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Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oysters

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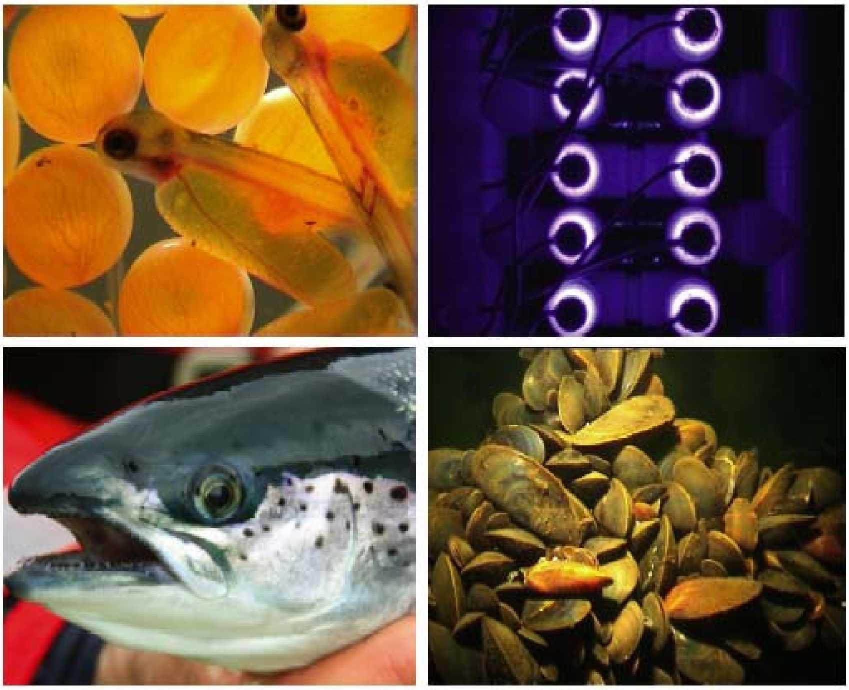

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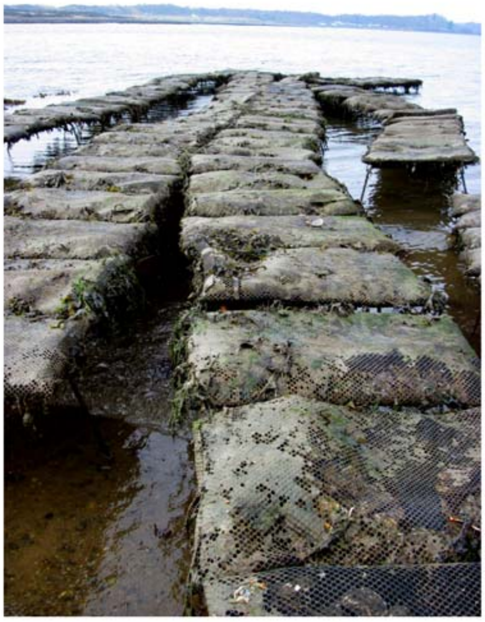

Carbon footprint of Scottish suspended mussels and intertidal oysters

Final Report

December 2011

SARF

Carbon Footprint of Scottish Suspended Mussels and Intertidal Oysters

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Date: 6 December 2011

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EXECUTIVE SUMMARY

The Scottish Aquaculture Forum (SARF) is a registered charity and an independent company whose main aim is to promote, encourage and support research and development in aquaculture and related areas. SARF was formed as one of 33 priorities for action identified in the Strategic Framework for Scottish Aquaculture, published in 2003 by the Scottish Executive. The framework outlines a vision of an aquaculture industry guided by the principles of sustainable development, balancing economic progress with social justice and environmental responsibility.

Environmental Resources Management Limited (ERM) was commissioned by SARF (with co-funding by The Crown Estate) to conduct this study to provide a better understanding of the current cradle to farm gate carbon footprint of Scottish-produced suspended mussels and intertidal oysters. In a wider context, the report is intended to aid the promotion of low-carbon foods such as mussels and oysters. In addition, it is hoped that the report will provide material to stimulate debate regarding the contribution to sustainability made by the shellfish industry in increasing biodiversity whilst potentially acting as a long-term form of carbon sequestration.

METHOD

The method and data treatment as set out in the BSI Publicly Available Specification (PAS) 2050 *Assessing the life cycle greenhouse gas emissions of goods and services* (PAS 2050:2008) have been used for this study.

