aquaculture sector, works UK and internationally. Significant knowledge of the UK and Scottish aquaculture industry, its technologies, economics and research

[4]Matt Gubbins; *Mytilus trossulus* – managing the impact on sustainable mussel production in Scotland. SARF 064 Feb 2012

[5] Loch Etive integrated Coastal Zone Management plan – Argyll and Bute Council 2011 http://www.argyll-bute.gov.uk/lochetive

requirements. Long experience of assessing financial impacts of factors causing change to the aquaculture sector. Responsible for several studies on Scottish Fisheries and Aquaculture sectors in recent years for MSS and others including co-author of SARF 077 (algae in aqaufeeds).

James Wilson: Mon Mariculture Ltd. Highly experienced mussel mariculturist in the UK and Europe with background in marine science, fisheries management and law. Industry partner in past EU funded projects considering novel approaches to the provision of reliable sources of mussel seed. Long term collaborator with RTD's on matters associated with shellfish aquaculture and ecosystem interaction. Co-author of Bangor mussel producers and Countryside Council for Wales – Code of Good Practice for movement of seed mussels. Long term member of SAGB, UK aquaculture forum.

The study was predominantly desk-based and included literature searches and review, a detailed questionnaire on Scottish industry experiences and views on seedstock acquisition issues, as well as dialogue with international commercial and research organisations, MSS and other Scottish stakeholders.

The report is structured along the lines set out in the study brief. Section 2 is thus a wide ranging review of literature and experience regarding seed acquisition in other countries. Section 3 sets out recent experiences in Scotland, based on industry interaction, MSS surveys and a dedicated survey for this study. Section 4 discusses the potential for various new approaches, opening with a discussion of the regulatory and genetic backdrops to novel methods before discussing the main possible categories. Section 5 discusses the economics of possible new approaches, through industry's view on scope to absorb their costs as well as comparison to existing economic models. Section 6 brings together the main findings and conclusions.

The study refers to juvenile mussels as both "seed" and "spat" which are terms used interchangeably by industry and the scientific community. The term normally applies to small mussels from post-settlement up to c.20mm shell length, but can apply to any stock which is gathered or handled with the intention of further on-growing.

2 Literature Review and analysis

2.1 Introductory comments

Users of this report are likely to be reasonably familiar with mussel aquaculture both in the UK and further afield and so background explanation as to techniques and production areas will be limited.

This section thus attempts to review and analyse the mussel seed acquisition situation in leading production areas globally and focus in particular on strategies and techniques that might have application in Scotland. It is organised by main producer region and then drawn together to assess possibilities by the main technical options in use.

To act as a backdrop to discussion and guide the review, production statistics have been gained for the main mussel production areas in the world.

Table 1: Global farmed mussel production, 2011, by country and species, (excluding those countries where production<500 tonnes).

CONTINENT / country	Common Name	Scientific name	Output (tonnes)
AFRICA			
South Africa	Mediterranean mussel	*Mytilus galloprovincialis*	570
AMERICAS			
Brazil	South American rock mussel	*Perna perna*	15,970
Canada	Blue mussel	*Mytilus edulis*	25,509
Chile	Chilean mussel	*Mytilus chilensis*	288,583
Chile	Cholga mussel	*Aulacomya ater*	3,638
Chile	Choro mussel	*Choromytilus chorus*	825
United States of America	Blue mussel	*Mytilus edulis*	2,213
ASIA			
Cambodia	Green mussel	*Perna viridis*	1,200
China	Sea mussels nei	*Mytilidae*	707,401
India	Green mussel	*Perna viridis*	9,956
Korea, Republic of	Korean mussel	*Mytilus coruscus*	70,416
Malaysia	Green mussel	*Perna viridis*	2,625
Philippines	Green mussel	*Perna viridis*	22,443
Thailand	Green mussel	*Perna viridis*	84,665
EUROPE			
Albania	Mediterranean mussel	*Mytilus galloprovincialis*	1,300
Bulgaria	Mediterranean mussel	*Mytilus galloprovincialis*	642
Denmark	Blue mussel	*Mytilus edulis*	537
France	Blue mussel	*Mytilus edulis*	61,800
France	Mediterranean mussel	*Mytilus galloprovincialis*	15,000
Germany	Blue mussel	*Mytilus edulis*	20,830
Greece	Mediterranean mussel	*Mytilus galloprovincialis*	20,000
Ireland	Blue mussel	*Mytilus edulis*	22,671
Italy	Mediterranean mussel	*Mytilus galloprovincialis*	64,300
Netherlands	Blue mussel	*Mytilus edulis*	32,418
Norway	Blue mussel	*Mytilus edulis*	1,742
Spain	Sea mussels nei	*Mytilidae*	208,583
Sweden	Blue mussel	*Mytilus edulis*	1,470
United Kingdom	Blue mussel	*Mytilus edulis*	6,996
AUSTRALSIA			
Australia	Australian mussel	*Mytilus planulatus*	3,085
New Zealand	New Zealand mussel	*Perna canaliculus*	101,311

Source: FAO

It should be noted that FAO production statistics are not always fully reliable and depend on the (sometimes vague) arrangements for governments reporting their country's production to FAO. The figure for the UK is identical to that in the MSS survey for 2011. It appears that production in

England, Wales and Northern Ireland, which is almost entirely through on-bottom culture, has either been omitted or treated as fishery production and so reported separately.

The information available on seed acquisition is very varied and is drawn from the formal literature, also conference proceedings, student theses, workshops, project reports, governmental, industry, equipment and seed suppliers' websites. Two facets are worth noting:

- The volume of information available does not correlate with the production volume: very little information is available on seed supply in China, the world's largest producer, whereas there is reasonable information on USA and Canada, relatively modest producers. Even within Europe there is divergence. Spain is the largest producer with a large suspended culture industry mainly in Galicia, where seed supply is one of the lesser issues impacting on success of the industry and so has little coverage.

- Issues relating to seed acquisition are just one of many production issues facing growers and the associated scientific and regulatory community. As such information on seed supply often to be found within papers, reports etc. which cover a range of issues, not just seed supply. As a consequence sometimes coverage is rather light.

The study brief also calls for a review of new approaches to mussel seedstock acquisition. As such, and due to limited resource for the review, the team has tried to concentrate just on recent papers and publications, generally later than 2005.

2.2 Americas

2.2.1 North America: west coast

This is one of the few areas of the world where farming hatchery produced seed makes a significant contribution to mussel output. The native mussels are *Mytilus trossulus* although there is hybridisation with *Mytilus edulis,* and *galloprovincialis*[6]. Unreliable in quality and regularity of settlement, together with hatchery facilities for other bivalve species, have provided the opportunity for hatchery production of mussels, predominantly *M. galloprovincialis* according to producers websites[7], (although the FAO production summary at table 1 states M.edulis*).*

Production on the west coast is heavily focussed on Washington State and Puget Sound in particular. West USA mussel production in 2009 was said to be 3.06 million pounds live weight according to the Pacific Coast Shellfish Growers Association [8] (approx. 1,400 tonnes), worth $4.1 million (about £2.7m at current exchange rates). It is worth noting that mussel production is dwarfed by oyster production (33,000 tonnes) and clam production (4,600 tonnes).

[6] See, for example, Encyclopaedia of Life entries and distribution maps for Mytilidae at http://eol.org/pages/449961/overview
[7] See, for example, http://www.coastseafoods.com/mussels.html, http://www.taylorshellfishfarms.com/products-and-prices.aspx
[8] http://pcsga.net/wp-content/uploads/2011/02/production_stats.pdf

Information on commercial aspects is somewhat scant. There appear to be three hatchery seed suppliers, two of which offer mussel seed. Mussels appear to be a relatively minor interest to the hatcheries which focus primarily on oysters, also clam species. The price list given for Taylor Seafarms *M. galloprovincialis* is $17 per ft[9], for spat of some 1mm settled onto ropes. Taylors hatchery has been host to some trials to assess the potential of a partial algal replacement diet for mussel spat, produced by INVE of Belgium[10].

In western Canada the mussel industry is also at a small scale due to problems with the native *Mytilus trossulus.* Production is reliant on the single shellfish hatchery diverting efforts to produce *M. galloprovincialis*[11]. British Columbia Shellfish Growers Association describe some techniques for ongrowing hatchery seed. The basic approach is setting directly onto ropes for grow out. However systems are under development to settle spat on framed screens in dedicated suspended nursery sites. Once the seed is hardened they are transferred to fine mesh bags hung from longlines for about three months, after which they are socked and ongrown in conventional suspended culture. This source also quotes alternate methods used by Taylor Seafarms in Washington State, whereby seed are held in upwellers until 2-3mm and then placed on framed screens and hung in floating nursery rafts for 3-6 weeks after which the seed are striped off the frames, graded and socked for ongrowing.

Again little information is available on commercial aspects. The British Columbia Shellfish Growers Association website cites experiences in Washington State whereby a raft grower gained 18,000 pounds live weight from 10,000 feet of socked material. This seems rather meagre at a yield of some 2.5kg per metre. Assuming the Taylor Shellfish price for socked seed of $17 per foot, the seed cost on this basis would have been $170,000. The value of the harvest from data available at the Pacific Coast Shellfish Growers Association suggests a value of $1.34 per pound live weight, giving a crop value in this example of around $24,000. Even at the retail value quoted by the Taylors website of $4.25 per pound for cleaned graded packed product, the seed cost would not be covered. This is clearly uneconomic on the face of it. However what is not certain is the amount of thinning and restocking which may have taken place between stocking and harvest.

Mussel production is small in scale in British Columbia, official statistics showing just 300 tonnes in 2011[12].

2.2.2 North America: east coast

Eastern Canada produced 25,000 tonnes of mussels in 2011, over 20,000 tonnes of which were farmed in Prince Edward Island (PEI)[13]. In the USA, firm production statistics by state are not

[9] http://www.taylorshellfishfarms.com/products-and-prices.aspx
[10] http://www.thefreelibrary.com/Use+of+a+formulated+diet+for+mussel+spat+Mytilus+galloprovincialis...-a0168820710">Use of a formulated diet for mussel spat Mytilus galloprovincialis (Lamarck 1819) in a commercial hatchery.
[11] http://bcsga.ca/about/industry-encyclopedia/mussels/
[12] http://www.aquaculture.ca/files/documents/AquacultureStatistics2011.pdf
[13] http://www.aquaculture.ca/files/documents/AquacultureStatistics2011.pdf

available, however national output is given as c 1 million pounds (450 tonnes) by one source[14] and some 333 tonnes by another[15]for years 2010 and 2009 respectively. This is below the amount given for the USA west coast alone by the trade association there (see above), suggesting east coast USA production must be minimal. A further source suggests the state of Maine harvested 0.8m pounds (362 tonnes)[16].

The PEI industry uses predominantly suspended culture. The industry has been largely successful and had a rapid expansion phase to about 2000, after which production has been relatively stable, though trending up again in the last 2-3 years[17]. Seed supply and quality is a contributory factor that has slowed the industry's growth. The industry was said to need 9 million pounds (4,100 tonnes) tonnes of seed in 2004, giving a harvest weight: seed weight ratio of some 5:1. Seed is derived from a number of sources:

- Wild seed (assumed dredged or inter-tidally gathered)
- Dedicated spat collection sites
- Imports from other provinces in maritime Canada.

The seed collection sites are identified as separate from ongrowing areas in survey information and these and may or may not be adjacent to ongrowing areas. Seed movements between collection sites and ongrowing sites appear to be the norm with grading and re-socking of seed taking place in preparation for grow-out. Transplants appear to have variable success, with reports of some within-PEI transfers resulting in high mortality, while the same occurred in seed transfers from New Brunswick to PEI in 2003. In New Brunswick itself, the industry appears to be disaggregated into specialist seed suppliers and ongrowers. Ongrown production is quite modest at 440 tonnes in 2001, while the same year some 180 tonnes of seed stock was sold outside the state, mostly to PEI. In turn Nova Scotia is said to have poor natural seed supplies and imports seed from both PEI and New Brunswick. Industry and regulators have various concerns over seed movements within and between states, notably introduction of exotics, fouling organisms, *Mytilus trossulus* presence, general quality/fitness, genetic issues.

To overcome some of these issues, a system of seed certification was proposed, but it is not clear if this has been implemented.

To assist seed producers and on-growers, PEI also has a comprehensive system of surveys of waters in all the main embayments used for mussel farming around the island. Surveys take place every 1-2 weeks through the spring, summer and autumn and provides information on water temperature, larval concentration, size and stage, also other parameters of interest to growers such as plankton concentration, presence of predators, and presence of fouling organisms, in particular invasive tunicates, also in months of risk (autumn) potentially toxic phytoplankton are monitored. The information is published in annual report cited above and, usefully, near real-time information on

[14] http://coastal.msstate.edu/aquamussels.html
[15] http://www.fishwatch.gov/seafood_profiles/species/mussels/species_pages/blue_mussel_farmed.htm
[16] http://hermes.mbl.edu/mrc/research/pdf/sne_mussel_workshop.pdf

[17] http://www.gov.pe.ca/photos/original/FARD_Tech250.pdf

larval counts and meat yields is available on the website of PEI Department of Fisheries, Aquaculture and Rural Development[18] .

These surveys assist growers in placing settlement materials at times that will gain optimal settlement. They also assist in timing to avoid the worst of settlement of tunicates which would otherwise out-compete farmed stock. Also the surveys serve to give warning of a "second set" or secondary spawning of mussels that can produce a heavy settlement of spat in the autumn. This can cause nuisance settlements on either young seed which settled earlier the same year, or on mussel crops approaching market size.

The small industry in Newfoundland also appears to have a distinction between seed settlement sites and ongrowing sites. Problems had been encountered with high proportions of *Mytilus trossulus* and *M edulis* / *M trossulus* hybrids. A two-year study was undertaken to examine spatial and temporal settlement patterns[19]. In general spatial or temporal patterns of *Mytilus trossulus* abundance were not clear, although at some sites already favoured for commercial seed collection, earlier settlements tended to have lower proportions. Research has also been undertaken recently on stress factors associated with transporting seed and treating them for removal of invasive species.[20]

2.2.3 Chile

Chile is a significant player on the world stage with production approaching 300,000 tonnes live weight, most of which is exported as cooked frozen meats. 72% of exports go to the EU, with 4% to the UK[21].

The industry in Chile rears mussels predominantly in suspended culture and uses naturally occurring seed. Seed shortages occur periodically and are of significant concern to producers. A shortage was reported in 2012 and concerns were raised by industry to government[22]. It seems apparent from the concerns raised that there is disaggregation into seed collection and fattening within the industry and "incompatibility" between the two operations. Consideration of reserves solely for the collection of seed and studies into factors influencing seed distribution and abundance are suggested. Separation of seed production and ongrowing is also apparent from an article in the Global Aquaculture Advocate which suggests there are 63 seed producers, along with 1,120 grow-out sites and 40 processing plants. Mussel hatcheries as a solution are reported to be uneconomic[23]. No further information is available on any novel approaches to overcoming seed shortages.

[18] See for example http://www.gov.pe.ca/fard/fisheries/area.php3?area=4
[19] http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/acrdp-pcrda/fsheet-ftechnique/pdf/10-eng.pdf
[20] http://collections.mun.ca/PDFs/theses/Vickerson_Andrew.pdfs.
[21] http://pdf.gaalliance.org/pdf/GAA-Rojas-Sept11.pdf
[22] http://www.shellfishtrader.com/news/104-chile-uncertainty-and-concern-expressed-by-mussel-farmers-due-to-shortage-of-seed
[23] http://www.globefish.org/bivalves-september-2012.html

2.3 Asia

As mentioned previously, very little information is available for seed stock acquisition in some of the larger producing countries in Asia.

In China there is an established shellfish hatchery industry focusing on scallops and oysters and it is not clear the extent to which these facilities are providing seed for mussel ongrowing (a smaller, lower value industry by Chinese standards). Mussel settlement was said to be a nuisance factor to the other suspended shellfish industries in the past[24].

Korea appears to adopt a broadly similar approach to that in China. Seed area available through wild settlement and are probably the dominant source. However hatchery technology exists and may contribute to some extent. Hatchery production is primarily for oysters which are grown on a huge scale in Korea, and for this species too, the sourcing is both natural settlement and hatchery produced. Mussel ongrowing is predominantly on longlines[25].

In Thailand the green mussel industry is relatively basic and relies entirely on natural spatfall on a variety of collector materials such as wooden poles etc. and the spat merely grow out on these until harvest[26], or are transferred to simple structures and protected with mesh[27] .

In India, seed collection is carried out on fixed structures or fished from sub-tidal beds. It is then hung on ropes using a socking system derived from locally available materials using a simple rack system to support the ropes. Hatchery technology is said to be available but currently uneconomic[28].

The situation in the Philippines is not clear as regards seed production. However shellfish culture is a relatively low value subsistence activity in the Philippines and seems unlikely to incorporate sophisticated means of seed stock acquisition.

Remaining Asian countries producing mussels are low volume and probably low value and have not been specifically researched. It is probable that similar basic technologies to those in India and Thailand are employed without sophisticated or novel approaches to seedstock acquisition.

2.4 Europe

2.4.1 Spain

The vast majority of mussel cultivation takes place in Galicia on the north-west coast of Spain. The Galician industry is based on suspended cultivation using rafts inside four main Rias (large semi-

[24]http://china.nlambassade.org/binaries/content/assets/postenweb/c/china/zaken-doen-in-china/import/kansen_en_sectoren/agrofood/rapporten_over_agro_food/an-overview-of-chinas-aquaculture
[25]http://www.lib.noaa.gov/retiredsites/korea/main_species/mussel.htm
[26]http://www.fao.org/docrep/field/003/ac231e/AC231E10.htm
[27] See, for example, http://www.thaifolk.com/doc/greenmussel_e.htm
[28]http://eprints.cmfri.org.in/7508/1/528-KSM_-_TECHNICAL_BILLETIN_MAMIAL_ON_MUSSEL_TRAINING_____2003.pdf

sheltered estuaries) and has an annual production of 200-250,000 tonnes. Seed sourcing is primarily from wild inter-tidal accumulations of seed, the remainder being collected on collector ropes. The industry is reported to require some 9,000 tonnes of seed[29] and this has been confirmed by industry sources. This equates to a ratio of return around 25:1 (harvest: seed) overall on average. However seed is taken off the collector ropes and thinned once or twice further during the grow-out stages[30]. Rope is stocked at about 1kg of seed per metre on average. Supply activities have been traditionally fulfilled by individuals, often not connected to the aquaculture enterprise, collecting mussel seed, scraped off rocks and then distributed to growers. Seed price is around €0.70 to 1.00 per kg[31]. To date there has been no known extended period where lack of mussel spat has been evident. However the high volume required is acknowledged by industry and some trials have been undertaken on different types of ropes as settlement material with the aim of enhancing seed stock supplies from this source.

2.4.2 Italy

Collector ropes are set within the framework of cultivation areas and are then re-stripped and socked for grow out. Some cultivation operations are known to have preferential seed settlements within their areas of control and trading in settled ropes is not uncommon.

2.4.3 Greece

The Greek industry uses mainly long line cultivation and relies entirely on natural spatfall.

2.4.4 France

The mussel cultivation sector has producers who utilize both long line and bouchot cultivation techniques. Seed ropes are deployed by the long line sector in the Atlantic area, the offshore cultivators in the Mediterranean deploy ropes and on-grow. (There are a number of hatcheries in France which have focused on supplying seed oysters for the oyster cultivation sector. The influx of the new variant oyster herpes virus since 2008 has reduced demand and some hatcheries are known to be looking at alternative work streams. Grainocean – a Brittany based hatchery, were a participant in the BLUESEED project (see later discussion) and successfully produced triploid (3n) mussel seed.