The study considers the 'cradle-to-gate' impacts of the shellfish, from spat collection in the case of mussels, and hatching in the case of oysters, through growing, harvesting, depuration, and packing ready for dispatch. To illustrate the carbon impacts of the full life cycle, a scenario is examined that, based on various assumptions, illustrates the potential impacts of distribution, retail, consumption and disposal of the shells.

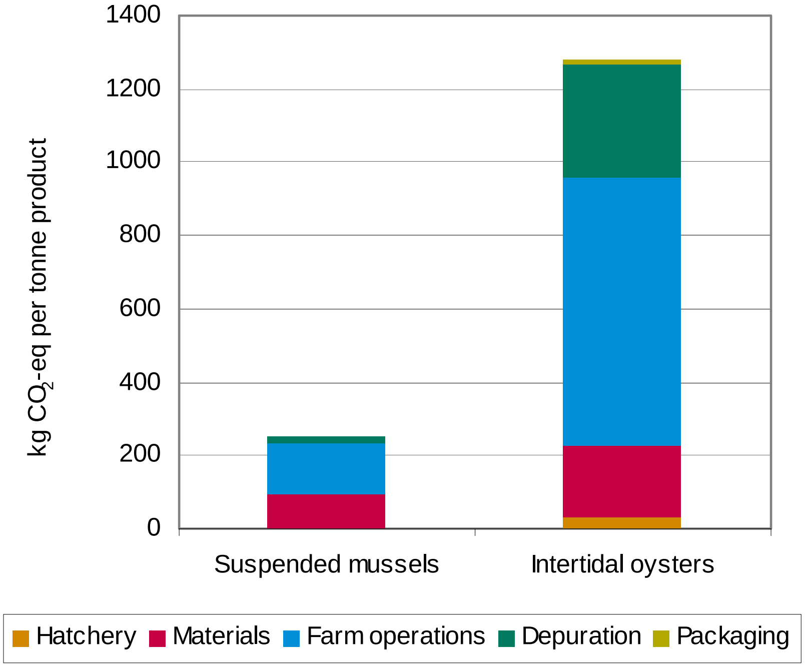
The carbon footprints were calculated by analysing operational data for 2010 production collected directly from select shellfish farmers and secondary and generic data from industry and literature sources. The primary data collected cover material use, electricity consumption and fuel use. Secondary data are used to cover material production, electricity and fuel generation, transport emissions, and waste management processes.

THE CARBON FOOTPRINT OF SCOTTISH PRODUCED SUSPENDED MUSSELS AND INTERTIDAL OYSTERS

The cradle-to-gate carbon footprints of harvested shellfish have been calculated to be 252 kilogrammes of carbon dioxide equivalents (kg CO_2-eq) per tonne for suspended mussels and 1,281 kg CO_2-eq per tonne for intertidal oysters.

Extrapolating across all Scottish farmers, the total carbon footprint of all Scottish suspended mussel and intertidal oyster production for 2010 is 1,585,948 kg CO_2-eq and 297,264 kg CO_2-eq, respectively.

Figure 0.1 ***Cradle to farm gate carbon footprint summary (kg CO_2-eq per tonne)***



CARBON HOTSPOTS

More than half of the cradle to farm gate carbon footprint for both suspended mussels and intertidal oysters is from farm operations, ie the electricity and fuel used to cultivate and to harvest the shellfish. If depuration is included, the contribution from farm operations to the footprint is 62% for mussels and 81% for oysters. Depuration can constitute a significant proportion of the cradle to gate carbon footprint.