2.4.5 Ireland

The Irish Industry is comprised of both longline and on-bottom cultivation. Seed collection for the rope farming sector on the west coast is conventional in that spat collector ropes are deployed in licensed sites. The on-bottom sector seed fishery is largely located on the east coast (albeit with Cromane on the West and Lough Swilly and Foyle in the North). The mussel seed fishery is highly regulated and managed on the basis of quota allocation per aquaculture licence site. Responsibility for management is shared between the Republic and the North, with the Department of the Marine in the South, the Loughs Agency in Lough Foyle and Carlingford and DARD in Northern Ireland issuing mussel seed licences. Regular mussel seed surveys are conducted in the South by BIM[32] and in the

[29] Filgueira R, Peteiro L, Labarta U and Fernandez-Reinz MJ; ‘ Assessment of spat collecting Ropes in Galician mussel farming’ Aquaculture Engineering 37 (2007) 195-201
[30] Jose Fuentes CIMAR, 2012
[31] Dr Alicia Sanmamed, pers comm
[32] http://www.bim.ie/our-publications/aquaculture/

North by AFBI[33]. However, somewhat ironically, despite the mature regulatory system and intense and well established mussel seed surveying, the sector in Ireland as a whole has experienced a number of consecutive years of mussel seed failure (2010 – to date).

There has been some interest shown in developing hatcheries to provide for mussel seed supply (Cartron Point) but these have largely been funded through development grants and have not been seen to become commercially viable.

A wide ranging report on issues surrounding the supply of seed for the bottom culture industry in Ireland[34] suggests in some years where prolonged biotoxin events in rope growing areas such as Bantry Bay have caused rope growers to sell their stock to bottom growers so as to clear their lines and realise some value for their stock. These could be considered emergency measures and not a long term solution for either category of producer. Nevertheless this has provided something of a market for the rope grown mussel and helped to satisfy some of the demand from the on bottom sector.

The study also provides some estimates of cost of spat from hatcheries from a variety of global sources as at 2007, as follows:

Washington State, USA: Seed size: 0.5 to 1 mm, attached to dropper ropes: €1,480 to 1,950 per million (dependent on quantity)

Tasmania, Australia: Seed size: 0.5mm: €1,230 per million

Tasmania, Australia: Seed size: 4mm, attached to dropper ropes: €1,750 per million

Ireland shellfish hatchery estimate: Seed size 1mm, settled onto trays, €575 per million

2.4.6 The Netherlands & Germany

The Dutch and German mussel sector is largely based on on-bottom cultivation with some small scale rope farming operators in both countries. Traditionally mussel seed was sourced from large intertidal and semi-sub-tidal sand-flats in the Waddenzee. Largely as a consequence of conflict between environmental NGO's and the bivalve shellfish sector, both the Dutch and German sector have invested in offshore seed collection devices known as MZIs – which are extensive heavy surface set nets which can be deployed in fleets within defined locations at particular periods of time.

Both Dutch and German seed mussel fisheries, in the Waddenzee and Eastern Schelde seas have been highly researched and managed[35] for a considerable period of time, with management based upon transferable access rights inside the framework of a total allowable catch which is derived using strict scientific criteria[36]. However, even under this management system, it was not

[33] http://www.dardni.gov.uk/index/fisheries/aquaculture/mussel-seed-fishery.htm
[34] Maguire, J. A., Knights, T., Burnell, G., Crowe, T., O'Beirn, F., McGrath, D., Ferns, M., McDonough, N., McQuaid, N., O'Connor, B., Doyle, R., Newell, C., Seed, R., Smaal, A., O'Carroll, T., Watson, L., Dennis, J., Ó Cinneide, M., 2007. Management recommendations for the sustainable exploitation of mussel seed in the Irish Sea", Marine Environment and Health Series No. 31, Marine Institute 2007
[35] Small A.C, Lucas L., Regualtion and Monitoring of Marine Aquaculture in the Netherlands. Journal of Applied Ichthyology. Vol 16 Issue 4-5, p 187-191 July 2000
[36] Smaal A C ' European mussel cultivation along the Atlantic Coast: Production status, problems and perspectives' Hydrobiologia September 2002 Vol 484 Issue 1-3 pp 88-98

sufficiently clear in respect of incorporating environmental management requirements into its structure. As such the management systems did not prevent a simmering dispute with wider civil society developing. The consequences for the mussel cultivation industries in both Germany and the Netherlands have been profound, with the Dutch government signing an agreement with its industry in October 2008 agreeing that all seed collection from naturally occurring seed beds in the Waddenzee and Eastern Schelde have to have ceased by 2020. Subsequently and directly as a consequence of this threat to the continuing viability of these industries, the Dutch and German sectors have directed considerable resources toward developing alternative ways of satisfying their mussel seed requirements. In light of this it is somewhat ironic that within both seed areas in the Netherlands, recovery of the mussel seed reefs have seen substantial mussel seed fisheries 2012 and 2013 (+/- 60,000mt in total[37]).

After the agreement between the mussel sector and the Dutch Government in 2008[38], several of the larger players in the cultivation and processing sector, which is centred in Yerseke, took an active interest in a potential solution focused on “mussel seed collector devices”, (Mossel ZaadInvang installatie in Dutch or MZIs). These differ from other forms of conventional collector largely as a consequence of the target market – which is the Dutch on-bottom sector. This industry has produced up to 100,000 tonnes per year, but more recently has produced around 30,000 tonnes per year – which is still a substantial activity[39] and means that substantial quantities are needed. Given an optimistic 3:1 ratio of harvest weight to seed weight, or more realistic 1.5:1, the requirements of the Dutch sector remain in excess of 20,000mt of seed per year. Direct industry contact suggests total harvests from MZIs are around 9,000 tonnes currently and the industry have been making up for spat shortfall by importing mussel seed, as well as catching some in the Waddenzee. All imports of seed are banned from 2015.

This requirement when seen in the context of The Netherlands having a highly structured and planned use of marine environment incentivised companies to look at collector design that could provide a lot of settlement area for a small headline. A number of different approaches have been developed and performance assessed. An extremely good overview of the range of MZIs in 2009 is available.[40] Considerable innovation in the systems has occurred since this presentation was made.

2.4.7 Denmark

The Limfjord mussel fishery is a more conventional fishery as opposed to an enhanced one – so does not fall within the remit of cultivation. There are a small number of businesses engaged in longline cultivation. The process of seed collection is undertaken through the deployment of collector ropes (stripped and re-socked) at appropriate times of the year.

2.4.8 Norway& Sweden

Both countries are relatively small producers using long line production and natural spatfall. Seed availability is just one of many issues constraining the industry. However considerable effort is being put into improving use of seed through socking and management[41]. Work has also been undertaken

[37] Hans Neilis mussel fisherman Yerseke pers comm. 2012
[38] Signed on the 21st October 2008
[39] http://pdf.gaalliance.org/pdf/GAA-Smaal-Mar09.pdf
[40] http://www.mzi.nu/rapporten/wetenschappelijke-publicaties/mussel-seed-collecting-systems.pdf
[41] see for example http://hermes.mbl.edu/mrc/research/pdf/socking_continuous020711.pdf

on assessing the efficacy of various spat collection materials[42]. There has also been commercial development of MZI-type collectors (see discussions for The Netherlands and Germany) which are manufactured in Norway and exported[43]. Harvesting trials from these collectors have been undertaken at farms in the Swedish Baltic under the AquaBest project[44], a collaborative project on aquaculture in the Baltic Sea Region.

2.5 Australasia

2.5.1 Australia

There is a relatively small industry in Australia at about 3,000 tonnes per year, predominantly based in the Port Lincoln area of South Australia. There are about 900 tonnes of mussel produced in Tasmania[45]with some production in Victoria. Production is entirely through long line culture which relies mainly on natural settlement of *M galloprovincialis*. Concerns over reliability of settlement have led to a hatchery techniques being developed by South Australian Research and Development Institute (SARDI) in conjunction with some industry partners. Capital costs of a hatchery have been estimated at some US$484,000, but with no information on capacity[46]. There is a commercial independent hatchery in Tasmania[47], though it is not clear how much production this supports.

2.5.2 New Zealand

New Zealand has a significant industry based on the green-lipped mussel *Perna canaliculus* which produces around 100,000t of marketable mussels per year. Spat supply is achieved through collection of naturally occurring spat which settles on drifting macro-algae and is washed up in large quantities at Ninety Mile Beach, a long exposed sand beach in the north of the North Island. Stranded macro-algae is collected and the spat is separated from the algae and stocked onto growing ropes utilising cotton mesh tubes. Various estimates of volumes of material involved are given in the literature and direct contact with a key author confirmed that about 240t of spat mussel collected on Ninety Mile Beach amounts to about 80% of the industry's spat needs, a ratio of harvest product: seed is therefore around 350:1[48]. The remainder is collected on dedicated spat collection ropes close to the main farming areas. Retention of spat sourced from Ninety Mile Beach on the growing ropes is often poor and thought to be related to various stressors relating to collection, transport and handling[49]. The high (by European standards) ratio of production is achieved because the spat are very small indeed (about 500 microns) and so very numerous. The survivors are periodically thinned and re-socked in the nursery stage of grow-out, which also helps yield. Spat handling and the growing process generally utilises a high degree of mechanisation and the use of continuous ropes strung from the main long lines.

[42]Lekang O-I, Stevik T, Bomo A, 2003: Evaluation of different combined collectors used in longlines for blue mussel farming. Aquacultural Engineering Volume 27, Issue 2, 89–104
[43]http://www.smartfarm.no/?lang=en
[44]http://www.aquabestproject.eu/
[45]http://www.skills.tas.gov.au/employersindustry/workforceplans/tasseafoodindustryplan2013.pdf
[46]http://www.pir.sa.gov.au/aquaculture/aquaculture_industry/marine_aquaculture/mussels
[47]http://www.springbayseafoods.com.au/spring-bay-mussels
[48] Andrea Alfaro, Earth and Ocean Sciences Research Centre, Auckland University of Technology, pers comm
[49]Carton, A.G., Jeffs, A.G., Foote, G., Palmer, H., Bilton, J. (2007) Evaluation of methods for assessing the retention of seed mussels (*Pernacanaliculus*) prior to seeding for grow-out.Aquaculture, 262: 521-527.

Hatchery techniques have been under development for some time, particularly at the Cawthron Institute which has been exploring various avenues to improve commercial viability of the mussel hatchery concept, extrapolating techniques in commercial use for other species, particularly oysters[50]. There is a long established connection between industry, government and the research establishment with regard to selective breeding and development of hatchery techniques. It has been recognised for some time that there is an inherent strategic weakness in relying on spatfall at Ninety Mile Beach, which is the result of little understood biological oceanographic processes. However, although wild caught spat acquisition in New Zealand is open to risks of natural variation in volumes, timing and quality, it is viewed overall as a very cheap source, which a hatchery would have difficulty competing with[51]. Optimistic press releases (see for example from 2010[52]) do not appear to have been followed by significant commercial hatchery output so far. Direct contact with researchers at the Cawthron Institute in New Zealand has confirmed that there is virtually no published information on hatchery economics in that country. The Institute are currently assisting a few production companies involved to establish a hatchery for their own needs. This is expected to be on stream in 2014. Expected benefits are continuity of supply, better retention, also selective breeding leading eventually to better, more uniform growth. However the potential benefits are apparently largely unquantified. Further substantial R&D funding has been announced by Government last year[53], with up to NZ$26m (~£13m) being committed by industry and government combined over 7 years.

2.6 Discussion

Bringing this all together, it is clear that spat supply is a significant constraint which most mussel rearing industries have to grapple with. Substantial parts of the global industry could be said to be in the “do nothing” category, making the best of what natural spatfall is available, for example parts of Asia, Chile and parts of Europe and accepting production shortfalls in times of low spatfall. Some countries have either discussed or are actually implementing studies to better understand spatfall and monitoring to help growers deploy collection devices at appropriate times. The PEI example is interesting and appears to be of genuine assistance to growers.

The availability, size and cost of spat is also intrinsically linked to the farmers’ practices in grow-out. Where spat is collected at a very small stage and/ or it is deemed expensive, the part-grown crop is stripped and re-socked at lower densities to gain better overall yields, in terms of both weight and numbers of animals at harvest compared to amounts stocked. Galicia and New Zealand are particular examples of this. Galician[54] and New Zealand Sectors undertake a distinct nursery stage for the re-socked mussel spat which is followed by a final grow out stage. In New Zealand this results

[50]http://www.cawthron.org.nz/aquaculture/hatchery-nursery-technology.html
[51]Jeffs A, 2003: Assessment of the potential for Mussel Aquaculture in Northland. NIWA Client Report ALK2003-057
[52]http://www.stuff.co.nz/nelson-mail/news/3581392/Firms-unite-on-mussel-spat-supply
[53]http:/ /www.fish.govt.nz/en-nz/Press/Mussel+programme+to+revolutionise+aquaculture.htm

[54] Jose Fuentes CIMAR 2012 Pers comm

in initial socking densities evident during the nursery stages (1000-5000 spat per metre of growing rope) being reduced to 150 -200m for final grow out[55].

The MZI initiative in the Netherlands is interesting and driven by changing regulation. It appears to be meeting the demand of the industry in part, though with a significant cost and, in the short term at least, economics are confused by variable wild supplies.

The role of hatcheries appears niche at present. There are several examples of hatcheries being associated with public sector R&D activities (west coast USA, Canada, South Australia, New Zealand). There is also the BLUESEED project undertaken by several collaborative R&D and industry groups across Europe (and discussed at length in the context of the hatchery option in later sections of this report). There seem to be only 2-3 fully commercial hatcheries, two in west coast USA which are precursors for a relatively small production industry, where there is no acceptable natural spatfall and which are primarily used for production of other species. There is one hatchery in Tasmania which appears to be providing for the needs of one on-growing business, although no information is available on actual throughput or economics. The commitment in New Zealand to fund further R&D is impressive and appears to result from a deeply supportive government approach and some large, well-funded production companies who feel very exposed to reliance on a single and variable source of spat.

[55] http://aquaculture.org.nz/products/greenshell-mussels/farms/

3 Status and trends in seed availability in Scotland

3.1 Introduction

The aim of this section is to assess recent experiences and trends with seed acquisition in Scotland as a backdrop to the discussion of possible novel approaches in Section 4.

The main sources of information for this section are as follows:

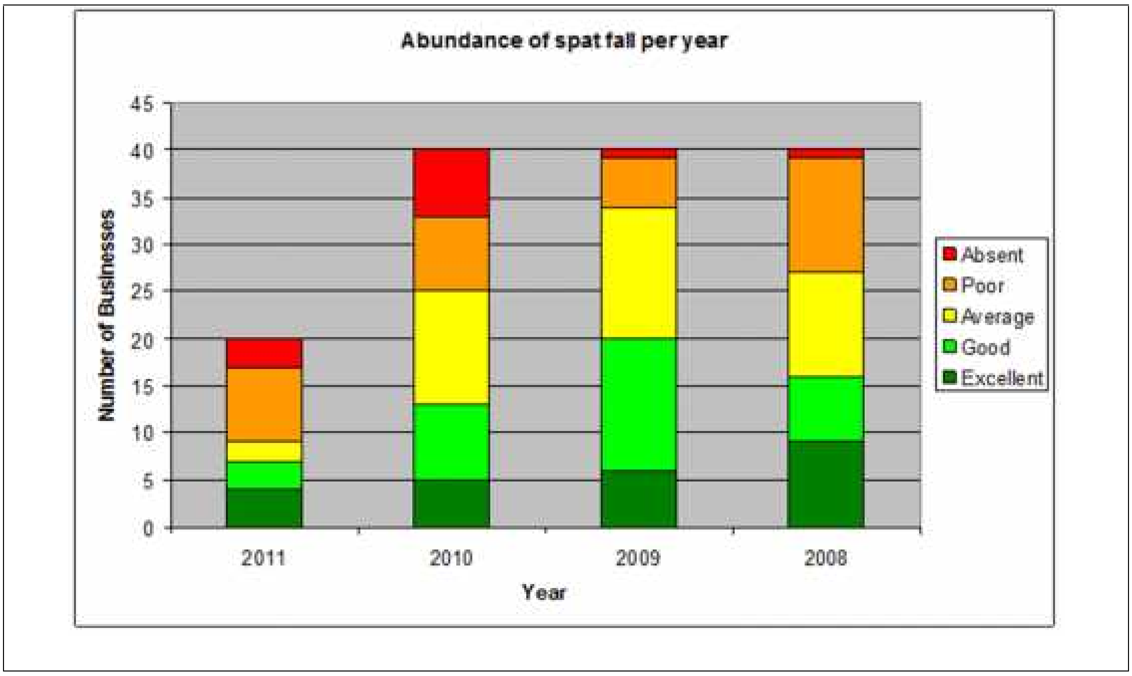
1. Report of a survey undertaken by Marine Scotland Science in late 2011/early 2012 regarding mussel settlement and mortality in the Scottish mussel industry[56]
2. A dedicated survey for this study
3. Dialogue with industry and other stakeholders
4. Web articles, workshop reports etc

3.2 Dedicated surveys

3.2.1 MSS survey

As with this study, the MSS survey was undertaken in response to industry concerns that there was a general problem with spat abundance in recent years in many of the production areas in Scotland. The survey asked for information relating to degree and timing of spatfall in the years 2008 to 2011 with related questions on fouling organisms, environmental factors and monitoring undertaken. The survey was undertaken through questionnaire and follow up phone calls. 43 out of 96 (45%) of businesses contacted responded quantitatively. The trends are shown below.

Fig 1: Trends in spatfall abundance at mussel farm sites in Scotland, 2008 – 2011



Source: MSS

[56] A. Mayes MSS 2012: Scottish Mussel Settlement and Mortality on Farm sites Questionnaire

The 2011 responses are fewer than for other years as the survey was conducted before spat had fallen for some producers, (note the time progression above is shown right to left). There is an increase in reports of spatfall being both "poor" and "absent", and a correspondent decline in "good and excellent" when considering the four year interval. The progress of both trends is not smooth within the four years, with 2009 standing out as a better year. The proportion of respondents reporting "poor" or "absent" in 2011 is worryingly high, at 55%, albeit with a smaller sample size. Also in 2010, 7 out of 40 respondents reported an absence of spat (18%) and these are said to represent 12% of industry capacity. 2011 was only a little better with 15% reporting absence.

3.2.2 Current study

Both studies asked similar questions over a similar period regarding spatfall. This was partly because the MSS results only came to light after the survey for this study had been circulated. However gaining replicate views on this key issue is potentially useful. The current survey asked for spatfall results in a slightly different way – as a percentage of optimal, while the MSS survey used the descriptors absent-poor-average-good-excellent. The current survey has also covered six complete years up to 2012 while the MSS survey covered four complete years, but with fewer responses for 2011.

The period of coverage in this survey was 2007 to 2012. It asked background questions regarding the region of production, number of sites and production levels. The survey asked for experiences with spat fall, equipment and any special measures used to overcome shortages. The survey went on to ask about additional production which could have been expected had spatfall been optimal in the years covered, and potential interest in the type, unit value and quantity of alternate sources of seed, were they to become available under some of the possible novel approaches identified in the literature review. The survey form for the current study is shown at Appendix 1.

The current survey forms were initially distributed in May by ASSG to members known to be involved in mussel production, and by Seafood Shetland to their mussel producing membership. The initial response rate was very low and so two rounds of telephone or email follow up were undertaken in July / August based on information provided by Marine Scotland for the mainland / Western Isles producers, and through Seafood Shetland's listings of mussel farmers in their website. In spite of efforts made, the response rate was low at 10 quantitative responses from 75 contacts, (56 Mainland & Western Isles, 19 Shetland), or 13%. Reasons for the low overall response rate are not fully clear, but comments from those who declined to provide quantitative information were wide ranging and included lack of time to respond, lack of interest in the topic, more pressing priorities, not being in production, changing crops to other species and general scepticism. Survey fatigue (possibly given the MSS survey a year before), may also have contributed. Having said that, some respondents were large producers and were very willing to participate, and in terms of production capacity, about 20% of the industry provided quantitative information, (see Table 2).