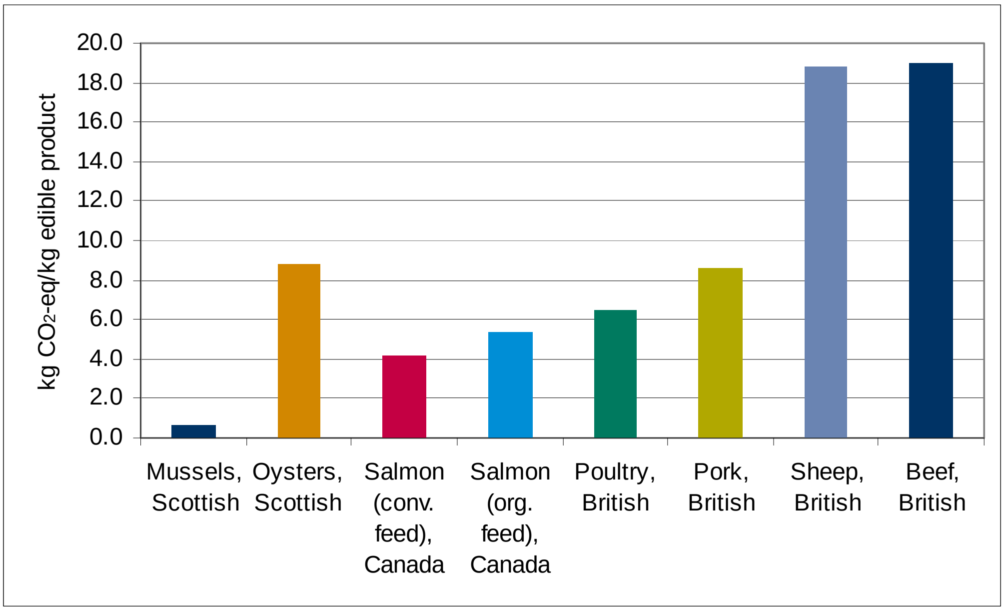
Scenarios were developed to determine the potential significance of the full cradle to grave carbon footprint of the shellfish. The destination of the shellfish (place of consumption) and the format in which it is delivered (fresh or pre-cooked) determines the level of processing the shellfish undergoes, the distance it travels and the mode of transport, the loss rate along the supply chain, the preparation of the shellfish and possibly also how the shells are disposed of after consumption. The life cycle stages of distribution, retail, and use can all have a significant impact on the overall carbon footprint of shellfish. For mussels, processing can also have a significant impact.

COMPARISON WITH OTHER FOODS

Other protein sources competing with mussels and oysters include other fish products as well as meat products such as beef, lamb, pork and poultry. Various data sources were consulted and the figures were converted into similar units to enable a level of direct comparison.

The comparison of mussels and oysters with meat products is shown in the figure below. The sources have not been compared with regard to the methods applied for determining the carbon impacts. However, the data suggest that shellfish perform favourably against meat products and that mussels specifically can justifiably be promoted as a low-carbon food product.

Figure 0.2 *Carbon footprint of seafood and meat products*



CARBON SEQUESTRATION

There are three main ways in which shellfish production sequesters carbon: in the shells of the mussels and oysters harvested and distributed for sale; in the shells of the mussels and oysters that are dead on thinning/grading or harvesting; and in the shells of the mussels that die at sea, detach and sink to the bottom.

The the carbon sequestered in the shells of the mussels harvested amounts to 218 kg CO_2-eq per tonne of mussels harvested and for oysters, the equivalent figure is 441 kg CO_2-eq per tonne of oysters harvested.

Based on assumptions of a drop off rate of 1% per month and a linear growth rate, the carbon sequestered in mussels that die at sea amounts to 12 kg CO_2-eq per tonne of mussels harvested.

The net carbon sequestered is a function of the carbon sequestered during growth and the carbon released following disposal. In the UK, a considerable proportion of the shells that are harvested for human consumption will end up in landfill sites with the remainder (approximately a quarter) being incinerated.

With the carbon contained in shells remaining locked for a long period in landfills, and calcination of shells during incineration, the net carbon sequestered is calculated to be 180 kg CO_2-eq per tonne of mussel and 359 kg CO_2-eq per tonne of oysters. If the carbon sequestered in the mussels that die at sea, detach and drop to the seabed is included, the net carbon sequestered in mussels is 192 kg CO_2-eq per tonne of mussels harvested.

It must be noted that these calculations are based on assumptions and that further research would be advisable to confirm the results.

It should be noted that increased ocean acidity and the possible effect this may have on the ability of shellfish to grow shells, as well as the rate of shell degradation, is outside the scope of this study.

Carbon credits and the shellfish sector

Carbon credits and carbon markets are a component of international, national and voluntary attempts to mitigate the growth in concentrations of greenhouse gases in the atmosphere. By purchasing carbon credits, one conceptually 'neutralises' the emission of a quantity of CO_2-equivalents in one location by avoiding the emission of the same quantity of CO_2-equivalents elsewhere.

The defining characteristic of carbon credits (offsets) is 'additionality'. Additionality is a challenging issue and a difficult concept to explain not by virtue of its definition, but because of its application in practice. Designing rules effectively to test whether offsets are additional is challenging.

If shellfish farming were to be developed as a carbon sequstration project, one obstacle would be achieving consensus on the inclusion of living organisms. Another is likely to be providing evidence of the permanence of carbon sequestration in the shells. Credits under the CDM for forestry projects are only temporary credits, ie the offsets are not permanent and they eventually expire. As a consequence, the price of forestry credits compared to renewable energy credits etc is much lower and has not created significant demand from investors.

The voluntary market, which would be the most likely avenue for any potential future aquaculture carbon credit projects, follows the same criteria for additionality. However, where they differ are on less stringent criteria to permanence.

STUDY LIMITATIONS

This study relies on a combination of primary data collected from shellfish farmers and secondary and generic data from industry and literature sources. The farmers contributing to this study were a group of four shellfish producers, representing approximately 23% of total Scottish mussel production and 37% of total Scottish Pacific oyster production. Although this sample is considered broadly representative of Scottish shellfish production, some caution should be exercised when drawing conclusions for Scottish-produced suspended mussels and intertidal oysters in general, due to its limited coverage.

With regard to the data, accurate electricity and fuel use data is most critical to calculating a carbon footprint for shellfish as the majority of the footprint is from energy used during cultivation, harvesting and depuration. Considerable differences are seen between the shellfish farmers contributing data to this study. This may be natural variance due to different water conditions and nutrient levels, as well as possible differences in farming methods used. However, it may be worthwhile to keep in mind when reading this report, and may present an opportunity for efficiency, and reduction in the carbon footprint in the future.

1 INTRODUCTION

1.1 BACKGROUND

Environmental Resources Management Limited (ERM) was commissioned by the Scottish Aquaculture Research Forum (SARF) (with co-funding from The Crown Estate) to conduct this study in order to provide a better understanding of the current carbon footprint of Scottish-produced:

- suspended mussels; and
- intertidal oysters.

The study considered the cradle-to-gate impacts of the shellfish, from spat collection in the case of mussels, and hatching in the case of oysters, through growing, harvesting, depuration, and packing ready for dispatch. To illustrate the carbon impacts of the full life cycle, a scenario is included that, based on various assumptions, illustrates the potential impacts of distribution, retail, consumption and disposal of the shells.

In addition to the main scope of the study, the capture and sequestration of carbon in the shells was also assessed. The purpose of this was to provide background information for discussions regarding the potential benefits secured in terms of affects on carbon sinks and the possibility of the award of carbon credits in the future.

The objective of the study is to provide SARF, its members and wider stakeholders with information about the carbon footprint of shellfish. In a wider context, the report is intended to aid the promotion of low-carbon foods such as mussels and oysters. In addition, it is hoped that the report will provide material to stimulate debate regarding the contribution to sustainability made by the shellfish industry in increasing biodiversity whilst potentially acting as a long-term form of carbon sequestration.

1.2 CONTEXT

Blue mussels and Pacific oysters are the two main species of interest when considering Scottish mussel and oyster production. A small quantity of native oysters is also produced. Production is mainly focused in Shetland, Orkney, the Western Isles, and along the western shores and isles of the Highlands and Strathclyde where the deep sheltered lochs provide ideal cultivation conditions.

In 2009, production of mussels in Scotland exceeded 6,300 tonnes and oysters 250 tonnes, as detailed in *Table 1.1* below. Mussel farming has seen considerable growth in the last 10 years, mainly as a result of rapid increase in production capacity in Shetland, whereas oyster farming has only seen slight increases in growth (Scott *et al* 2010). Compared to the rest of the European Union, Scottish production remains low.

Table 1.1 Scottish shellfish production by region, 2009

Region	**Businesses**	**Mussel** (tonnes)	**Pacific oyster** (quantity)	**Native oyster** (quantity)
Highland	49	718	302,000	0
Orkney	8	0	0	0
Shetland	34	3,698	0	0
Strathclyde	51	931	2,593,000	490,000
Western Isles	16	955	5,000	0
All Scotland	**158**	**6,302**	**2,900,000**	**490,000**
Weight (tonnes)		**6,302**	**232**	**39**

Only sales directly for human consumption are shown. Sales to other businesses for on-growing are not shown.
Average individual oyster weight: 80g (based on industry figures).

(Source: Mayes and Fraser 2010).

With regard to mussels, the UK market is divided approximately 80% retail and 20% foodservice (Scott *et al* 2010). In the higher value retail sector, an equal split between live and cooked (vacuum packed) products is seen. Strong growth in retail sales has been seen in recent years, driven by price promotions and reduced unit price. The main increase is in cooked sales, with live retail sales having remained static.