Respondent capacity

Table 2: Production history of respondents compared to all Scotland

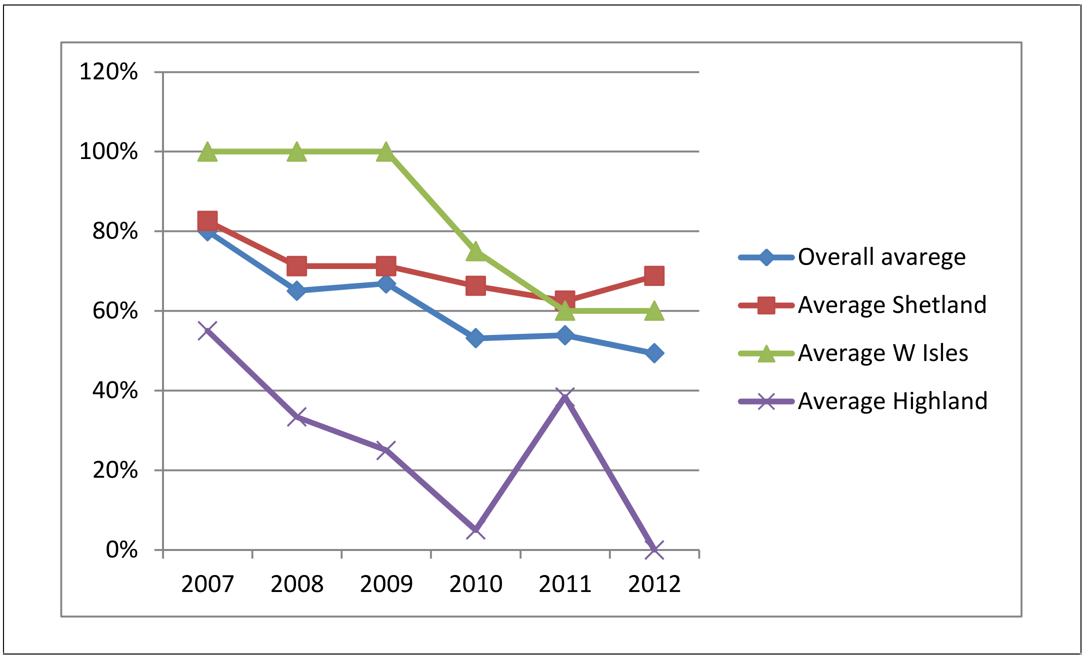
Location	No of respondents	Aggregate harvest by year (tonnes)					
		2007	2008	2009	2010	2011	2012
Shetland	4	657	386	446	582	666	549
W Isles	2	211	401	591	831	759	400
Highland	4	122	72	87	110	78	174
Total	10	990	859	1,124	1,523	1,503	1,123
Total Scotland	75	4,806	5,869	6,302	7,199	6,996	6,277
Prop covered	13%	21%	15%	18%	21%	21%	18%

The total harvest tonnages quoted by respondents generally follows the trend shown for all Scotland as recorded in the MSS annual surveys. The number of sites operated by respondents was 37 in aggregate in 2012. Unfortunately use of sites is not disaggregated by species in the MSS annual surveys, (only "businesses"), so it is not possible to gain a view of respondents as a proportion of total number of sites.

Degree of shortfall

Spat settlements in recent years were expressed as proportions of what would be optimal levels in the views of each respondent. Average spat shortfalls are aggregated by region and shown in the graph below.

Fig 2: Proportions of "optimal" spatfall experienced, 2007 to 2012, by region and overall



Although a rather small sample, it is probably fair to say that from the producers' perspective:

- There is a downward trend in spat supply in all areas
- The situation is worse in Highland than other areas
- The overall shortage appears to have increased from some 80% of optimal to some 50% of optimal in 5 years.

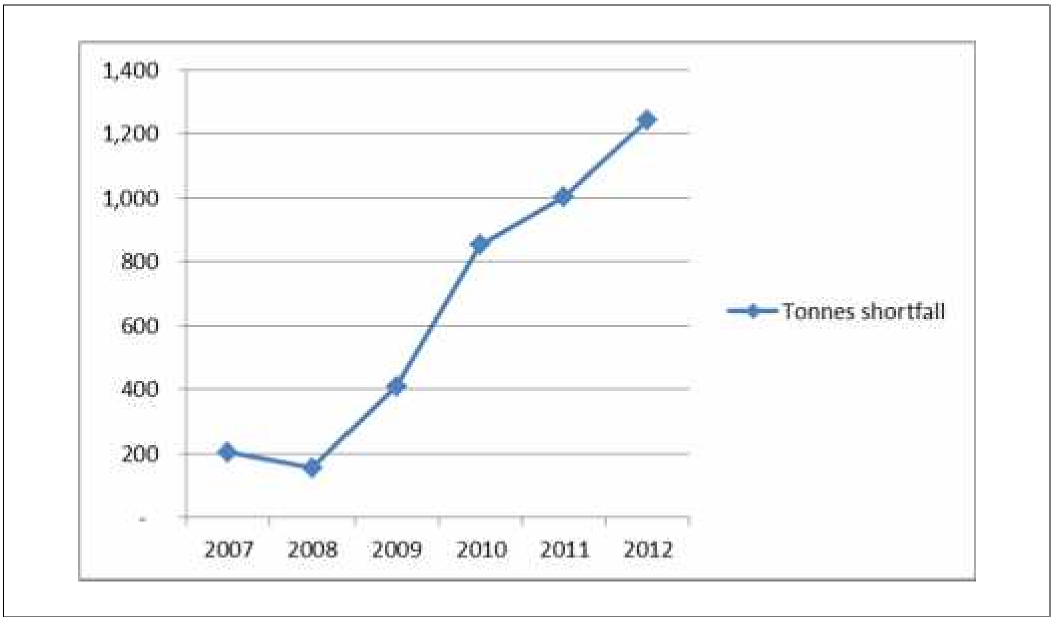
Note that two of the Highland respondents did not supply figures in all years, the figures shown are the averages of those that did. From more general engagement with the industry and related stakeholders, it would appear that the patterns provided by respondents and shown in Fig 2 generally hold true, but that the situation in Highland is not as dire as it appears: there is significant variation within this large area. Variation at a more local level was also reported verbally, for example west Shetland is said to enjoy better spat fall than the east and the east coast of the Western Isles has experienced better spat conditions than the west in recent years. Variations were also reported at much finer scales of a few km, but cannot be discussed individually for reasons of confidentiality.

The pattern derived from this study shows a fairly similar trend with the MSS study shown above, with 2009 a pause in what is otherwise a general downward trend. The questions in the surveys were slightly different. The most recent year in the MSS survey, 2011, with 55% of those responding reporting poor or absent spatfall, i.e. probably of no productive use, and 35% reporting good or average, coincides with a response of spatfall being 54% of optimal in this survey. The general view in this survey that spatfall was about 50% of optimal in 2012 is possibly a little optimistic.

Impact on production

The impact of the shortfalls was also requested in terms of estimated resulting lost harvest weight. Responses were not provided by all producers for all years, but those that did have been aggregated and are shown in Figure 3.

Fig 3: Aggregated reported production shortfall due to spat shortages



Given the increasing perception of shortage of spat it is not surprising that there is a corresponding rise in the perceived shortfall in production. Again not all respondents provided an estimate for all years, but nine out of ten respondents provided a figure for 2012 which amounts to some 1,250 tonnes in aggregate. If scaled up across the whole industry, the combined shortfall could be in the order of (1,250 / 20%) = 6,250 tonnes. This figure should be taken as highly approximate, given the relatively small proportion of the industry capacity covered by these responses. It is not impossible that the responses gained are over-representative of those who have been suffering seed supply problems: such producers could be more likely than the average to respond to surveys such as this. Nevertheless it seems reasonable to assume that the industry could potentially have produced a few thousand tonnes more than actual levels in recent years, had spat supply been continually optimal, (and ignoring for the moment capacity of businesses to handle and sell such extra volume).

Spat settlement equipment

Respondents were asked about the type of equipment used at present to achieve seed settlement. Each respondent is coded to anonymise answers and the listing is random.

Table 3: Equipment currently in use for spat acquisition

Respondent code	Equipment in use	Location
1	Rope droppers	In main farm
2	Itsaskorda rope dropper, net	Main farm and dedicated seed sites
3	Itsaskorda rope dropper, net	Main farm and dedicated seed sites
4	Net strips	In main farm
5	NZ spat loop and ladders	In main farm
6	Pegged rope	Main farm and dedicated seed sites
7	Ladders	In main farm
8	nd	
9	Pegged rope	In main farm
10	NZ spat rope, pegged droppers	In main farm

As can be seen, there is a significant variety of equipment in use, with most reporting some incremental measure beyond the standard pegged rope. One third of producers report using dedicated seed sites in addition to placing seeding ropes in their main on-growing sites, (albeit from a small sample). There is little correlation between the collection material or sites used and the proportion of optimal settlement experienced. This is much more closely linked to region of production. One producer in Highland reported trying a New Zealand continuous settlement rope system but gained no spat.

Recent additional measures used

Regarding additional measures used in recent years to overcome shortages of seed supply, three producers (30%) reported taking one or more measures and expenditure. These can be summarised as:

- Thinning and re-socking of their own seed: Two producers every year from 2007, one from 2011
- Buying in seed: One producer every year from 2010, one from 2011, one from 2012 (two sourced their seed locally, one from Ireland)
- Contract seed sites: One producer from 2011

Of those that took additional measures, these have become progressive as seed supply has worsened, i.e. taking on multiple measures in more recent years. Decisions surrounding additional measures to secure supply appears to be closely tied to financial ability to do so, (see later discussion in Section 5).

To summarise recent trends, the MSS survey and this survey has confirmed what the industry have been saying for some time, also reported by Scott et al[57] and others, i.e. that spatfall has been poor in recent years and appears to be on a downward trend. This survey is disaggregated by area and shows the position to be considerably worse in Highland than Shetland and Western Isles, although there is significant local scale variation. Additional measures to combat shortage of supply have been undertaken by a minority of producers.

The MSS annual surveys provide evidence that some growers appear to have made some structural changes to their existing business operations, with mussels produced for the purpose on ongrowing elsewhere or by others increasing from <50t prior to 2008 to more than 300t in 2012, with some 8 sites dedicated to this purpose.

3.3 Wider discussion of recent trends

It is not uncommon, from a wider perspective, for a series of less than optimal years of spatfall to be experienced. Given the considerable number of environmental variables that can impact on the larvae stages of mussels during their life cycle as plankton, coupled with an extended larval time frame, the prediction and capture of mussel seed can be considered an inherently uncertain process. As already set out in the literature review, a number of major mussel producing countries have experienced variable levels of spat collection. Whilst it is a more common problem for the bottom culture sector, which relies on dense aggregations of juvenile mussels occurring onto the seabed, it is also a feature within the rope farming community, (as discussed for Chile, Canada, New Zealand etc). Research into these occurrences has suggested that there is sometimes correlation with large scale environmental factors, for example the view of the Dutch Industry as suggested by Dikkerna[58] whereby poor spat falls in the Waddenzee appear to occur after warm winters. The theory here is about the impact on the warm winters on the wider ecosystem, and the better survival of other

[57] http://www.scotland.gov.uk/Resource/Doc/295194/0118352.pdf

[58] Dijkema R: 'Spatfall and recruitment of mussels (*Mytilus edulis*) and cockles (*Cerestoderma edule*) on different locations along the European coast' ICES C.M. 1992/K:45 Shellfish Committee

species, notably the brown shrimp (*Crangon crangon)* in the Dutch example, which are then thought to extensively predate on the newly metamorphosed mussel pediviliger. This principle of warm winters producing poor spat settlement and cold winters good settlement appears to hold true for the Dutch mussel sector in recent years, with 2012 and 2013 having two of the coldest winters for a decade, which have resulted in the largest settlement of mussel seed for a decade[59].

This pattern does not appear to have been duplicated across Scotland. Nevertheless there is a wide-spread appreciation that the past few years have brought somewhat unusual weather conditions. There is no clear indication that the potential impact of these changes on the timing of deployment of collector ropes has been taken into consideration by the sector at large. Thus it is would be useful to establish a set of agreed relevant and fit for purpose environmental indictors that might assist growers in planning their deployment decisions.

It is also useful to establish what the overall requirements are for mussel seed at a farm level, at a regional level and at a sectorial level. Making a conservative assumption, the yield ratio (tonnes harvested : tonnes stocked) for the Scottish industry of between 5:1 and 10:1 that would equate to a current requirement of between 600-1200t of 20mm seed, rising to 1200-2400t, assuming maintenance of current practices, as the Scottish sector moves to achieving the target growth aspirations. These yield of return are discussed at more length in section 5 (Economic aspects).

Mayes' review makes clear the apparent idiosyncratic nature of water monitoring and the deployment of spat collectors for much of the Scottish sector. It is clear that there have been some adaptations undertaken in some regions but there does not appear to be any centralized structure of control and information management associated with the activity of spat collection to assist growers decision making process in terms of when and where to deploy. The deployment of spat collecting medium has in general followed a fairly regular and predictable cyclical pattern in Scotland with the earliest ropes deployed in April, a peak of settlement occurring in late June/July and collectors removed or relocated in August. However, Workshops held in Scotland in 2011[60] highlighted the limited amount of monitoring of the wider environmental indicators and also of the condition of 'broodstock' – the sexually mature mussels - to provide for a finer and better tuned approach to deployment, even on a site by site basis. Whilst it is possible for an extremely large number of larvae to be produced by a very small number of mussels[61], as fertilization of the egg takes place externally, the sexual mixture of males and females needs to be in appropriate balance to provide for higher probabilities of successful fertilization. Given that external sexing of mussels is extremely difficult[62], a degree of uncertainty will always be attached to this very early part of the process.

[59]WimVerwijs, Premier Mussels Bv July 2013 Perscomm..
[60] As reported in 'The Grower – newsletter of the Association of Scottish Shellfish Growers. March 2012
[61] It is suggested up to 7 x 10 ^{8} eggs produced by a fully ripe female Mytilus edulis – in Honkoop PJL and Van der Meer J (1998) 'Experimentally induced effects of water temperature and immersion time on reproductive output of bivalves in the Waddenzee.' J Exp Mar BiolEcol 220: 227-246
[62]Petes LE, Mange BA, Chan F & Webb MAH : Gonadal tissue colour is not a reliable indicator of sex in rocky intertidal mussels. Aquatic Biology Vol 3 63-70 2008

4 Novel approaches to seed stock supply in Scotland

4.1 Regulatory backdrop

The regulatory framework in Scotland within which all developments and adaptations to existing practices at mussel farms must adhere is thorough and can appear quite complex. It can be broken down into two main components: a structure that relates to the physical nature of the farm (incorporated through the process of obtaining planning permission) and the framework in place to manage the impact of the site on the environment.

4.1.1 Planning

Principally, the major difference in the burdens faced by those engaged in shellfish cultivation in Scotland as opposed to elsewhere in the United Kingdom relate to the incorporation of aquaculture within the framework of the terrestrial planning system. This occurred prior to the development of any system of marine planning, provided for by the Marine (Scotland) Act 2010, application of which is currently underway.

In this sense, any shellfish farm development has been considered under the framework of the The Town & Country Planning (Scotland) Act 1997 (as amended by the Planning etc (Scotland) Act 2006) since the 1st April 2007. As the planning system in Scotland is plan led, the 1997 Act is the principle piece of statute to which all development must comply. Section 26 of the Town & Country Planning (Scotland) Act 1997 as amended by Section 3 of the Planning etc (Scotland) Act 2006 defines 'development' to mean –'*the carrying out of building, ……, or the operation of a marine fish farm in the circumstances specified in Section26AA'*, which notably states that fish farming is defined to mean *'the breeding, rearing or keeping of fish or shellfish (which includes any kind of sea urchin, crustacean or mollusc)'*.

The Town and Country Planning (General Permitted Development) (Scotland) Order1992 grants permitted development rights subject to compliance with the general provision of the Order and regulations 60 to 63 of the Conservation (Natural Habitats, &c.) Regulations 1994.

The Town & Country Planning (Marine Fish Farming (Scotland)) Order 2007 brought fish farming within the capture of the planning regime. These Regulations, which came into force in March 2007, meant that marine fish farming (out to the 12 nautical mile limit) under the jurisdiction of the planning system from the 1 April 2007. Prior to this date, consents for the development of fish farms fell within the jurisdiction of the Crown Estate.

The Town and Country Planning (general permitted developments) (Fish Farming) (Scotland) amendment Order 2012 does allow for some restricted changes to a permitted shellfish farm providing certain stipulations are adhered to (Class 21 (e)).

The plan led nature of developments in Scotland also ensures that local development plan objectives are an integral part of the process of any new proposal. Such plans have been developed for most of the Scottish coastline.

In addition all aquaculture sites that occur in the marine zone, must secure a lease from The Crown Estates: the owners of most of the foreshore and all of the seabed around the UK. The provision of any such lease will be dependent on ensuring that no other consented activities are infringed upon by the proposed development and that an agreement is made in terms of the recompense payable to the CEC. The Crown Estates, along with other parties, are conscious of the significant number of licensed sites which are currently unutilized. It would be considered a 'win-win' by parties[63] (CEC, Local Government) if these areas might be bought into activity in one form or another.

4.1.2 Environment

Many Scottish mussel farms lie within the boundaries of European marine sites, either Special areas of conservation (SACs) or Special Protection Areas (SPAs) which are collectively known as Natura 2000 sites. For those sites that do occur within boundaries of such areas, the Conservation (Natural Habitats etc) Regulations 1994 make provision for the implementation in the UK of the EU Habitats Directive. Regulation 3(4) of the Regulations state that "*every competent authority in the exercise of any of their functions, shall have regard to the requirements of the Habitats Directive so far as they [the requirements] may be affected by the exercise of those functions.*"

The competent authority is required to have regard to the requirements of the Habitats Directive in exercising its function as a planning authority. Proposals which are likely to have a significant effect on a Natura 2000 sites must be subject to an Appropriate Assessment. One of the foremost considerations for the Statutory agencies engaged in site management, beyond any physical interaction with site features, relates to the potential introduction of any invasive non-native species (INNS) that might be facilitated by a proposed shellfish aquaculture development. Within the Habitats directive, article 22 (b) states that Member States shall:

> *ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction.*

However there is some confusion over whether a movement of spat into a mussel farm which lay inside the boundaries of a Special Area of Conservation/Natura 2000 Site, would necessarily trigger the requirement for an Article 6(3) assessment, as to do so any such movement would have to be considered as a 'plan' or a 'project'[64]. For this to occur it is generally held that the activity would have to require permitting by a competent authority. If this process, that of seeking permission for moving in spatted rope/mussel seed, is not required and is considered as part of the normal course of operations it may well then fall to be assessed at the point that the farm site is first applied. Nevertheless, even if an Article 6(3) assessment is not triggered, there is an argument that an assessment of the activity under Article 6(2) of the Directive should then be undertaken.

For mussel sites both within and outside the boundaries of a Natura 2000 area, aquaculture is one of the few activities that has a sector specific regulatory framework, namely Council Regulation (EC) no.708/2007 of the 11 June 2007 concerning the use of alien and locally absent species in aquaculture. A new broader council regulation is currently under consultation, which could have a considerable impact on the way in which member states at large tackle the issues associated with invasive non-native species. The restriction presented by EC regulation no.708/2007 relates only to

[63] Alex Adrian CEC & James Bromham Highland Council

[64] Case C-127/02 *Landelijke Vereniging tot Behoud van de Waddenzee, Nederlandse vereniging tot Bescherming van Gogels v Staatssecretaris van Landbouw, Naturbeheer en* Visserij (*Waddenzee);* relevant to Article 6(2) and 6(3), Habitats Directive

those invasive (and locally absent) species that are 'directly' used within aquaculture systems. Therefore it does not necessarily cover any INNS which may be inadvertently introduced within a movement of, for example, seed mussel from one location to another.

The requirement to prevent introduction of such species is self-evident in many instances, as the experiences of growers in Loch Etive with *M.trossulus* illustrates. Fouling with ascidians is also a well known issue. The experience of mussel growers in Nova Scotia might serve as a further example of what can occur should new species be introduced that do not adhere to established ecological boundaries[65].This has been recognized within the sections 11 & 12 of the Aquaculture and Fisheries (Scotland) Act 2013.

There is also a general Biodiversity duty which occurs under Section 1 of the Nature Conservation (Scotland) Act 2004. This states that all public bodies have a duty when exercising their respective functions to further the conservation of biodiversity, so far as is consistent with the proper exercise of those functions. Scottish Planning Policy defines the term "biodiversity" as the variability among living organisms from all sources including terrestrial, marine and other aquatic eco-systems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems (UN Convention on Biological Diversity, 1992).

The responsible authorities and control regimes (other than planning) that relate to marine fish farming also include the Aquatic Animal Health (Scotland) Regulations 2009, which sets statutory responsibilities for the health of farmed fish and shellfish. The Regulation requires the authorization of all Aquaculture Production Businesses (APB). The authorization procedure is undertaken on behalf of the Scottish Ministers by the Fish Health Inspectorate (FHI) based at the Marine Scotland, Marine Laboratory in Aberdeen. All new fish and shellfish farms are required to apply for authorization before any development takes place. The details of the specific locations (sites) at which that the APB will be authorized to farm will be included in the authorization of the APB. The details of each site at which the APB operates will be published in the publicly available register. This mechanism is effective for controlling the movement of notifiable fish and shellfish diseases and for structuring any response to any newly determined incidence. For shellfish species, the notifiable diseases consist of Bonamiosis – *Bonamia ostreae* and *B.existiosa*; *Martellia refrigens*, and also recently the new variant of oyster herpes virus, (OsHV-1 µvar).

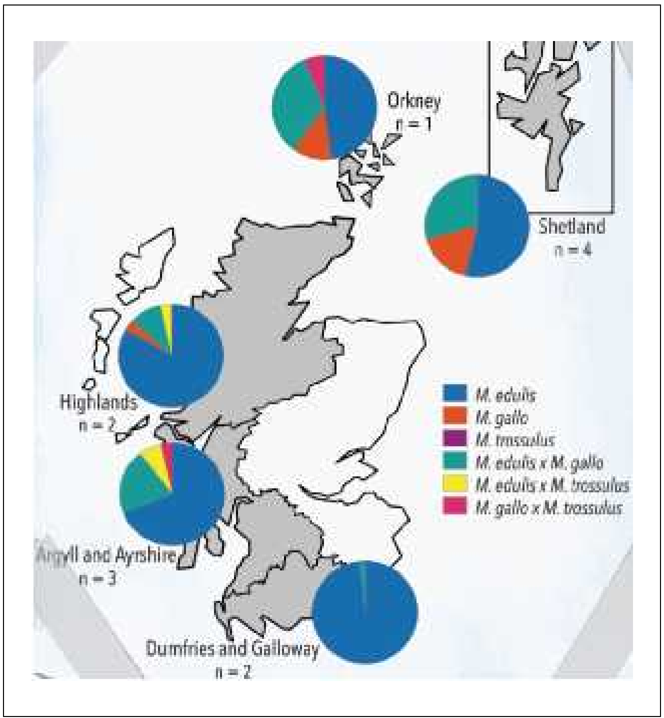
In summary, whilst there is a clear framework for controlling the inadvertent (or deliberate and somewhat foolish) introduction of shellfish product from areas which are known to harbour notifiable diseases, there is no such easily discernible and universal system available for the regulation and risk management of movements for invasive non-native species. The Welsh Government has re-instated the requirement for APBs to incorporate the stipulations of the Control of Deposits order 1974, which provides a functional framework which could be adopted by other administrations.

[65] Mussel rope cultivation in Nova Scotia, Canada has been severely impacted by the inhabitation of an invasive turnicates species ,(Cionaspp – a solitary sea squirt) in shellfish growing areas (http://www.cbc.ca/news/canada/nova-scotia/story/2013/07/24/ns-mussels-tunicates.html A similarly invasive species of the same family, *Didenmun vexillium* (the carpet sea squirt) is already found in one location within Scottish waters, and found in several locations on the South coast of England and on the West Coast of the Republic of Ireland

4.2 Genetic backdrop

It is well known that mussels in Scotland are not all pure *Mytilus edulis.* Introduction and hybridisation has taken place resulting in three species (*Mytilus edulis, M.galloprovincialis and M.trossulus*) and their hybrids being represented. Research of genetic complexes has been ongoing in recent years[66,67] and the most recently available summary is shown below.

Fig 4: Findings of studies into genetic origins of mussel spat used in aquaculture in Scotland



Source: as footnotes

It is clear that mussels in each area surveyed differ from one another in terms of proportions of species and hybrids within the population. The situation with the undesirable characteristics of *M.trossulus* and hybrids for farming is also well known and has been subject to SARF 064 (already referenced) and other research. *M.galloprovincialis* and hybrid with *M.edulis* is not considered a threat to farming operations and indeed *M.galloprovincialis* is the basis of the very substantive farming industry in Spain. *M.trossulus* hybrids appear to be present in Highland and possibly Orkney.

Several of the possible solutions to seed supply discussed later in this section involve moving seed from one place to another. Clearly this would create a risk of spreading the undesirable *M.trossulus*, should seed be moved from impacted areas of Argyll or elsewhere to areas where *M.trossulus* is absent. It also goes against the Code of Good Practice followed by ASSG[68]. Nevertheless there is no universal legal barrier to the movement of stock from one area to another, nor import from the rest of the UK (or indeed the EU). No sensible operator is going to introduce seed with characteristics which might compromise their own farms. However there is a small risk of widespread damage from unintended transfer. This would be challenging to legislate for in normal circumstances. However the Aquaculture and Fisheries (Scotland) 2013 Act does make the opportunity available for the

[66]http://assg.org.uk/#/conf-papers-09/4535539760
[67]http://www.masts.ac.uk/media/76849/joanna_wilson.pdf
[68]http://assg.org.uk/cgi-bin/download.cgi

Minister should the stipulations of the relevant segments of the Act come into play. In the meantime therefore, the best approach is felt to be to continue to keep awareness and vigilance high and to continue to monitor the species and hybrid mixes in the main production areas. The general principle should be that seed movement should be planned along lines of legislation currently used to prevent spread of aquatic disease, i.e. introductions should only be allowed where the source is material is of equal or better status than the destination. If seed is to be brought from other areas, especially from outside Scotland, then its genetic status should be established first.

4.3 Approaches specific to the Scottish situation.

This study has identified four potential strategies that could be applied to resolve at least some of the uncertainty associated with the process of seed provision:

1. Adaptations of existing practice
2. Buying in mussel seed
3. Deploying specific collector systems in new locations
4. Hatchery production

These four approaches can be divided roughly into two camps. Approaches (1) and (2) require relatively modest investment, with approaches (3) & (4) would require considerable capital expenditure, perhaps at a regional scale, but also possibly at the farm scale.

4.3.1 Adaptations of existing practice

Current practice, as derived from interviews shown in Section 3 above and from wider stakeholder dialogue, generally relates to the deployment of dedicated spat collectors such as furred up rope or the insertion of clean lines. For the dedicated spat collectors, once settlement has taken place, lines may be stripped of settled mussel seed which will then be re-socked onto the growing rope medium, sometimes as set densities. It is still however common practice to have clean lines deployed which, once settled are not stripped but simply grown on without any process of thinning of lines undertaken.

Given the often highly stratified nature of the water column in many production sites, the extent of effective collecting medium is often restricted to the upper portion of the water column in most Scottish growing waters, so maximizing the settlement surface area is considered highly important. Many equipment manufacturers have recognised this requirement and have developed lines that provide for this[69].

There is widespread acknowledgement of the unusual weather patterns experienced around the Scottish coastline during the past few years. However there is no indication that there is good understanding of how these large scale changes might be affecting the processes of spat settlement. For example, for some Loch systems which have high degrees of water column stratification evident, excessive rainfall may considerably reduce salinity within the upper five metres of water. If this

[69] http://xplora-uk.com/

occurred during periods of seed settlement, it could affect the survival and the byssal thread making capability of the early life stage mussel[70].

The MSS survey of growers discussed earlier highlighted how few farms undertook monitoring of larvae in the plankton. Recent contact with North Atlantic Fisheries College in Shetland, which has undertaken studies on timing of larval settlement in the past[71], confirmed that industry in Shetland undertakes little or no monitoring of larvae[72]. Monitoring could be undertaken by growers at the individual business level. This could assist significantly with timing of collector rope deployment and increase chances of a successful settlement. In terms of resources, it would need two people (for safety) a small boat and 1 trip per week to monitor mussel larvae in the plankton over the spring / summer period. There would be a need for a microscope, pumps and meshes for filtering sea water, associated sampling equipment and a reasonable indoor facility to process and count samples.

Another possible approach is that a public body undertakes the monitoring as a support service to the industry. This is the model followed in Prince Edward Island (PEI), Canada, where mussel larvae are monitored on a weekly or fortnightly basis at 7-8 main growing areas around the island, (along with meat yields of harvestable mussels, temperature, toxic algae, fouling tunicate larvae and other pests), by the Department of Fisheries, Aquaculture and Rural Development, (see more discussion in Section2.2.2 earlier). This appears to take two field staff, a trailable boat and significant lab back up to cover all the variables measured. PEI is some 120 miles long and so to replicate this service in Scotland would probably need a team in each of the west coast mainland, Western Isles and Shetland. Not all the variables mentioned need to be measured. Potential bodies to undertake this monitoring would be MSS and NAFC in Shetland, also possibly SAMS or Seafish. There could also be hybrid industry/governmental approaches.

At a wider level, the industry could, perhaps in conjunction with Marine Scotland Science / SAMS / SARF, request that some study is undertaken that (a) attempts to describe any alterations in prevalent environmental conditions at the appropriate scale, and (b) develops better understanding of mussel larval dispersal from prominent production areas. Indeed the workshop at SAMS in February 2012 discussed earlier suggested a potential combined industry / SAMS initiative along these lines.

It should not be overlooked that there are considerable existing knowledge resources which could assist the sector. For example there are a number of well developed and high definition larval dispersal models[73, 74] which might be investigated to develop a better understanding of the manner in which any reproductive output from existing licensed production sites behaves. In addition the

[70] Young G A., Byssus Threads formation by the mussel, Mytilus edulis: Effects of environmental factors. Mar Ecol Prog Ser Vol 24 261-271 July 1985
[71], Lindsey Clark, Beth Leslie: Shellfish Environmental and Biological Monitoring Programme: Feasibility Study, February 2008
[72] Richard Shelmerdine, NAFC, pers comm
[73] S P Neill & M J Kaiser 'Modelling the sources and sinks for scallop populations in the Isle of Man' School of Ocean Sciences, Bangor University for the Isle of Man Government at http://fisheries-conservation.bangor.ac.uk/iom/documents/1_002.pdf;
[74] P E Robins, S P Neill, L Gimenez, S R Jenkins & S K Malham' Physical and biological controls on larval dispersal and connectivity in a highly energetic shelf sea. Limnology and Oceanography 58 (2) 2013

Marine Scotland Science work on west coast ecosystems[75] is a huge resource that could assist identify areas of higher potential along the west coastline.

Under utilised sites

The scope of this study does not extend to an in-depth review of currently productive and non-productive sites. The Crown estates have highlighted the numbers of existing licensed mussel cultivation sites which are not utilised or fully utilised as been worthy of investigation as to whether they could be adapted as dedicated spat collection sites.

Some anecdotal evidence from the west coast suggest that the further up a loch a site is located, the better the site is for the collection of spat[76]. However equally the further away from the open sea, the more likely it is to be impacted by freshwater inputs which could stress the salinity tolerance limits for settling plantigrade d larvae[77].

Given the requirement in Scotland for shellfish farms to come under the remit of planning permission[78] , the use of already licensed sites has its attractions. In addition to the possibility of deploying spat collectors in latent sites, overall production could increase significantly[79] if such sites were brought into full use, without having to resort to a full approach to the planning authority.

However, whilst this route might be appropriate to increase spat supply in some areas with the right biophysical characteristics, for other areas, (particularly those that have noted populations of invasive non- native species[80]and /or commercially damaging species[81] within the locale), this approach should be considered and undertaken only after a thorough assessment of the impact of the activity within an appropriate risk based framework[82].

Using 'locally' sourced spat intuitively should represent a much lower risk of inadvertent (deliberate) transfer of either an undesirable organism or disease.

From a logistical perspective, the smaller the distance between point of supply and location of demand, the lower the associated costs of transfer should be. However if this approach is to be used, consideration is needed of the physical difficulties which could be encountered in moving substantial weights of spatted rope from one location to another.

[75] N Bailey, DM Bailey, LC Bellini, PG Fernandes, C Fox, S Heymans, S Holmes, J Howe, S Hughes, S Magill, V McIntyre, D McKee, IP Smith, G Tyldsely, R Watret and WR Turrell: 'The West of Scotland Marine Ecosystem: A review of scientific knowledge' Marine Scotland Science (November 2011) 292 pages
[76]Alex Adrian (CEC) 2013 pers comm.
[77]John C Bonnardelli (p8) The Grower March 2012
[78] The Town and Country Planning (general permitted developments) (Fish Farming) (Scotland) Order 2011 (as amended by the Town and Country planning (general permitted developments) (fish farming) (Scotland) amendment Order 2012)
[79] From the floor at ASSG 2013 the view was expressed that if it were possible to bring these latent areas into production would considerable help to achieve the Scottish governments targets for growth in the sector
[80] Article 22(b) of the Habitats Directive (92/43/EEC of the 21st May 1992)
[81] Sections 11- 15 of the Aquaculture and Fisheries (Scotland) Act 2013
[82] Which would accommodate the more usual bio-security arrangements inclusive of any areas with notifiable diseases (as described in Council Directive 2006/88/EEC) – currently in Scotland Loch Sunart and West Loch Tarbet are controlled zones for the haplosporidian parasite, *Bonamia ostreae*

A more collective approach to the process of spat collection could be developed. As mentioned in the Current Trends discussions (Section 3), this is happening in a few instances, but involves the contracting in of supply as opposed to collective or sharing arrangements. Sharing of costs and subsequent sharing of benefits would allow the burden of risk associated with the use of formerly un-utilised sites or the development costs associated with new sites to be reduced for individual businesses. Similarly, if there are existing licensed sites which have a more predictable and steady annual spat fall than seen across the whole sector, investigations could be undertaken with the relevant operator to discuss the prospects of insertion of more collector ropes under mutual arrangements with other growers in the area. However the operator might see these sites as good business opportunities in times of shortage and may wish to retain control of production.

The potential importance and value of the Dornoch Firth Tain mussel fishery should not be overlooked. This is an important resource, with considerable potential from both a biological and economic perspective. Whilst it is accepted that the performance of this fishery has been troubling from an economic perspective in the recent past, over the longer view it has produced significant output of a very distinct mussel for the wider continental market. Former sites in Cromarty Firth which used to experience dense settlement may also be worth investigating.

4.3.2 Hand gathered seed

Hand gathered or hand collected mussel seed is the least capitally intensive way of providing for seed needs, although it is not without its capital requirements. It is possible to split the identity of hand gathering into two distinct groups: those which gather for a specific cultivation medium and those who gather and sell to whichever is the highest paying market.

In terms of the former group, two of the most significant mussel producing industries globally have dependency on hand-gathering, Galicia (Spain) and New Zealand, as described earlier.

In terms of the latter 'family' of hand gathering, that which gathers to market demand, activity is evident within the wider UK where occasionally large 'ephemeral' beds of seed mussel can accumulate inside intertidal coastal areas, such as the Solway Firth, Morecambe Bay[83] and the Burry Inlet. The process of exploiting a mussel seed bed can be time consuming, more so in areas where settlements might be rare or haphazard. However for those locations where there is greater regularity, management systems are often in place to facilitate timely exploitation. Once seed beds have been identified within these areas, and relevant permissions[84] have been obtained to commence exploitation, significant quantities of mussel seed can be harvested for use. The most common destination for the output from these sources is the bottom culture sector, as hand gathered seed is known to have a harder shell than that sourced off ropes. It is also generally thought to translocate well, as the biophysical stresses on the animals are limited and the animals have adapted to intertidal patterns and periods on non-immersion. On average, seed harvested from

[83] http://www.nw-ifca.gov.uk/ContentDetails.aspx

[84] IN the UK – many of the known areas of regular seed settlement lie within the boundaries of areas designated under the Habitats Directive (92/43 EEC of 21st June 1992). Activities not associated with the management of the designated site conservation objectives are required to undertake an assessment to determine any likely significant effect of the proposed activity – under Art 6(4) (or 6(2) of the MS transposition regulation)

the shore or by vessel will have already obtained a large enough size to be easily gathered and will not often be <20mm and sometimes > 40mm.

Once collected, seed from such sources would need to be transported to the farmer's jetty, transhipped to work boats and then re-socked onto growing ropes. Although the resocking process is simple and cheap and effective Spanish equipment is already in use in Scotland, resocking large quantities is no small undertaking. Rates of resocking are likely to determine the rates at which seed deliveries can be made. The ability to re-water the mussels on arrival will also determine delivery rates. Each farm site will be different and arrangements would have to be made with collectors on logistics on a case by case basis. Transport to the Western Isles and especially to Shetland will add to logistics issues and costs.

4.3.3 Mussel seed beds

The large accumulation of juvenile mussels directly onto the substrate is termed a 'mussel seed bed'. These naturally occurring phenomenon can sometimes occur in close proximity to existing areas of mature mussel settlement, such as within the Dornoch Firth and the Wash. They are also common in locations that may not necessarily have mature beds of mussel geographically close by, such as within the Burry Inlet, along the Kent and Essex coastline, and within the Irish Sea, in Morecambe Bay and along the Cumbrian coast. It should be noted that those areas which have seed beds that persist, and which over time establish mature mussel bio-reefs, are generally not included within this determination. This is because the high levels of biodiversity evident within a mature bed of mussels mean that any commercial exploitation is likely to be curtailed[85]. Seed beds occur, and have been central in the historical development of mussel industries in the Netherlands and Germany, with the tidal flats in the Waddenzee being a principle area of regular mussel seed settlement. On a wider scale, beds of seed are also known to occur on the Canadian and US (Maine) Eastern seaboard. Generally areas which share certain physical characteristics associated with depth, substrate type and hydrodynamic connectivity with beds of sexually mature mussels, are those that are likely to have some mussel seed beds in evidence.

Many of the areas that harbour the ephemeral mussel seed beds utilised within mussel cultivation, are protected in terms of environmental management designations. The majority of the known mussel seed beds in the UK, Ireland and The Netherlands /Germany occur within the framework of areas designated as European marine sites[86] . Any activity proposed, which is not part of the management of the site has to be assessed to establish the impact of the activity. If the activity is deemed likely to have (potentially) a significant adverse effect on the site, based on the best available evidence, then that activity cannot be consented. Indeed one of the most significant pieces of case law associated with the interpretation of Member States obligations in respect of the Habitats Directive, came about as a consequence of a proposed cockle fishery in the Waddenzee[87].

[85] Within OSPAR and in the UK mussel bio-reefs are a biodiversity action plan habitat feature http://jncc.defra.gov.uk/pdf/UKBAP_BAPHabitats-04-BlueMusselBeds.pdf
[86] Collectively known as Natura 2000 sites
[87] European Court of Justice case See Case C-127/02 *LandelijkeVereniging tot Behoud van de Waddenzee, Nederlandsevereniging tot Bescherming van Gogels v Staatssecretaris van Landbouw, Naturbeheer en* Visserij (*Waddenzee); r*elevant to Article 6(2) and 6(3), Habitats Directive. This was associated with a challenge to a long established cockle fishery undertaken by fishing vessel largely based in Zeeland, bought by an NGO. The Cockle fishery in the Waddenzee was subsequently closed November 2009

There are two main user groups of the mussel seed bed; those who utilise the resource as part of a farming operation, and those who utilise the resource to sell.

There are a variety of management approaches taken in respect of how seed mussel fisheries are regulated.

In England and Wales, access to mussel seed beds which occur within six nautical miles of coastal baselines are managed through byelaw, both as a way of legitimizing a fishery for a resource which is below the MLS (45mm in UK[88]) and also to on occasion allow large vessels to undertake activity in inshore waters. The byelaw authorisations provide managers with some ability to impose controls or restrictions on vessels which wish to participate in any fishery. These restrictions may relate to vessel size, dredge size, hours/days/tides during which any fishing activity may occur. There have for example been recent extensive mussel seed bed fisheries, undertaken by vessels <14m in the North Sea off Skegness. Much of the output from this fishery was sold to German and Dutch mussel farmers[89]. Similarly mussel seed fisheries along the Kent and Essex coastlines are largely undertaken by conventional commercial fishing vessels which then sell the output to growers, in this instance most commonly in the Wash[90]. Often the largest seed mussel fishery in England occurs within Morecambe Bay, where seed settles on a series of remnant rocky outcrops. Seed from Morecambe Bay has for some time been the mainstay of the extensive mussel cultivation beds in the Menai Strait, from which vessels regularly participate in this fishery[91]. Over the last two years, this fishery has also been prosecuted by vessels whose base of operations is in Northern Ireland. The North Western Inshore Fisheries and Conservation Authority (NWIFCA) report that the mussel seed settlement in 2012 was amongst the largest seen for some time with a standing biomass in July 2012 in excess of 25,000t[92], with some 15,000t fished.