The greatest demand for oysters is from the upmarket foodservice sector, with more limited retail sales (Scott *et al* 2010).

Scott *et al* reports that existing Marine Spatial Plans suggest there is limited scope for new, economically viable, mussel production developments on inshore sites. Offshore development is considered unlikely in the short term due to planning uncertainties, higher costs, and greater risks. However, the offshore renewables sector may offer future opportunities. Short to medium term growth is considered most likely to come from use of unused capacity and more efficient production. Scott *et al* finds that if these issues are addressed, significant growth in production is feasible, subject to market demand and other constraints.

According to Scott *et al*, existing oyster sites are at or near capacity, and there is limited scope to develop new sites, especially on the West Coast, due to planning constraints and lack of suitable foreshore. Conservation interests constrain some of the ideal sites with large areas of foreshore (eg as found in the Solvay). However, Scott *et al* reports a strong market demand for Scottish oysters and suggests that, through marketing the provenance and quality of Scottish oyster and addressing some of the limitations, further growth in the industry should be possible.

2 PRODUCT CARBON FOOTPRINTING METHOD

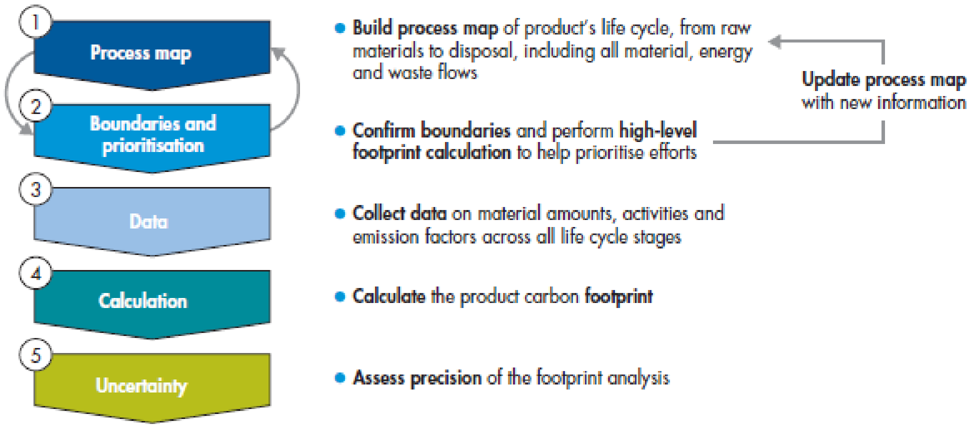
2.1 CARBON FOOTPRINTING

A carbon footprint reports the greenhouse gas (GHG) emissions which arise from the life cycle of a product (or service) as kilogrammes of carbon dioxide equivalents (kg CO_2-eq). The full life cycle may be assessed from raw material extraction, through production, distribution, and use, to recycling and final disposal. An alternative boundary that is often used is all life cycle stages up until the product leaves the production site for distribution and sale. These two approaches are often known as 'cradle to grave' and 'cradle to gate', respectively.

Product carbon footprinting is a specialised version of life cycle assessment (LCA). A LCA typically appraises a range of environmental impacts of a product or service from cradle to grave. A carbon footprint is an LCA that is restricted to a single environmental impact, climate change.

The method and data treatment as set out in the BSI Publicly Available Specification (PAS) 2050 *Assessing the life cycle greenhouse gas emissions of goods and services* (PAS 2050:2008) has been used for this study. The following figure outlines ERM's method for this streamlined study. It is based on the framework set out by the ISO standards for LCA and PAS 2050 (ISO 14040 and 14044, PAS 2050:2008).

Figure 2.1 ***Steps to calculate a carbon footprint***



Source: Carbon Trust PAS 2050 Guide

2.1.1 PAS 2050 and biogenic carbon

PAS 2050 (PAS 2050:2008) specifies that all GHG emissions arising from biogenic carbon sources are to be included in the calculations, except for carbon dioxide (CO_2). CO_2 emissions from biogenic carbon sources is only included where it arises from land use change.

The reason for excluding the biogenic CO_2 contained within materials is that, generally, there is a relatively short timescale from the point at which the carbon is taken up from the atmosphere (eg during plant photosynthesis and growth) and its release back into the atmosphere through degradation or combustion. Therefore, over this timescale, there is a net CO_2 balance of zero.