In the Republic of Ireland and Northern Ireland, it is prohibited[93] to fish for any mussels which are not directly for human consumption without a specific mussel seed licence[94]. To obtain one of these licences, which are free on provision, applicants must be registered as an aquaculture production business under the Aquatic Animal Health (Northern Ireland) Regulations 2009. In addition each company which is granted a seed licence is also awarded a TAC, based on the amount of ground available for the company to cultivate mussels and past utilisation of the resource. In theory this principle is in place to prevent any seed mussel sourced from the Irish Sea or from Cromane, (on the west Coast of Ireland), from being sold without any husbandry practices applied. Management of the Irish Sea mussel seed resource has been the subject of much research[95] as well as real time

[88] Except where local byelaws stipulate a different MLS
[89]http://www.marinemanagement.org.uk/licensing/public_register/cases/documents/lid6/esfjc_comments.pdf& Hans Neilis, Premier mussels pers comm
[90] WH Wright & DJ Bailey 'Investigations into the biology, spatial distribution, harvesting and management of seed mussel populations in Kent and Essex Sea Fisheries committee district' May 2009 at http://www.marinemanagement.org.uk/fisheries/funding/documents/fcf-mussel_seed_beds.pdf
[91]www.msfoma.org/.../Menai-Management-Association-Papers-Oct-2011.p...
[92] Mandy Knott senior Scientific officer NWIFCA pers comm..
[93] The Mussel (prohibition of fishing) regulations (Northern Ireland) 2013 (SI no 1 Sea Fisheries)
[94]http://www.dardni.gov.uk/index/fisheries/aquaculture/mussel-seed-fishery/application-for-license-to-collect-mussel-seed.htm
[95] Maguire JA et al 2007 'Management Recommendations for the sustainable exploitation of mussel seed in the Irish Sea' Marine Environment and Health Series No. 31. National Development Plan p87

management involvement[96]. However 2013 looks like another poor year in terms of recruitment of mussel seed to this Irish sea fishery, following on from 2011 & 2012. This issue has been raised recently in a debate in the Dáil[97], with the Minister for Agriculture, food and the marine recognising the difficulties which the sector currently faces and also making reference to the alternative approaches to sourcing mussel seed that the Industry and Government agencies are considering.

This study has not been able to firmly determine indications of seabed settlements within wider Scottish waters. The process of surveying potential settlement areas is not at all developed beyond the anecdotal as there has been little economic interest shown in any such resource to date. Previous reviews into the subject have also produced very little additional understanding beyond the settlements which are evident within the Dornoch and wider Moray Firth systems[98]. However discussions with some North Irish based mussel companies have suggested the possibility of some such areas off the Clyde and the wider Argyll coastline[99]. There appears to be no physical barrier to preclude such settlements occurring. As such it might be of interest for the industry or for interested agencies to undertake some *ad hoc* surveys to establish status.

The location of origin for sources of mussel seed that could be brought in to service the needs of the Scottish sector will be likely to vary on an annual basis, as the ability to anticipate whether a mussel seed bed will occur year on year is beset with the same series of environmental variables and uncertainties as any other type of juvenile mussel collection. Nevertheless it is plausible to break possible sources down to:

- Intra-Scotland (East coast / West Coast / Islands),
- outside Scotland / rest of UK,
- elsewhere (it is likely that this will be limited to anything that could be sourced from the Republic of Ireland).

However, mussel seed can be collected from a number of different sources, from shoreline or intertidal ephemeral settlements[100], such as those occasionally found in the wider Solway Firth; from offshore sub-tidal sites where it might accumulate sporadically; or from mature beds that are subject to a degree of self-recruitment where, due to carrying capacity restrictions, the juveniles are unlikely to fully recruit into the fishery[101]. These source points are all known to occur within Scottish inshore waters as well as further afield.

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[96]http://www.bim.ie/our-publications/aquaculture/
[97]DáilEireann 02/May/2013 Written answers No.195-203 at http://oireachtasdebates.oireachtas.ie/debates%20authoring/debateswebpack.nsf/(indexlookupdail)/20130502~WRW?opendocument
[98]Sublittoral ephemeral mussel seed resources of the United Kingdom – M.Syvret for the Sea fish Industry Authority.Seafish report No. SR554 November 2003
[99] Emerald Mussels, Donegal Pers comm. 2013
[100] Settlements which will not naturally persists as a consequence of non-human interventions (e.g. . annual weather cycles, high predation, exposure to tidal regimes once the bed reaches certain stage of development) -
[101] For example – The King James Tain mussel fishery – as run by Highlands Council through Highland Fresh mussel company: (James Bromham pers comm.)

Gathering of mussels from the shoreline or seabed in Scottish waters has been considered as a right of *Regalia Minora*[102] in that the Crown estate has expressed some management over the utilisation of any such fishery.

Perhaps the major concern that relates to risks of importing mussel seed to an area relate to the potential environmental harms that might manifest as a consequence of such practice.[103] As mussel seed source locations may not lie within classified production sites[104], there may not always be what is considered by some stakeholders to be the appropriate level of regulatory bio- security and environmental management oversight easily evident within the process[105]. As such, movements of 'product' do not necessarily require to be accompanied with a movement document identifying source location. However the receiving location, as a licensed production site must comply with the regulatory bio-security requirements associated with notifiable areas and diseases[106]. The areas within Scotland that are impacted by this requirement are restricted to Loch Sunart and West Loch Tarbet, both of which have had recent positive tests results for the occurrence of *Bonamia ostreae* in native oyster stock. Whilst any activity within these Lochs is free to receive inputs from other areas, any bivalve shellfish which are exported from these locations must only be taken to areas that have the same or lesser equivalent status, if there is a risk that that exported shellfish may come into contact with the new water course. The number of locations which are known to have infections of notifiable diseases present in Scotland is small and these are generally well known to the industry.

In conclusion, should the sector wish to buy in seed mussel, there are a number of potential source locations to consider, including the Solway Firth, along the Argyll shoreline and Dornoch Firth in Scotland. There are also well understood ephemeral intertidal and sub-tidal seed mussel beds within reasonable proximity south of the border, for example along the Cumbrian and Lancashire Foreshore (Siloth, Beckford Flats[107], Morecambe Bay[108]).

[102] ***Regalia minora*** Rights which belong to the Crown, but which can be made over to private individuals. These include the use of the seashore and fishing for salmon and oysters in the sea, as well as taking mussels and clams from the seabed (http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageLibrary_ShowContent&propertyType=document&id=HMCE_CL_000157

[103] Brown, J.H., McLeod, D.A. and Scott, D.C.B. 2006.Development of best practice in relation to movement of bivalve shellfish stock. Report of Project No FC1017/CSA7049 commissioned by DEFRA, 68 pp

[104] If bivalve shellfish are not been placed directly on the market for human consumption, providing the mussel are to be on-grown within a licensed and classified production site, there is no requirement to be in compliance with the requirements of classified production areas as described within Council Regulations 853/2004/EC and 854/2004/EC

[105] The importation of mussel seed from the West coast of the Republic of Ireland in 2011/12 was not subject to an appropriate assessment in compliance with the requirements of Art 6 (4) of Habitats directive 92/43 of 21st May 1992 (David Donnan SNH Pers comm.)

[106] Council Directive 2006/88/EEC – areas with known populations of animals infected with *Bonamia ostreae*, and/or *Marteilia refringens*). More recently, the new variant oyster herpes disease (Oshv-1) has also been captured by the scope of this regulation and is also now a controlled disease (under Article 43)

[107] http://councilportal.cumbria.gov.uk/Data/Cumbria%20Sea%20Fisheries%20Committee/20061201/Agenda/(item%208)%20Mussel%20Stock%20Assessment.pdf

[108] http://www.nw-ifca.gov.uk/ContentDetails.aspx

Seed from wild beds will normally be delivered to a port close to the fishery and so will then attract the same logistical costs and issues between collection and resocking on growing sites, as discussed for hand-gathered seed.

4.3.4 Stand alone mussel collection sites

4.3.4.1 General considerations

The requirements for developing sites follow a well understood framework. Planning permission through the Town and Country Planning (Scotland) Act 1997 (as amended) will be required as it is likely that spat collecting systems, even if they remain in the water only for the restricted period of highest spat fall, will breach the 28 day limit which describes a temporary installation which does not require planning consent[109]. The process of obtaining a planning consent can be arduous. However regional planning authorities seek to assist applicants in first instance by recommending that a pre-application scoping approach is made, so as to try to resolve issues prior to the full formal procedure.

Any area used within the remit of an aquaculture operation will need to be licensed in compliance with the Animal Health (Scotland) Regulations 2009, administered by the Fish Health Inspectorate. In addition, as the Crown Estates[110] express ownership of almost all the seabed within UK territorial waters, a new lease for the area would be required. For shellfish cultivation operations, these lease charges are based on the volume of equipment specified in the lease. However there is some question as to whether charges could be applied to the dedicated spat collection area. This would be a relatively straightforward process for a dedicated site owned and operated by a single legal entity, such as a business or association. However in the cases where a loose grouping of growers had taken a combined approach and jointly invested in new collection sites, then these would be considered on a site by site basis. In any case charges would be reasonable. The Crown Estates take a positive approach to marine use, providing the wider social and regulatory obligations are considered.

Given the costs involved both in equipment and in passing through the regulatory process, operators (individual companies or collectives) will only want to deploy collectors in such areas that are understood to have a greater likelihood / certainty of producing the required spat.

Should the proposed site lie within the boundaries of a Natura 2000 area, or infringes on other areas of environmental sensitivity; any development will have undergo an assessment to articulate the scale of any impact on site conservation features, on the basis of a stand-alone activity and also any cumulative effect of new developments on the overall integrity of the site. The application of the legislative framework surrounding the Natura 2000 (also known as N2K) network has been the subject of much dispute, with considerable case law already developed. Principally the foundation of N2K lies under the overarching EU banner of sustainable development and as such the EU commission have produced sector specific guidance to assist both applicant and administrators in any review of proposals[111].

[109] James Bromham, Highlands Council July 2013
[110] The Crown Estates Act 1961
[111] European Union DG environment –
http://ec.europa.eu/environment/nature/natura2000/management/docs/Aqua-N2000%20guide.pdf

4.3.4.2 Technical considerations

Globally there are two major families of spat collector deployed: the more established long line rope material which are strategically deployed in appropriate locations at appropriate times of year, and the more recent purpose built floating net systems, known as MZIs.

Rope systems

The more conventional type of collector is that which is deployable using established grow out mechanisms. As referred to earlier, the French bouchot and long line sectors deploy furred coconut rope[112] at strategic points in the year to maximize their utilisation of natural spatfalls. Similarly, whilst both the New Zealand and Galician mussel sectors are highly dependent on sourcing seed from the inter-tidal, increasing proportions of the requirements of these industries are satisfied through the deployment of collector ropes. Filgueira reported that up to a third of the Galician industry's requirements are met via rope collectors[113]. The New Zealand sector similarly has begun to broaden its horizon away from dependency on the settlement from Ninety Mile Beach, with rope collectors regularly deployed on farm sites in Coromandel and Marlborough Sounds.

The Scottish industry already uses a variety of collector rope types, (conventional pegged rope, ladders, Spanish collector rope, New Zealand continuous loops). Should this route be followed to try to improve seed supply, it is envisaged that with these materials mounted on conventional long line systems would continue to be used.

MZI systems

These novel systems have been, and to some extent remain, under development to meet the needs of the Dutch and German bottom cultivation sectors.

Work on mussel collector systems commenced in the early 2000's with an individual grower, who possessing only a small quota for taking seed from mussel seed beds, sought alternative ways of increasing supply of mussel seed. The systems themselves, for example the popular Easy Farm[114], (which is based on an adaptation of the Norwegian SMART Farm units[115]), have 100m-200m of headline below which are strung tensioned collector nets which provide the settlement surface for the spat.

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[112]Robert R, Sanchez J L, Perez-Parelle L, Ponis E, Kamermans P &O'Mahoney M: 'A glimpse on the mollusc industry in Europe' Aquaculture Europe 2013.12pp

[113]Filgueira R, Peteiro L, Labarta U and Fernandez-Reinz MJ; ' Assessment of spat collecting Ropes in Galician mussel farming' Aquaculture Engineering 37 (2007) 195-201

[114](see http://www.youtube.com/watch?v=RQ6rgK-qwGM)

[115] http://www.smartfarm.no/mussel-seed-mussels-seaweed/smartunits-for-on-growing-mussels?lang=en

Figure 5: Net-type MZI device

Source: Blueseed project

The MZIs are inserted into spatially discrete areas of the marine zone, toward the open sea and are highly regulated by number and also temporally[116].

The more exposed areas appear to have lower settlements, or settlements that are more easily impacted adversely by prevailing conditions. Prior to insertion much monitoring of the water column is undertaken to assess the larval count to establish the optimal time for insertion. Well run MZI systems will provide multiple cropping opportunities for the grower[117]. Many growers have multiple units licensed to deliver product for their farm sites. Whilst in many ways the Dutch mussel sector has internal strong bonds, these do not always easily translate to cooperative working. As such much has been invested by individual private companies into developing capacity in this area, but this is paying dividends with in excess of 9,000mt of mussel seed produced through the MZIs in 2011[118].

[116] 500 Ha in 9 MZI locations in the Waddenzee, 200 Ha in 4 Locations in the Oosterschelde – not all locations have been fully utilised by 2013 http://www.wageningenur.nl/en/show/Mussel-Seed-Capture-Installations-MZIs.htm
[117] Premier Mussels, Yerseke NL – pers comm
[118] Pauline Kamermans IMARES NL - REPROSEED 2011

Figure 6: MZI device ready for harvest

Source [119]

A useful summary of designs and harvest results suggests that the most commonly used type of collector is netting suspended from a plastic pipe[120]. Yields are said to vary between 20 and 80kg per m^2 of netting, with an average of 40kg. Other industry sources suggest a net of dimensions 5m x 100m will support up to 10t of spat mussel per cycle, although collector nets of 10m deep are also available.

The capital costs associated with MZI systems are some €10-15,000 per system excluding moorings. However many of the systems though can require very specific machinery to harvest off the seed (such as seed brushing systems) which can be are often expensive (€200,000+)[121]. It needs to be also borne in mind that the primary customers for this type of collecting medium are mussel growers with sea bed areas to grow the mussels on to market size. The vessels that are engaged in utilizing the MZI systems thus tend to be Dutch type mussel dredgers. As such, much of both the deployment and harvesting machinery has been engineered with this class of vessel in mind. Overall costs of production per tonne of seed are thought to lie in the region of between €500 and €800. Selling out price can vary from as low as €500 per tonne but on occasion can reach €2500-3000pertonne. Thus at a realistic yield of 1.5 tonne product to 1 tonne of seed laid out for ongrowing, MZI produced seed can absorb most of the crop value in a low price scenario, but also enable considerable profit in the high price situation.

[119]https://publicwiki.deltares.nl/display/BWN/Knowledge+-+Mussel+Seed+Capture+Installations
[120]http://www.mzi.nu/rapporten/wetenschappelijke-publicaties/mussel-seed-collecting-systems.pdf
[121] Premier Mussels, Yerseke,NL – pers comm

Figure 7: Automated brushing harvesting machine for MZIs

Source: Blueseed project

2013 represents a very interesting year in the evolution of the MZI systems. There has been a very substantive seed fishery (in excess of 60,000mt), the first for a number of years and which has been targeted the fleet of 65 licensed mussel dredgers. MZI systems are generally owned and operated by the same mussel farming companies that also still have the ability to fish for wild mussel seed. However timing dictates that MZIs are deployed in early spring each year, often before the amount of wild seed available to be fished that year is evident, so costs associated with MZIs continue to be incurred.

MZIs would be new to Scotland, but the technology involved is not complex, (apart from possibly the harvest machines). Floatation pipes are the same as those in common use for salmon farms and anchoring systems will also be similar to those currently used for mussel long lines. Visual impact is very low[122] which may aid planning issues if potential sites are in sensitive locations. Harvest brushing machines would need to be sourced from Dutch manufacturers, or self-built, with significant modifications to large work boats needed to mount and operate the machines.

As with stand-alone rope systems, potential locations for, and timing of, deployment of MZIs locations would ideally be guided by significantly better understanding of larval distribution.

4.3.5 Hatcheries

Hatchery production of spat is central to the global production of much other bivalve aquaculture. For oysters and clams it is an accepted part of the process. In the UK, (including Guernsey) there are three commercial hatcheries in operation: Seasalter (Whitstable) in Kent, Seasalter (Walney) in Cumbria, Guernsey Sea Farms, and Viking Seafarms in Argyll. These are principally engaged in the

[122] see for example review of MZI's listed above and Smart Farm website http://www.smartfarm.no/mussel-seed-mussels-seaweed/smartunits-for-on-growing-mussels?lang=en

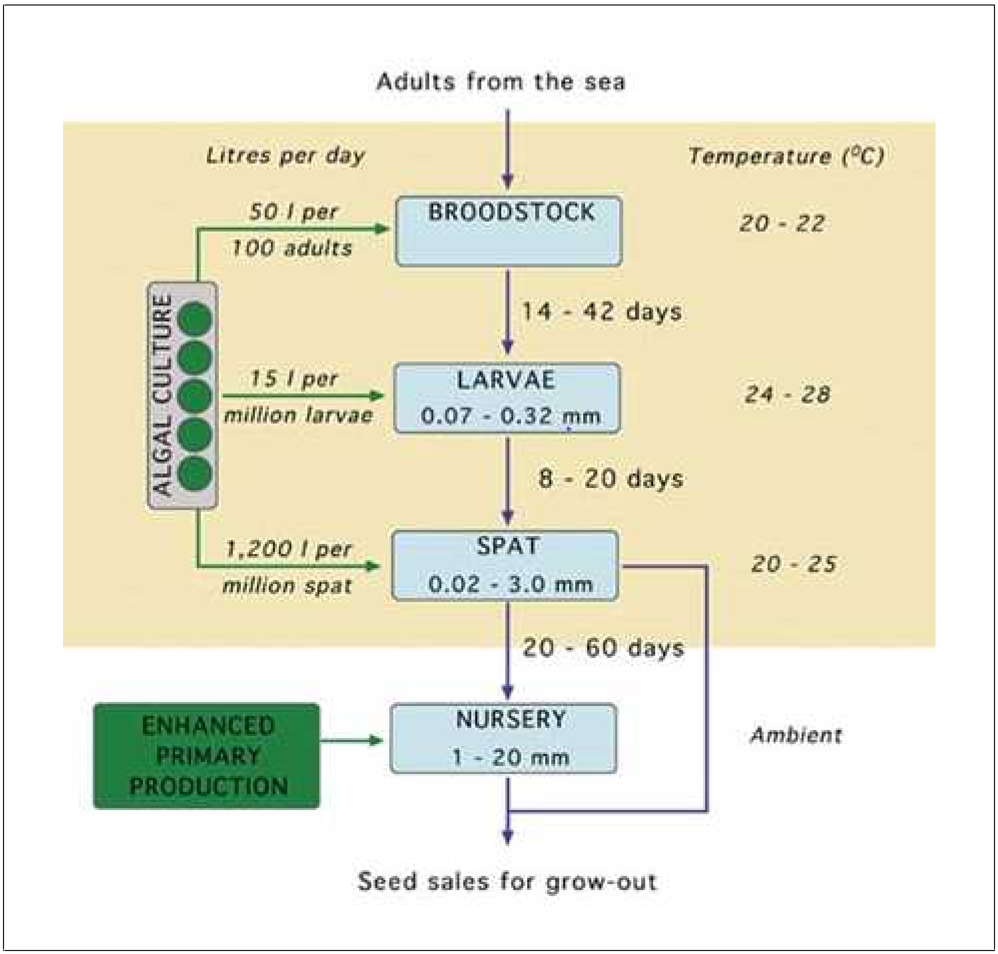
production of Pacific oyster (*Crassostrea gigas*) seed to supply oyster farmers in the UK and further afield. The UK hatcheries have also been occasionally involved in cultivating and supplying small amounts of other bivalve seed such as clam seed (mainly Manila clam – *Ruditapes phillipinarum*, though also small amounts of palourde carpet shell clam – *Ruditapes decussateus*). However none, to date, have commercialised assets toward the production of mussel spat. This situation is mirrored across Europe[123].

An additional and currently influential factor that requires note is the impact on the UK hatcheries of the creeping geographical extension of new variant oyster herpes ($OsHV_{-1}$) across from France and the Republic of Ireland. This has effectively closed down access to both Seasalter (Whitstable) and Guernsey Sea Farms to Scottish oyster producers already. Seasalter (Walney) announced, earlier in 2013, that Loch Fyne Seafoods (LFS) had taken a controlling shareholding in their operation[124], a move in part motivated by LFS need to better ensure that their oyster seed needs are met.

The techniques to cultivate mussels, of the Family Mytildae & Perna spp, currently the two most highly cultivated mussel families, are well established and understood, both through significant research effort in New Zealand[125], Canada[126], in the Netherlands[127] Italy and elsewhere[128], also by extrapolation from other bivalve species, particularly oysters. The needs of the two species are not dissimilar. Although most users of this report will be familiar with the main components needed in a bivalve hatchery, it is worth briefly summarising requirements.

[123] http://www.reproseed.eu/Dissemination/End-users/Molluscs-hatchery-development-in-Europe
[124] http://www.lochfyne.com/press_releases/loch-fyne-oysters-invests-in-morecambe-bay-oysters/
[125] http://www.stuff.co.nz/nelson-mail/news/3581392/Firms-unite-on-mussel-spat-supply
[126] http://viudeepbay.com/2012/04/13/debuting-our-new-compact-shellfish-research-hatchery/
[127] http://archimer.ifremer.fr/doc/00126/23737/21744.pdf
[128] http://www.reproseed.eu/Dissemination/End-users/List-of-European-hatcheries

Figure 8: Simplified process flow for hatchery production of bivalves



Source: Helm et al, FAO manual[129]

[129] FAO FISHERIES TECHNICAL PAPER 471, Hatchery culture of bivalves, A practical manual, Prepared by Michael M. Helm, FAO Consultant, Nova Scotia, Canada and Neil Bourne, FAO Consultant, British Columbia, Canada, FAO 2004, available at http://www.fao.org/docrep/007/y5720e/y5720e00.htm#Contents

Figure 9: Mussel broodstock, (Blueseed Project)

Photo: authors

The key component to successful hatchery production is a reliable source of good quality algae as feed. Algal production is split into various stages and involves laboratory and sterile conditions initially then successively larger growing containers to produce the bulk supplies needed. This takes a significant space, skilled labour and energy, principally for light. Light requirements in later stages can be met by outdoor culture in low latitudes but this possibility is limited in northern Europe.

Figure 10: Typical mass algal culture facilities, Spain

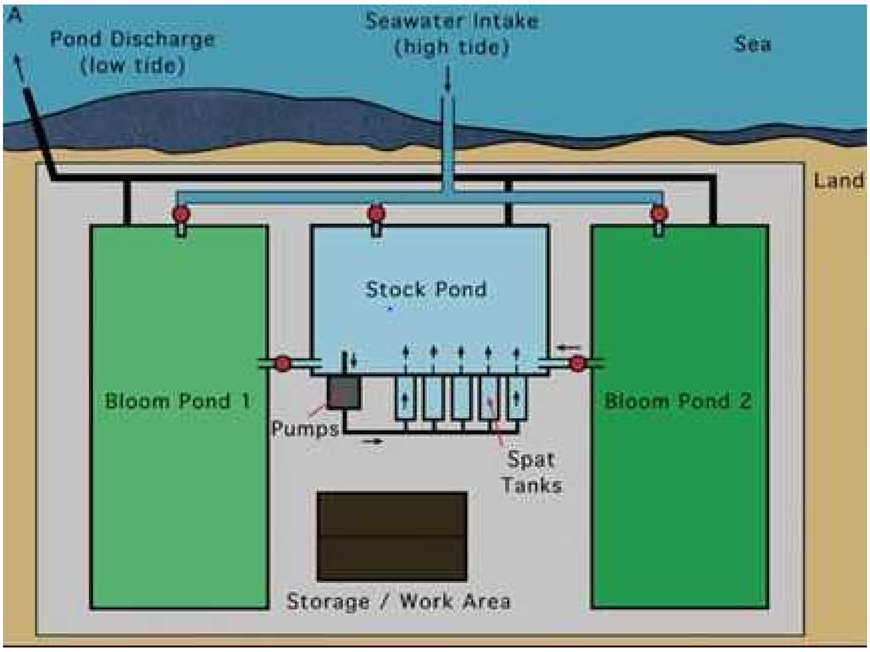
Source: Reproseed project

Figure 11: Typical shellfish larval rearing tanks, Spain

Source: Reproseed project

The algal feed requirements increase rapidly as the stock grows. Once past certain growth stage of perhaps 2-3mm in most species, the controlled production of algae in hatchery conditions becomes impractical and some kind of nursery rearing is used to bring the animals to a size where they are suitable for stocking in the sea for ongrowing. The primary consideration is again algal supply and nursery systems are usually depend on outdoor natural or constructed ponds which are fertilised to produce algal blooms, which then grow in natural sunlight.

Figure 12: Simplified layout for nursery production of bivalves



Source: Helm et al, FAO manual

There are very many variations in the nursery stage, both land and sea based, and much depends on species, the facilities available, climatic conditions, the requirements of the ongrowing systems. Most commercial hatcheries are integrated with nurseries and have evolved these basic methods and processes to suit their local conditions and markets.

The reliable and cost effective production of mussel seed in Europe has been one of the central objectives of two large pan-European research projects; REPROSEED[130] and BLUESEED[131] and an INTERREG IIIA project with participants in the Republic of Ireland and Wales[132].

The opening paragraph of the BLUESEED report articulates well the justification of utilising hatchery technology to produce mussel seed.

A more reliable seed supply, and the possibility of bringing "all-season" mussels to the market will enhance competitiveness in all European Atlantic blue mussel producers. The availability of hatchery-produced seed will bring more stability to the market, long-term security in jobs, development of coastal areas and alternative jobs and products to fisheries.

It is a useful exercise to break down this paragraph into its constituent parts and focus on what is being said and finally what is not mentioned.

[130] http://www.reproseed.eu/Home-page
[131] http://www.blueseedproject.com/index.php/51/results/
[132] Technological and Scientific development of mussel hatchery techniques in Ireland and Wales – INTERREG III A project (ref 55432) University of Wales, Bangor and University College Cork

'A more reliable seed supply..' Shellfish Hatcheries in Europe reliably produce juvenile shellfish seed for a number of different species that are economically important for the sector. Often hatcheries will have their annual programmes organized in cycles that mirror the requirements of the species being grown. Thus for current UK hatcheries, with *Crassostrea gigas* far and away the dominant product demanded, the hatchery assets are set up in such a way as to maximize the production of the spat oysters. For a hatchery to set up for producing mussel spat - from the point of identifying and collecting broodstock, to bringing the animals into optimum condition, preparation of the primer populations of phytoplankton and so on - is a multi-month process and one which incurs substantive cost for the hatchery operator. Thus, for a hatchery engaged in the production of mussel spat, pre-production contracts would have to be signed with prospective customers to provide the hatchery operator the same level of assurance. Any other approach would be a considerable business risk as there is no guarantee that mussel growers would complete an order, particularly if natural spat settlement met the growers' needs.

..possibility of bringing "all-season" mussels to the market will enhance competitiveness in all European Atlantic blue mussel producers . For any mussel spat produced inside a hatchery system in regions where natural settlement of spat also may occurs, to be of interest to the grower, it needs to be distinct. Hatchery technology is a route to selective breeding which could in time produce juveniles ready to place out in the sea at any time of year.

The BLUESEED project final report states that year-round spawning can be achieved. However although improvement from year one to year two of the project was evident, there still appears to be significant seasonality is success of spawning and d-larvae production.

One of the outputs from the BLUESEED project, was the development of techniques to produce triploid mussel spat. Triploid (3n) mussels are those with an additional chromosome, making the animal sterile. This has the benefit of providing a year round mussel available to the market that does not lose condition during its breeding cycle, as conventional diploid animals do, my directing much energy to development of their reproductive organs. This new product can only be produced in hatchery environments and to date the take up of interest in a triploid mussel has been minimal. Perhaps one of the reasons for this is that the market is conservative. From a technical perspective, there are difficulties associated with inducing triploidy in bivalves. Of the two main approaches, the most effective is to use tetraploid (4n) broodstock. The technique to produce these tetraploids however is subject to a patent[133] and all users must be licensed. In Europe IFREMER hold exclusive rights to use this method until 2015, as they sought to apply its techniques toward the production of *C.gigas*. 3n oysters compose about 30% of all oysters produced in France currently[134]. The alternative method of inducing triploidy involves using a chemical stimulant (a mycotoxin called cytochalasin B – a known carcinogen) during meiosis to prevent the 'natural' reduction of one set of chromosomes succeeding. Whilst this technique is standardized, it is relatively crude and a proportion of the induced triploid spat are known to revert back to diploid, thus undermining its validity and purpose.

[133] Appl. No. 08/895,077 – Inventors :Guo, Ximing, Allen, Stan J – filed July 16 1997 exp July 16 2015
[134] Although 3n oysters are still impacted by disease such as $OsHv_{-1}$, so subject of much recent mortality

For hatcheries looking to supply mussel spat to an accepting market it may be that 2015 represents something of a change. The fall of the Rutgers University patent (held by 4C technologies[135]) should enable the widespread use of the 4n approach to production of 3n animals.

The availability of hatchery-produced seed will bring more stability to the market, long-term security in jobs, development of coastal areas and alternative jobs and products to fisheries. Hatchery produced mussel seed can potentially deliver on all these aspirations. Given the uncertainty and unreliability of natural settlements of mussel seed, the amount regional producers grow will vary, sometimes substantially on a year by year basis. Having a regular and reliable alternative source of spat will iron out these peaks and troughs.

The final sentence of the BLUESEED paragraph is important as it raises the issue of costs of production. Hatchery operations can be extremely costly as well as very extremely complex. For production of sufficient numbers of spat mussels to satisfy the requirements of a small but growing sector, such as that in Scotland, substantive amounts of space would be required within the hatchery proper, as well as for production of the necessary algae for conditioning and feeding purposes. For the nursery stage, as mentioned there is a need for substantial ponds or similar to bloom algae so as to supply a continuous feed source in aerated floating upwelling systems within proximity of the hatchery site. It should not be forgotten that whilst a hatchery can produce a reliable supply of bivalve spat of variety of species, there are risks, often significant, associated with the mass production of early life stages of marine animals. Catastrophic mortalities may be experienced as the result of equipment failure, pathogenic infection, or issues associated with failures of the feed algal supply. This could have major strategic implications for an industry potentially dependent on a single hatchery.

There are a multitude of other resources and opinions available associated with the pros and cons of producing shellfish spat inside hatchery environments. Some of the most pertinent come from countries (or parts of countries) not associated yet with mass production of mussel.

From the west coast of Canada, Vancouver Island University undertook a scoping exercise looking at the viability of a stand-alone shellfish hatchery on its Deep Bay research campus[136]. It concluded: *A new BC stand alone hatchery is only economically feasible if funding for capital costs (for building construction and equipment) and purchase/ lease of a suitable site can be obtained from other sources.*

A global review of hatcheries by the Nuffield Scholar Ian Duthie based in Australia[137]calls for nations to embrace hatchery technologies where appropriate and enable shellfish cultivation to attain its fullest potential. In Australia, Tasmania is home to one of the few commercial mussel hatchery operations producing *M. galloprovincialis* (Spring Bay Seafoods[138]).

Another report from British Columbia commented on the concepts of “modular hatcheries”, which has been of some interest globally for various species including for example lobster[139] . The basic

[135]http://www.4cshellfish.com/about-triploidy/natural-triploidy.php
[136]http://www.viu.ca/csr/documents/HatcheryFeasibilityReport080606CSR_002.pdf
[137]http://www.nuffieldinternational.org/rep_pdf/1360548206IanDuthiefinalreport.pdf
[138]http://www.springbayseafoods.com.au/
[139] http://aquahive.co.uk/Hatchery-in-a-Box.html

process flow for shellfish hatcheries discussed above is unavoidable, although efficiencies are often common through phased production. This study has not been able to find any objective information to shed more light on economics of "modular hatcheries" compared to others. However, a recent unpublished review of work undertaken by Island Sea Farms, from Salt Spring Island in British Columbia on a Department of Fisheries and Oceans contract, concludes that *innovative technology that proved, through implementation and optimization, that an innovative hatchery design scaled to production levels and modular in design is the key to accelerated hatchery production. The modular hatchery has allowed Island Sea Farms to expand mussel production, improve environmental performance, and have a proven technology to market locally, nationally and internationally*.[140]

The supply of spatted mussel ropes is not uncommon on the US West Coast, with both large hatcheries (Coast seafoods[141]& Taylors Shellfish Farms[142]) able to produce just such a product. Taylors retail out spatted mussel rope for $17 per foot – (which equates to about $56 per metre or £35 per metre. It should be noted that both these facilities, and others in the region such as Island Scallops of Vancouver Island, are also vertically integrated shellfish producers in their own right. This is also true of another functional mussel in Australia, at Spring Bay Seafoods, in Tasmania, which is the sole mussel hatchery functioning in Australia without additional Government support. Duthie suggests that the prices evident in the US are approximately 50% of those evident in Australia.

Marine Scotland have expressed support for the development of an economically viable shellfish hatchery in Scotland. There are clear strategic benefits in having just such a facility in Scotland, with issues associated with the sufficient provision of not just mussel spat, but also oyster (*C.gigas*) and heightening concerns over the natural recruitment of king scallops (*Pecten maximus*). Such a facility would require significant capital investment and a suitable site with coastal ponds (or land from which to construct them) for nursery lagoons. So as not be reliant on ongoing Government financial assistance, such a facility in be able to be viable not only in terms of running costs, but in servicing costs of capital and equipment depreciation. Even if seed could be produced at a price that was acceptable to growers, (see later discussion) the market would be variable depending on natural spat fall available to growers.

For prospective UK prices, the BLUESEED project developed a functional economic model for making an assessment of likely costs. Although the model had limitations and was aimed at the bottom growing sector, the project also made some useful comparisons with estimated mussel seed production costs from other commercial or R&D hatcheries around the world.

The omens for successful establishment of dedicated mussel hatchery facilities are not good. The REPROSEED project, which aims to develop more reliable and cost effective ways of producing bivalve mollusc seed, has largely directed efforts at other species such as scallop, because of concerns associated with costs of production and demand for mussel spat. The project has had some success in undertaking induced metamorphosis trials that would assist in developing a line of products, similar to the Taylor Shellfish farms, of ready spatted rope. However attempts to improve on closed recirculation systems for the supply of mussel larvae and open systems for elevated production of feed algae have been less successful. It is of some significance that Roem Van Yerseke

[140] Island Sea Farms Hatchery development Report April 2012 – Linda D Hiemstra
[141] http://www.coastseafoods.com/facilities.html
[142] http://www.taylorshellfishfarms.com/about-taylor-shellfish.aspx

– one of the Industrial partners in both the REPROSEED and BLUESEED projects, who have developed their own hatchery capacity - have recently pulled these assets away from the production of mussel spat in the hatchery environment.

It has been suggested during the course of this study that some kind of "low cost" or simplified "artisanal" hatchery could offer potential in the Scottish situation. The rationale would be that the seed were kept in the indoor and controlled, and so expensive, part of the process for as short a time as possible, before being transferred outside to ponds or other enclosures with enhanced algal production. The literature review set out in section 2 is quite exhaustive and has been carried out with a view to unearthing published information on potential low cost alternate routes of seed production. There is some evidence of "low cost" hatchery routes in western USA and Canada. As has been discussed, in the former, a commercial shellfish hatchery 1mm seed is settled directly onto ropes and then sold to growers. There is no information on stocking densities, growth and survival rates, nor how much production arises from this route. The price mentioned earlier is the only information available and emails to the firm involved have not elicited response. In western Canada trials have been undertaken at R&D facilities whereby hatchery raised seed are put to sea in an intermediary holding device (frames) as soon as possible, with the nursery stage essentially carried out in suspended culture in the sea and so potentially lower cost than they would be on a land-based facility. Again there is no information on actual amounts produced, nor economics.

It is thus very difficult to provide useful guidance on methods nor production economics that might apply to a Scottish situation. It appears that to produce large quantities of larvae in controlled conditions, it is unavoidable that the conditioning of broodstock, spawning, larval rearing and settling would all need to be carried out in a conventional hatchery facility, based on land and with relatively large volumes of cultivated algae. Such facilities are inherently expensive to build and run. Savings can only realistically be made by moving spat out at the lower end of the range shown in the process flow derived from Helm et al (Figure 8 above). It is worth noting that all attempts to commercialise mussel spat production elsewhere have taken place either in commercial facilities primarily aimed at producing other bivalves, (mostly oysters), or some kind of R&D situation where true costs do not have to be recovered by sale of spat. To maximize efficiency and lower cost in the expensive hatchery stage, production year round would be necessary, through broodstock conditioning and controlled spawning. At many times of year in Scotland, this route would entail transfer of spat outside or into the sea when primary productivity was low, so onward survival may well suffer. Possible ways forward in the longer term with existing commercial hatcheries serving the Scottish sector are discussed in Section 5.

5 Economic aspects

5.1 Introductory comments

This section of the study attempts to assess the business cases of employing some of the novel approaches to seed supply. This can be used to inform choices as to possible ways forward for acquiring the seed needed to meet long term growth aspirations.

The assessment is in two steps:

1. Scope to absorb costs.

   This looks at the potential scope for industry to absorb the likely additional costs associated with novel sources of seed supply. This assessment uses two sources:

   a) existing simple profit and loss models
   b) extrapolation of the industry survey for this study.

2. Estimations of costs of alternatives.

   This step looks at the likely costs of the main alternative sources of seed supply discussed in Section 4.

To assess viability, the costs of each alternative sources in Step 2 are simply compared to the margin estimates from Step 1, both at the unit weight basis (cost per tonne harvestable product) and at the whole industry level.

As is clear from the discussions above, potential novel approaches are for the most part untried in Scotland, (apart from adaptations to existing practices). Novel approaches to seed supply elsewhere have generally been developed in the context of particular circumstances of given production systems and their markets in different locations. Therefore what limited cost data as is available can only loosely be applied to the Scottish situation.

The following discussions should thus be taken as very approximate and represent a framing or bounding of possible costs and benefits, as opposed to firm guidance for investment. They are inherently too approximate to justify any more detailed methods of economic analysis than a simple test of the effects on margin.

5.2 Scope to absorb costs of alternatives

The cost models in the report by Scott et al at the 500 tonne level (without grant[143]) suggest production costs of around £700 per tonne in 2010, implying an approximate margin of £300 per tonne. The model for the 100 tonne farm selling "off the ropes" suggests costs of £530 per tonne

[143] All discussions of costs models in this study are on a "without grant" basis. Scott et al show inclusion of capital grants can make a significant difference to various indicators of viability for mussel farming projects . However it is not certain at what level, if any, grants under the new EMFF will be available, so are omitted for safety at this stage.

(without grant) and selling today might be some £600 per tonne, so a margin of £70 per tonne. A rough industry-wide margin based on a blend of the two is taken as some £200 per tonne on a unit weight basis. At the whole industry level, potentially the industry has scope to absorb a maximum cost of (6,000 tonnes x £200 = £1.2m) per year for an optimum seed supply on a continual basis.

This figure has several provisos.

1. Discussions with industry suggest that actual margins may be lower than reported by Scott et al in several cases. Aside from spat issues, factors such as predation, drop off, fouling, water quality and, particularly acute in 2013, toxic algae, as well as machinery, labour, transport issues etc., can all work to erode actual margins, which are understood to vary significantly between sites and businesses.
2. Although there is an apparent shortfall of seed at around 50% below optimal, this is a crude estimate from a sample of industry, which at face value implies that there is space within existing farms to grow double current quantities of seed, should it become available. It seems likely that, in practice, spare usable capacity is not as great as implied and any increment in spat supply is likely to be patchy in time and space. Thus, to take advantage of potentially increasing supply levels, it seems likely that some additional capital expenditure (capex) will be needed to increase growing capacity - either refurbishing or expanding existing sites, or developing new ones. Apart from liquidity issues, (discussed later), increased capex will have a depressing effect on residual margin available to spend on seed.
3. It is also likely that investors putting in capex and/or additional working capital needed to grow out increased quantities of spat would want to see better returns than those currently achieved. The actual margin across the industry which could be devoted to sourcing spat is thus likely to be significantly lower than the above estimate.

On the other hand, the margins reported by Scott et al will already incorporate a degree of sub-optimal experience with spat supply, also other production problems, and margins per tonne would move upward with efficiencies gained from optimal seed supply. Thus combining all these factors, at a reasonably conservative view that the industry could potentially devote 25-50% of existing margins to new seed supply, the bounds within which potentially tolerable costs of optimised seed supply lie is perhaps £300,000 to £600,000 per year, on an industry-wide basis.

Industry interest in alternative sources

Another estimate of capacity to absorb costs to acquire seed has been derived from the industry surveys. As part of the survey described in Section 3, producers were asked to comment on the interest and affordability of five possible future alternative sources supplies of seed in Scotland.

The choices of type of seed and likely size range were set out in the questionnaire and are reproduced here for ease of reference.

Table 4: Possible future seed sources and indicative sizes

Alternative seed source
Wild seed from dredged sources,(typically 15-25mm, in bulk for socking)
Wild seed inter-tidal hand gathered, (typically 15-25mm, in bulk for socking)
Wild seed from suspended collectors, (typically 10-20mm, in bulk for socking)
Wild seed on ropes, (typically 10-20mm)
Hatchery seed on ropes, (typically 1mm)

The affordable price level was requested in the context of average financial circumstances of the farm business and delivered to the farmer's jetty.

Table 5: Interest and affordability in possible future seed sources

Respondent code	Interest					Affordable price				
	Wild dredged	Wild hand gathered	Wild from collectors	Wild on ropes	Hatchery on ropes	Wild dredged	Wild hand gathered	Wild from collectors	Wild on ropes	Hatchery on ropes
1	nr	nr	nr	nr	nr					
2	yes	no	yes	yes	no	£400 / t		£400 / t	£400 / t	
3	no	no	no	no	no	£200 / t	£200 / t	£250 / t	£0.75 / m	£1.5 / m
4	no	no	yes	no	no			£500 / t		
5	no	yes	yes	yes	yes		£300 / t	£400 / t	£2 / m	£2 / m
6	yes	yes	yes	yes	yes	nd	nd	nd	nd	nd
7	no	no	no	no	no					
8	no	no	no	no	no					
9	no	no	no	no	no					
10	no	no	no	no	no					

nr = no response, nd = no data provided

Under half of the producers expressed an interest in buying in seed from alternative sources, were it to be available. The producer coded 3 stated that their farm aimed to be self- sufficient and they would only consider buying seed if there was a total failure. That producer has nevertheless indicated affordable prices. On the other hand producer 6 has indicated interest in all sources but not given a view on affordability.

Of the alternatives, wild seed from dedicated collectors generated the most interest, followed by wild seed settled on ropes. Wild seed from dredging, inter-tidal collection and cultured seed from hatcheries ranked equal third in terms of interest from producers.

Views on affordable prices are informative. For all types of bulk supply for resocking, the range is from £200 to £500 per tonne delivered. Different producers seem to have differing price ranges that are applied across the board. The source of most interest, wild seed from dedicated collectors, seems to be valued the most highly, with producers coded 3 and 5 marking it out as more valuable than other bulk sources. From discussions with industry, prices per metre for rope seeded wild and hatchery seed are probably linked to recent experiences in local inter-farm trading of seeded rope. One producer attached a higher value to the hatchery seeded rope compared to wild, probably on the basis of size and so number of seed purchased per metre.

Estimates of quantity likely to be of interest on a regular basis were requested on the basis of likely response to a) natural settlement being 50% of optimal and b) the business being in its average financial position. Responses and are shown below.

Table 6: Estimated volume requirements in possible future seed sources

Respondent code	Volume considered				
	Wild dredged	Wild hand gathered	Wild from collectors	Wild on ropes	Hatchery on ropes
1					
2	50 t	0	50 t	50 t	0
3	0	0	0	0	0
4			20 t		
5		20 t	100 t	10,000 m	10,000m
6	5 t		10 t		
7					
8					
9					
10					

Combining information from Tables 4 and 5, this sample of producers represent combined potential purchasing as follows:

Seed type	**Amount**	**Notional unit price**	**Notional value**
Wild dredged	55t	£300/t	£16,500
Wild hand gathered	20t	£250/t	£ 5,000
Wild from collectors	180t	£400/t	£72,000
Wild on rope[144]	~70t	£600/t	£42,000
Hatchery on rope	10,000m	£1.75/m	£17,500
Total			**£153,000**

[144] Notionally assumed 2kg/metre

The total combined willingness to pay of some £150,000 is derived from a sample of 20% of industry capacity. Extrapolated to the whole industry level, this would create an apparent willingness to absorb costs around £750,000 for optimal seed supply. Extrapolation is of course highly uncertain and may be biased as a result of those with more interest and willingness than the average to purchase seed responding disproportionately to the questionnaire. On the face of it, this industry-derived method provides an estimate of willingness to absorb costs somewhat above the estimate of potentially tolerable costs (£300k-£600k)derived from the profit and loss models discussed earlier.

Although a small sample, it is worth noting the preference for wild seed from suspended collectors, amounting to around half of the overall total in value terms.

5.3 Costs of alternative approaches

Discussed below are estimates of costs of each possible measure aimed at improving spat supply discussed in Section 4. As mentioned already, they are highly approximate.

5.3.1 Improvements to current practices

Improved monitoring

Monitoring of the environment local to the farm to improve timing of spat collectors could be quite simple and straightforward.

At a farm level it is estimated to need two people (for safety) a small boat and 1 trip per week to monitor mussel larvae in the plankton. Capex for specialist equipment would be in the area of £500 or so, assuming the boat and shore base were already available. For running costs, very approximately one could assume a wage rate of £10 per hour and 6 person-hours per week for six months over spring and summer (at most), and fuel costs of £30 per week. Thus running costs of such an operation would be (26 weeks x £10 x 6 hours) +(26 x 30) = approx. £2,300 per year, covering say 2-3 sites in reasonable proximity. This estimate could be revised up or down for smaller or larger businesses. At an industry level of say 50 active businesses (from MSS annual report) overall costs would be in the area of £120,000 per year.

A monitoring support service on the PEI model, but reduced to measuring fewer parameters and incorporating three teams might cost the following:

Capex	
3 x boats/trailers	£90,000
3 x sampling kit, microscopes etc	£ 3,000
Total	£93,000
Operating	
6 x biologists x 6 months x £3,000/m	£108,000
Boat running/dep'n	£ 15,000
Mileage, ferries etc	£ 20,000
Subsistence (crude estimate)	£ 50,000
Website, office support	£ 20,000
Total	£213,000

These figures are at best illustrative. Actual capex needs on boats, vehicles etc are likely to vary, depending on what local and hybrid arrangements could be made, for example with NAFC in Shetland or with SAMS.

The likely cost of initiatives that were identified at the SAMS workshop in February 2012 are unknown. The proposal is for multi-year monitoring and so costs are likely to be significant, perhaps £100,000 or more.

Ad hoc surveys for mussel seed beds in Scottish waters are also likely to be expensive. They ideally need a research vessel or a fisheries patrol vessel or similar and specialised sonar. Side scan sonar is utilised in Ireland by both BIM and The Agri-Food & Biosciences Institute when undertaking their surveys with impressive visual results. Surveys are thus likely to cost tens of thousands of pounds, depending on intensity and regularity.

Benefits from increased monitoring, surveys, modelling studies and so on cannot be predicted quantitatively. More information built up over time and more detailed knowledge of water bodies could provide better strategic deployment of collectors in time and space. It is likely in time that this will make better use of whatever settlements are available and so fill some of the demand gap identified. Of course these measures are no remedy for any profound long term environmental influences on spat levels which may be occurring.

Surveys searching out exploitable seed beds potentially have the chance to identify a completely new source of seed for Scotland.

Under utilised sites

The costs associated with converting under-utilised sites into spat sites are likely to be very specific to individual business situations. Sites need to be within a workable distance and some form of arrangement will be needed with the existing lease holder. It goes without saying that, before considering a reinstating a site, some local investigation and monitoring of the biological situation should be undertaken, should the business not already have thorough local knowledge of settlement patterns in the area of the unused site(s). Thus allowance may need to be made for some feasibility / start-up costs along the lines discussed earlier.

Installing trial longlines with settlement ropes on unused sites are likely to be in order of those shown by Scott et al, for a growing line of 200m in a low energy site, i.e. around £10,000. Use of second hand equipment could reduce this.

Benefits from making use of unutilised sites could be significant. Good settlements at a spat site might provide ropes which could be transferred directly onto an ongrowing site and achieve around 40 tonnes per long line after two years, the typical industry yield noted by Scott et al. Further benefits from settlements gained from such sites could be made with thinning part grown stock to increase yield. At the other end of the range, benefits could be negative, should deployment in old sites provide little or no settlement and capital and operational expenditure involved turn out to be wasted.

5.3.2 Buying in seed

Hand gathered

The costs of hand gathered mussel seed appear to vary little year to year, with a tonne of seed available for approx £150-180"off the beach"[145].

Critical to judging economics of bought in seed is the yield likely to be achieved (harvest weight: seed weight), from beach sourced seed.

Possible guidance on seed yield from other industries discussed in the literature review are shown in the table immediately below.

Table 7: Indicative yields expressed as Harvested weight: Seed weight in different industries considered.

Industry	Indicative yield	Comments
New Zealand rope	350:1	Very small seed, 0.5mm, high husbandry, (2 x thinning in growth cycle)
Galicia, Spain rope	25:1	Small seed, c 1-2mm, high husbandry, (2 x thinning in growth cycle)
PEI, Canada rope	5:1	Bought in from other rope sites, no thinning after stocking
Holland, Wales on-bottom	1.0 to 1.5:1 1.5 to 3:1	Dredged seed > 20mm, high predation MZI collectors 5mm, high predation

The PEI example is probably closest to what would be achieved in Scotland, given their buying in methods and husbandry practices post-stocking. A rough cross-check on possible yields can be made on a numbers basis, using a variety of information:

- Seed supplied from beach approx 2g, 25mm, (own experience).
- Bonnardelli's examples[146] of ideal density of mussels on lines as being between 500-600 per metre of rope at harvest.
- Natural drop off from 25mm to harvest at c 50mm = 50%, based on rough extrapolation of Bonnardelli's biomass estimation data[147]
- Numbers needed at stocking therefore say 1000 per metre, or 2kg per metre
- Harvest 9.1kg/metre (source Bonnardelli as above)
- Ratio therefore approx. (9kg / 2kg) = 4.5:1

Seed would need to be transported to the farmer's jetty and thence socked and transferred onto the longlines on site. Knowledge of transport costs suggests some £70 per tonne based on a full load truck of 22 tonnes from e.g. Morecombe to west coast Scotland giving a delivered price of some £250 per tonne. This estimate coincides with what industry feel is a fair price as derived from the survey (see Table 5). Note this estimate assumes that seed would be transported in bulk loads. As discussed in Section 4, there may be logistical problems in handling and resocking large quantities

[145] Irfish, Dunmore East, Republic of Ireland – pers comm. August 2013
[146] John C Bonnardelli (p8) The Grower March 2012
[147] http://www.aquacultureinsurance.com/media/Airm12_PDFs/airm2011-Stock-Control-and-Assessment-Strategies-for-Shellfish-Growers.pdf

and smaller loads may be needed, so pushing up transport costs. On the other hand sharing loads with farmers in the same area could mitigate this factor somewhat. Costs of delivery to the Western Isles and Shetland would be higher. Re-socking is estimated very roughly £150 tonne of seed. The total cost installed on the longlines might thus be £400-£500 per tonne or so, but with a lot of variability depending on source location, scale, local conditions and logistics. At a 5:1 yield, the effective seed cost per tonne harvested would be some £100.

This would be within the margin of some £300 per tonne for the 500 tonne per year model farm discussed earlier, and so at this level bought in seed appears to be a viable solution. At the 100 tonne scale farm with a £70 margin, the benefit appears doubtful. As mentioned earlier, Scott et al's cost models are based on industry feedback in the years up to 2009 and so contain some inherent seed shortages. Working a fully stocked farm (or part thereof) should see some efficiency improvements, so raising margins somewhat. Note also sales prices assumed in this study are working estimates. Any growers contemplating this approach should undertake careful analysis based on their own costs and likely income and consider possibly small-scale trials in the first instance to prove yield in their local conditions.

It is understood that mussel seed from the Solway Firth was offered for sale to (a portion of) the Scottish rope sector (and any other takers) in 2011, however without much uptake. The survey for this study elicited relatively little interest in seed from intertidal (of sub-tidal) beds at present, perhaps around 100 tonnes per year if scaled up from the sample of responses received.

Mussel beds

Mussel seed which is harvested by a dredger can in many instances be available for as low a price as £100-120 per tonne on a quay wall. However this is subject to opportunity costs associated with whether the vessel fishing the seed mussel was part of an aquaculture enterprise and was seeking to ongrow seed fished (to point of saturation), or if the vessel participating in the fishery was specifically doing so to sell the resource onward (as is common in both the Thames and East coast fisheries in England). On average, seed harvested by vessel will have already obtained a large enough size to be easily gathered or fished so will not often be <20mm and sometimes > 40mm.

The economic parameters for using mussels sourced from sub-tidal beds will be similar to those discussed for hand-gathered stocks above. Farmers would have to spend considerable time engaging with potential suppliers throughout the UK and be prepared to take advantage of opportunities rapidly as they arise.

Investment in a sea going second-hand dedicated dredger to exploit this source would be around £500-750k and would also entail significant running costs. It would give some independence of operation and would probably only be viable if significant and reliable beds were found in Scottish waters. One would think (and some of the growers in the North Ireland believe) that there must be such areas. Anecdotally, there have been settlements before in the Solway and Wigtown Bay and also on the Argyll coast, in addition to on the east coast in the Dornoch Firth and wider Moray Firth area. It would also need steady and significant purchase by the rope growers. As with intertidal seed, interest from industry currently appears to be limited, perhaps 250 tonnes per year at an acceptable price of £300 per tonne if responses gained are scaled up. This would probably not cover the running costs of such an operation. It would appear that there would need to be a strategic and coordinated approach to operating a dedicated dredger for the Scottish industry with uptake of 500-1000 tonnes purchased and stocked per year to make the approach viable.

5.3.3 Stand alone collector sites

Rope systems

This approach is similar to that described for using under-utilised sites, but goes above and beyond it with dedicated new sites being subject to the planning process. Actual costs of establishing a rope-based collector site would vary greatly depending on the individual situation. It is assumed that it would be undertaken by a business which was already farming mussels and so would share assets such as shore base, boats etc. There would also need to be a high degree of local knowledge and confidence that the site would yield good quantities of spat on a regular basis, derived either from local experience or dedicated surveys, with attendant start-up costs.

Broadly, a dedicated spat site could consist of standard longline system as discussed earlier, at about £10,000 capital expenditure per 200m longline, plus an allowance for planning and other start-up costs amounting to say £15,000 per 200m longline overall. Some savings might be made with buoyancy if it was assumed that the site would not be used for ongrowing at any point, also where second-hand equipment could be used.

Harvests could take place at any time between when the spat was able to be handled and the next spring, when the site would need to be cleared and clean droppers made ready for deployment. A harvest in winter/spring might be at about 2kg per metre of dropper, compared to an average of 5kg per metre overall for marketable stock in the model assumed by Scott et al. A long line with 8000 linear metres of dropper could thus yield around 15 tonnes of spat, with a good settlement.

Droppers could then be transferred to ongrowing sites and the stock grown on to 5 or more kg per meter, giving a yield of about 2.5:1. Pegged rope with good settlement and little drop off can achieve 8-10kg per metre (personal experience and Bonnardelli's biomass estimation data discussed above), giving a yield of 4 or 5:1. Alternatively ropes can be stripped and the material re-socked onto rope at lower density, which may result in higher yields overall, but at significant labour cost.

There is little information available about market prices for seed grown on ropes. Seed has recently been sold for €350 per tonne by rope farmers in the south-west of Ireland for on-growing elsewhere. Respondents to the survey suggest an acceptable price of £400 per tonne on average,(range £250-500, see Table 5). Some of them are already in seed contract arrangements. Price will be determined to some extent by size of the seed: smaller being more valuable per tonne as it should provide a higher overall yield in grow out. If seed sites need to operate as profit centres in their own right, then perhaps £500 per tonne would be a more realistic estimate.

Yields may vary with time of transfer and so size. A reasonable middle course based on discussion above is around £500 per tonne and a yield of 5:1, so again a seed cost per tonne harvested of some £100, as with seed off the beach or from sub-tidal beds. Generally rope derived seed is smaller and yields would be slightly higher than from wild beds, but then price is likely to be higher.

The same conclusions about viability discussed for beach-derived seed thus hold for this source.

MZIs

MZIs have been developing over recent years and different designs, deployment and harvesting results appear to give a wide range of indicative costs and sizes of seed.

The Bluesseed project summarised progress to about 2006 with costs of €1.35 per kg for 5mm seed. As noted in the description of MZIs above, commercial developments have moved on and MZI sourced seed prices are thought to be in the area €500-800 per tonne.

However, as discussed earlier, these results are based on experiences in The Netherlands, mostly in areas of extensive naturally occurring mussel beds and high reproductive capacity. It seems unlikely that these high yields could be reliably reproduced in Scottish waters. There are also practical aspects, as this approach is geared toward producing tens of thousands of tonnes of seed with capital intensive equipment and vessels, so as to be able to maintain a traditional bottom growing industry.

It thus seems that to follow this route it would require a few years of development trials, as has been seen in Holland, to establish what the production possibilities may be. The net collectors themselves are not particularly expensive at about €10-15,000 for a 100m unit with a net 5m deep and compare to dedicated longline deployment as discussed above. However the automated scrubbing harvesters are expensive at some €200,000. Thus to establish a meaningful trial with deployment of, say, 10 MZIs deployed at various locations, a harvest machine and £50,000 worth of adaptations to a service vessel, capital expenditure would need to be: ((€15,000 x 10) + €200,000x £0.85) + £50,000 = approx. £350,000. Operational costs might be £100,000 per year allowing for boat and staff time. The new European Maritime and Fisheries fund (EMFF) would be a potential source of funding.

Very speculatively, if in 3-5 years' time, trials showed that good locations could produce say 50% of Dutch yield, i.e. 20kg/m^2 net, with one harvest per year, then 10 collectors would produce (10 collectors x 100m x 5m x 20kg) = 100 tonnes. Costs are likely to be higher than the Dutch industry estimate of €500-800 per tonne, say £700-1,000 per tonne, at least to start with. There will also be costs associated with socking and stocking the seed for ongrowing. Actual cost will be highly business specific and depend on the extent to which operating MZI systems, possibly remote from the main growing area, might dovetail in with routine production. However costs will be inherently higher than dedicated rope systems for collecting spat, as allowance needs to be made for depreciation of equipment with higher capital cost.

There appears to be significant demand from industry for seed from collectors, about 900 tonnes if scaled up from the survey, with an acceptable price of around £400 per tonne. Given this system is inherently more costly than bought-in or rope-grown alternatives discussed above, then possibly MZI sourced seed might have difficulty in competing. Other sources give seed costs roughly around £100 per tonne of finished mussels and MZI sourced seed might amount to £150-200 per tonne and absorb all of the available margin. However it seems likely that MZI product would be harvested and re-stocked at smaller sizes and so potentially producing yields of better than 5:1. If yields could be increased to say 10:1, possibly with thinning and resocking during the growing cycle as seen in Galicia and New Zealand, then seed costs from MZIs could look comparable with other sources.

5.3.4 Hatcheries

As discussed earlier, there is a variety of information regarding attempts at commercialising mussel hatchery techniques at various locations around the world. There is hardly any transparent information on stand-alone production costs (i.e. truly independent of research or government funding) nor the extent of harvested volume that is hatchery derived. In practice it is probably very little: small amounts in each of western USA and Tasmania, the former produced in hatcheries where the main focus is oysters.

To try to frame discussions of the hatchery approach to Scotland, the following table pulls together all quoted information on seed production prices from published sources. (The source "Maguire et al" is a paper written for the Irish industry and discussed and referenced in the literature review).

Table 8: Estimates of cost of production of mussel seed from various sources

Location	Size (mm)	Currency	Pricing basis			Seed weight (no per kg)	Seed weight source	Currency convert	Price (£ per kg)
			Price per 1000	Price per kg	Price source Reference				
Washington State	0.5-1.0	€	1.48 to 1.95		Maguire et al	3,333,000	Blueseed	0.85	4,859
Tasmania	0.5	€	1.23		Maguire et al	10,000,000	Blueseed extrap	0.85	10,455
Tasmania	4	€	1.75		Maguire et al	98,000	Blueseed	0.85	146
Ireland	1	€	0.58		Maguire et al	3,333,000	Blueseed	0.85	1,643
Blueseed project	5	£	6.17	€ 430	Blueseed	56,000	Blueseed	1	346
Taylor, USA	1	$	25.00		Blueseed	3,333,000	Blueseed	0.62	51,662
Tasmania	4	$	3.00	$162	Blueseed	98,000	Blueseed	0.62	182
Canada	8	$	12.00	$126	Blueseed	17,000	Blueseed	0.62	126

The only other price available was from Taylor Seafarms in Washington State, at $17 per foot of spatted rope. Assuming this to be 1mm spat and 25,000 per metre, being Bonnardelli's estimate for densely settled new wild spat, then weight and price conversions as shown above suggest a price of about £4,200per kg.

Some rough / order of magnitude cross-checks can be made by using oyster spat costs as a proxy, given production and weight at size similarities between the two species at the hatchery stage. Only limited information is in the public domain. Various hatcheries in the USA suggest oyster seed for sale at:

- US$21 per thousand for ¼" (6mm) spat[148],
- US$8 per thousand for <5mm spat[149]
- US$8 per thousand for 2mm spat[150]

Taking a mid value of say US$10 per thousand for spat of around 5mm, size at weight of 5mm animals weighing some 0.032g as per the FAO manual by Helm et al, and currency conversion as

[148] http://www.shorethingshellfish.com/products-and-pricing.html,
[149] http://hatchery.hpl.umces.edu/index.php/oyster-seed-sales/
[150] http://www.johnnyoysterseed.com/

Table 8, this price converts to ((US$10 / 1000 / 0.000032kg) x 0.62) = £193/kg, which is in the same area as some of the larger seed quoted above.

A key issue when trying to assess production economics is to model how much seed will be needed to produce a given harvest weight of mussels. This can be done on either a weight basis or a numbers basis. The weight basis is quite simple and requires only yield estimates (weight stocked compared to weight harvested). A numbers basis needs an estimated number stocked, survival rate and average weight at harvest.

Taking a weight basis first, the price shown above can be applied to best estimates of yield. Yield obtained from very small seed in particular can be very variable and depends on adherence success, growing conditions and husbandry which any given throughput of animals experience. The best guidance available for small seed around 1mm is the New Zealand experience with about 350:1 yield using wild seed which ranges either side of 1mm. For medium sized seed, around 2mm and perhaps up to 5mm, the Galician industry is the most appropriate with yields about 25:1. For seed over 5mm, i.e. the Canadian seed at 8mm, a rough interpolation between the Galician yield and the rough estimate for 25mm dredged and beach seed above of 5:1, a value of around 20:1 seems reasonable. These yield estimates can be applied to prices to determine the weight of seed needed to produce a tonne of harvestable product, and thence the seed cost of that product.

Table 9: Estimated yields and costs of seed per tonne of harvested mussel

Location	Size (mm)	Price (£ per kg)	Yield estimate (harvest:seed)	Seed needed kg/tonne	Cost per tonne harvested (£)
Washington State	0.5-1.0	4,859	350	2.9	13,882
Tasmania	0.5	10,455	350	2.9	29,871
Tasmania	4	146	25	40.0	5,831
Ireland	1	1,643	350	2.9	4,695
Blueseed project	5	346	25	40.0	13,821
Taylor, USA	1	51,662	350	2.9	147,604
Tasmania	4	182	25	40.0	7,291
Canada	8	126	20	50.0	6,324

The table shows estimates of seed costs are several multiples of the value of the crop itself (working estimate £1,000 per tonne). These figures have involved several assumptions and extrapolations from one situation to another, so can only be treated as a rough guide. However they will not be wildly inaccurate and the lowest apparent prices shown of around £5,000 seed cost per tonne of harvested crop would need to be over-stated by a factor of 5 to bring the costs down to the total value of the crop, and by 50 or so to be comparable with cost levels apparent for other sources assessed.

The numbers basis is not presented as the major unknown is survival, particularly among very small spat. Bonnardelli postulates that natural spat might settle at 25,000 per metre of rope and through self-thinning end up at about 500 per metre at harvest, survival of 2%. No start size is given in his data and in practice the difference in survival rates between, say, 1mm and 5mm spat could be extremely large and make comparisons between the different estimates of commercial spat cost practically meaningless.

In terms of choice of approaches, it is felt a weight and yield basis is the safer on which to plan. Yields are quite well established in both the Galician and New Zealand industries, not least as they are purchased from third parties and so producers are very aware of amounts used. It seems appropriate to consider actual experiences gained from placing known weights of very small mussels in a culture system which is semi-enclosed for only part of the growth period (through socking). Calculating returns on a numbers basis requires reliable estimates of survival from the different sizes of possible seed. Bonnardelli's data seems to be the only information available and while generally informative, does not provide guidance on a starting size or weight and appears to be derived from one (albeit thorough) set of field observations. Yield on the other hand is a known average performance across the whole industry and for multiple years. Anecdotal evidence from a Scottish grower suggested that yield in Scotland from rope growing might be around 5:1, although the starting size of seed in this estimate is not known, probably fairly large and at a stage when the ropes might be moved between sites and so weight estimates made.

Earlier discussions suggest the cost model for a 500 tonne farm would need to have an effective margin available which could be allocated to seed of up to a maximum of £300 per tonne of harvestable product , with less in a small farm. Clearly the yield-based estimates in Table 9 are many multiples of this. It should also be borne in mind that yields in Galicia and New Zealand are achieved through at least one and more usually two thinning/ resocking processes to make the best of what is considered to be a limited resource. This would add significantly to labour costs in the basic Scottish model, which is based mainly on no husbandry intervention after initial settlement. The point is somewhat academic given the massive difference between likely costs of the hatchery seed and margin available to absorb them, but should not be overlooked when weighing up hatcheries as a solution to seed supply.

The feedback from industry on willingness to pay for hatchery seed is also informative. Value put on spatted rope was some £1.75 per metre on average. Assuming the Scottish view was that spatted rope would be left until harvest with a yield of, say, 8 kg per meter, worth £1 per kg, then the acceptable spat cost is (£1.75 / £8.00) or some 22% of harvest value. This is quite close to the total available working margin of (£200 / £1000) = 20% across the whole industry approach discussed earlier. £1.75 per metre is about 6% of the price offered by Taylor Seafarms, ($17 per foot). Although the context of the west coast USA and Scotland is rather different, it illustrates that hatchery output costs would have to fall very substantially to appear attractive.

Final points to consider are year round supply and quality. As mentioned in the technical narrative on hatcheries, hatcheries have the potential to produce triploid product and so potentially have harvested mussels in good meat condition all year, a point made by several others. Selective breeding would also develop mussels with good growth characteristics or other traits. This would appear to give some important advantages regarding business continuity, but the basic costs of hatchery stock would probably be somewhat higher than at present. It is informative that the oyster suppliers mentioned in the cross-check calculations above appear to charge a margin of under 10%

for triploid stock compared to diploid. The end market would not expect to pay significantly more for buying Scottish rope mussels in the summer compared to what it pays in the winter. It is difficult to quantify the profitability gains from having year round harvesting, or possibly from selectively bred stock, but overall the gains are likely to be modest and not absorb the apparent very high cost of hatchery seed.

5.3.5 Discussion of options

Earlier discussion suggested that on a whole industry basis, it could potentially tolerate costs of between £300,000 and £600,000 in filling the seed supply gap.

Some outline calculations have been undertaken to examine the potentially extreme scenario of the industry devoting all of the upper estimate of potentially tolerate costs, £600,000, to securing different categories of spat.

In the hatchery case, it is assumed, perhaps optimistically and to illustrate the point, in a 5-10 year outlook that there could be a future saving in hatchery production costs of 10-fold compared to those shown in Table 8, potentially achieved through new technology, artificial feeds, selective breeding, scale and strategic alliances with existing hatcheries such as Viking/Ardtoe (recently under new ownership[151]) or Loch Fyne/Walney. The most efficient calculated outcome of all the different seed cost and yield estimates in Table 8, in terms of additional harvestable production, is to purchase some 3.6 tonnes of seed 1mm seed which might produce some 1,200 tonnes additional production per year, based on the original cost estimate from Ireland for 1mm seed. The same assumptions for other sources and estimates of cost and yield give a range down to an additional 200 tonnes harvestable production from this expenditure (omitting the Taylor Seafarms USA cost as an expensive outlier at just 40 tonnes).

By contrast, if the industry invested £600,000 in 1,500 tonnes of beach or mussel bed sourced seed, costing £400 per tonne resocked and with a yield of 5:1, additional production would be some 7,000 tonnes and meet expansion aspirations. Rope sourced stock is assessed above as slightly more expensive and the same spend would result in a supply increase of 6,000 tonnes, provided good sites and collection protocols could be established. MZI sourced will be more expensive again and a similar spend on this approach could yield some 4,000 tonnes of additional production, again provided good sites could be found.

5.4 Next steps

It thus seems that a least costs / least risk business case for the industry is to buy in seed, accepting the proviso that it was of course genetically and physiologically suitable and there was no significant risk in introducing unwanted pests.

[151]http://www.fishupdate.com/news/fullstory.php/aid/20306/Benchmark_Holdings_takes_over_Ardtoe_marine_research_facility.html

This would at least buy time while further studies were carried out by both industry and research bodies to better understand spat settlement patterns and hopefully deploy rope collectors or MZIs in under-utilised sites or new dedicated spat collection sites with good characteristics.

The hatchery issue, whilst being strategically interesting for both the sector and the government, is troubled by questions of cost and wider viability. However with new approaches and techniques becoming established it could perhaps be re-visited in around another 10 years' time and production technologies and costs reassessed.

These figures used to arrive at these conclusions are indicative only and are more use for comparing to each other than in prediction of absolute outcomes. There also have to be some significant "reality checks" to take account of the actual position of many businesses currently. These will which will significantly influence ability and likelihood of taking forward both the least costs / least risk option, as well as further apparently attractive options.

Business liquidity and viability

Half of the producers who responded voiced business liquidity as being a barrier to purchasing more seed, even if it were available. They were mostly, but not all, smaller producers. A significant proportion of the industry would thus be constrained to following low or no cost routes to acquiring new sources of seed. This issue potentially impacts on the theoretical expansion possibility of 6,000 tonnes or so mentioned earlier, should seed supply become optimal. Liquidity and access to credit within the industry is obviously a highly complex issue and not one that can be addressed through grants or similar public intervention. It is thus impossible to estimate how much of a brake on potential expansion this factor alone would be – beyond an intuitive guess of perhaps 1-3,000 tonnes out of the total of some 6,000 tonnes mentioned above.

The potentially tolerable costs mentioned above are based on best estimates of a costs model (from Scott et al). The actual margin situation will vary widely between businesses as already discussed. Likewise decisions to invest in additional seed sourcing will be highly business specific.

Logistical issues with transporting and resocking

The realities of sourcing, transporting and resocking seedstock from elsewhere would entail many logistical challenges, which may deter growers even if liquidity and the business position issues were favourable.

Genetics and INNS

It is most important that any potential movement of mussels from one area to another should be checked to ensure that it is of acceptable genetic composition which will not compromise wild or farmed stocks in the destination area. It is also important to ensure it is not sourced from an area known to contain invasive or non-native species. Both of these issues will take time and costs to research.

Monitoring and research

Discussions on possible studies on mussel larvae and environmental factors affecting their abundance and distribution should be revived, priorities reconfirmed and funding sought.

Support should be provided to individual growers regarding monitoring through appropriate training, possibly by SAMS, NAFC, Seafish

A monitoring support service along the lines of that in Prince Edward Island should be considered.

Collector sites and novel device development

Development of new sites and devices for improving spat supply could be partly de-risked through use of capital grant through the new EMFF, as and when available.

APPENDIX 1:
Mussel seed survey questionnaire

NEW APPROACHES FOR MUSSEL SEEDSTOCK ACQUISITION

We are contacting all members of the mussel production industry in Scotland in relation to an assessment of the potential for new approaches to mussel seedstock acquisition within Scotland.

The assessment is being undertaken by Homarus Ltd, independent fisheries and aquaculture advisers, for the Scottish Aquaculture Research Forum (SARF). This research project was initiated as a result of ongoing concerns within the industry regarding unpredictability in mussel seed supply.

Link to SARF: http://www.sarf.org.uk/

Link to Homarus Ltd: http://www.homarusaquafish.co.uk/?id=home

(The full research objectives are available on request).

One objective is to assess the current status, recent and possible future trends for seed mussel availability. This is being done on a regional basis, and aims to identify bottlenecks and constraints.

We would be very grateful if you could spend a few minutes completing the questionnaire below regarding your experiences and views on the future of mussel seedstock supply.

This questionnaire is thus to ask about :

- your particular experiences with seed supply,
- the extent to which it is a constraint,
- any attempts you have made to overcome any shortages,
- views on desirability and affordability of possible alternative future supply methods.

We would be grateful if you could respond to the following questions, to the extent that you are able and is relevant to your mussel farm(s).

ALL RESPONSES WILL BE KEPT CONFIDENTIAL AND ANY INFORMATION EVENTAULLY USED IN ANY PUBLICATION WILL BE NON-ASCRIBABLE AND AGGREGATED BY PRODUCTION AREA, E.G. SHETLAND, WESTERN ISLES ETC

To respond by email please simply reply / forward this email to Homarus Ltd at: admin@homarusaquafish.co.uk and insert your answers in the spaces provided in the body of the email below.

Alternatively to respond in hard copy please print and answer in the spaces shown and return the questionnaire by post to Homarus Ltd:

Homarus Ltd, Estate Yard House, High Street, Beaulieu, Hants SO42 7YB

If you would like to discuss any aspect of this survey please contact Patrick Franklin at Homarus Ltd in the first instance, either using the email address shown or tel: 01590 611250

Question 1. Farm operation

Name of company / farm: __ ____

Name of person completing this form: ____

Number and location of sites Location (please mark in the box below) :

Location	No of sites
Shetland	
Orkney	
Western Isles	
Highland	
Argyll & Bute	

Recent harvesting activity (approx. tonnes., by calendar year, all sites combined. Please insert in table below. If you were not operating your site(s) in any of the years shown, or don't know, please insert "n/a". If your farm was active, but no harvesting took place, please insert "0")

2007	2008	2009	2010	2011	2012

Question 2. Current arrangements for acquiring seed

Rope or net type used to collect seed (please describe in box below)

Where do you collect seed? (Please mark x)

Within main farm: ___

Dedicated seed site: ___

Other (please describe in box below)

Do you use any dedicated spat collection equipment? (If so, please describe in box below)

Question 3. Recent trends

Please estimate the extent to which spatfall on your own equipment / sites has provided seed supplies in amounts and quality needed for optimal stocking of your farm(s).

Please express as a percentage of your optimal needs for each recent settlement season (Optimal supply = 100%, No supply or unviable quality = 0%). If you were not operating your site(s) in any of the years shown, or don't know, please insert "n/a"

Year	2007	2008	2009	2010	2011	2012
Needs met (%)						

Please add any comments you would like to about recent trends in quantity and quality of seed supply at your farm(s) in the box below.

Had seed supply been optimal in all recent years, please estimate additional production of marketable mussels you might have expected (allowing for other production-related problems such as predation, drop-off, shell fouling etc)

Year	2007	2008	2009	2010	2011	2012
Additional marketable production (tonnes)						

Question 4. Recent measures to overcome patchy seed supply

Please state what additional measures, if any, you have taken in recent years to overcome any problems experienced with seed supply /quality. (Please mark "x" in the table below as appropriate. If you did not experience problems in that particular year, please leave box blank. If you were not operating your site(s) in any of the years shown, or don't know, please insert "n/a".)

Measures taken to overcome problems	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
None						
Bought in[1]						
Re-socked part-grown						
Other[2]						

1: If bought in please describe type / size of seed, quantities, in box below, if known

2: Please describe any other measures in box below

Question 5. Economics of alternative supplies

We appreciate mussel farming is a difficult business and that any additional costs are not likely to be welcome. However we would appreciate your views on the value you would put to a predictable supply of seed stock, if it were available.

If your natural spatfall failed or was insufficient for your needs in future, would you be interested in purchasing any of the following alternatives, if they were available? (Please insert "yes" or "no" in the boxes)

Alternative seed source	Yes/no
Wild seed from dredged sources,(typically 15-25mm, in bulk for socking)	
Wild seed inter-tidal hand gathered, (typically 15-25mm, in bulk for socking)	
Wild seed from suspended collectors, (typically 10-20mm, in bulk for socking)	
Wild seed on ropes, (typically 10-20mm)	
Hatchery seed on ropes, (typically 1mm)	

What do you feel is a maximum fair / affordable <u>unit price</u> for any of the categories of seed which might be of interest in times of future shortage, given average financial circumstances of your farm? (Assume price includes delivery to your jetty).

Alternative seed source	Unit price
Wild seed from dredged sources,(typically 15-25mm, in bulk for socking)	£ / tonne
Wild seed inter-tidal hand gathered, (typically 15-25mm, in bulk for socking)	£ / tonne
Wild seed from suspended collectors, (typically 10-20mm, in bulk for socking)	£ / tonne
Wild seed on ropes, (typically 10-20mm)	£ / metre rope
Hatchery seed on ropes, (typically 1mm)	£ / metre rope

Assuming that in a given season in the future, the natural spatfall was 50% of optimal for your needs, what is the quantity of the categories of seed you could envisage purchasing, at the maximum fair / affordable price shown above, (again given average financial circumstances of your farm?)

Alternative seed source	Quantity
Wild seed from dredged sources,(typically 15-25mm, in bulk for socking)	Tonnes
Wild seed inter-tidal hand gathered, (typically 15-25mm, in bulk for socking)	Tonnes
Wild seed from suspended collectors, (typically 10-20mm, in bulk for socking)	Tonnes
Wild seed on ropes, (typically 10-20mm)	Metres rope
Hatchery seed on ropes, (typically 1mm)	Metres rope

Please add any comments you would like to on the economics of using alternative supplies:

Thank you for your time.

Scottish Aquaculture Research Forum

Charity Registration: SC035745
Company Registration: SC267177

SARF - Member Organisations

Industry

SEAFISH
Association of Scottish Shellfish Growers
Scottish Salmon SSPO
Shetland Aquaculture
British Trout Association

Government and Regulators

Scottish Natural Heritage
SEPA Scottish Environment Protection Agency
marine scotland
The Scottish Government
HIE Highlands and Islands Enterprise
Iomairt na Gaidhealtachd 's nan Eilean

Non-Governmental Organisations

The Crown Estate
Scottish Environment LINK
Rivers & Fisheries Trusts of Scotland
Safeguarding Scotland's Rivers & Lochs
ASFB The Association of Salmon Fishery Boards