This is not necessarily the case when considering carbon stored in the shells of mussels and oysters. As such, the study departs from the PAS 2050 method in order to assess the potential carbon sequestration from mussel and oyster cultivation. Consequently, the study accounts for biogenic CO_2 that is sequestered as carbon in the shells of mussels and oysters. No other biogenic CO_2 is considered.

It should be noted that the revised PAS 2050 (PAS 2050:2011) requires biogenic carbon to be considered, except for in assessing the footprint of human food and animal feed products. However, a number of exclusions from this rule apply, where biogenic carbon should be included. One such exclusion, which would apply to shells, is as follows:

> *"any biogenic component in material that is part of the final product but is not intended to be ingested (e.g. packaging)".*

Therefore, the approach taken in this study is consistent with the revised PAS 2050 (PAS 2050:2011).

2.2 *PRODUCT DEFINITION*

The products assessed as part of this project are Scottish-farmed:

- suspended mussels; and
- intertidal oysters.

The carbon footprint is reported per tonne produced and per serving. *Table* 2.1 below outlines the quantities of meat and shells (reference flows) associated with these. The weights are based on a small sample assessed by Scottish Shellfish specifically for this study.

Table 2.1 Measure of reporting for this study, including reference flows

	Per serving*		**Per tonne product**	
	g meat**	g shells	kg meat**	kg shells
Mussels	305	195	609	391
Oysters	71	369	160	840

* Assuming 500g fresh mussels (including shells) and 6 oysters per serving.
** Natural water content is included as part of the meat measure.

2.3 DEFINING THE LIFE CYCLE

The scope of this carbon footprint is from 'cradle to gate', including all life cycle stages of the mussel and oyster until transport to reprocessing or distribution to the customer (refer to *Figure 2.2* and *Figure 2.3*). These stages are summarised below.

Laboratory work associated with water sampling and testing, staff commuting and capital equipment in the form of vessels and machinery, and their maintenance, are outside the scope of this the study. To assess the contribution of these stages, since they are fundamental to reducing energy consumption and therefore lowering the overall carbon footprint, their contribution to the carbon footprint was considered based on information from one participating shellfish farmer.

Mussels

- *Mussel cultivation and harvesting*
    - *Spat collection*. The collection of spat (juvenile mussels) from plankton by suspending the production ropes in the top 2 to 3 metres of the water column. This takes place in the spring following the spawning and initial growing process.
    - *Thinning*. The mechanical reduction of the density of mussels on the ropes in order to prevent overcrowding and to promote optimum growth and productivity.
    - *Harvest*. Harvesting of the mussels at marketable size (45 mm shell length or above (1), with the live weight of the mussel at around 13 g (2)). The normal harvesting season is from late August/September through to April. To reach marketable size takes between 24 and 36 months.
    - *Grading*. The grading, washing and transfer of the mussels to the depuration tanks (if required). The entire process may take place on board the harvesting vessel. Mussels too small to market are re-hung on the line for further growth.
- *Depuration*. Storage of the stock in large seawater tanks in sterilised sea water to remove any bacteria accumulated in the mussel gut.
- *Packing*. The packing of the mussels ready for dispatch.

Oysters

- *Hatchery*. The production of oyster seed and delivery to the oyster farm.
- *Bagging*. The bagging of the oyster seeds and attachment to an intertidal trestle system.

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(1) Seafish (2002) The Suspended Mussel Hyperbook.
(2) Based on limited trial done specifically for this study.

- *Grading and re-bagging*. The grading of the oysters according to size, and re-bagging to reduce the density of oysters in the bags in order to allow growth to optimum size.
- *Harvest*. De-bagging of the oysters at marketable size (70 mm shell diameter or above (1), with the live weight of the oysters at around 73 g (2)) and transfer to holding tanks (half to a full day). To reach marketable size takes 42 months or longer.
- *Depuration*. Storage of the stock in large seawater tanks in sterilised (UV treated) sea water to remove any bacteria accumulated in the oyster gut.
- *Grading.* The grading and washing of the oysters (if required).
- *Packing*. The packing of the oysters ready for dispatch.

Although not a principal focus of the study, the carbon implications of the full product life cycle were also examined. This covers reprocessing, modes of product distribution to market, product loss through the supply chain, product preparation, and end of life (ie disposal of the shells). No primary data were collected for these life cycle stages.

(1) Seafish (2002) The Oyster Hyperbook.

(2) Based on limited trial carried out specifically for this study.

Figure 2.2 Process map and boundaries for calculating the cradle to gate carbon footprint for Scottish-produced suspended mussels

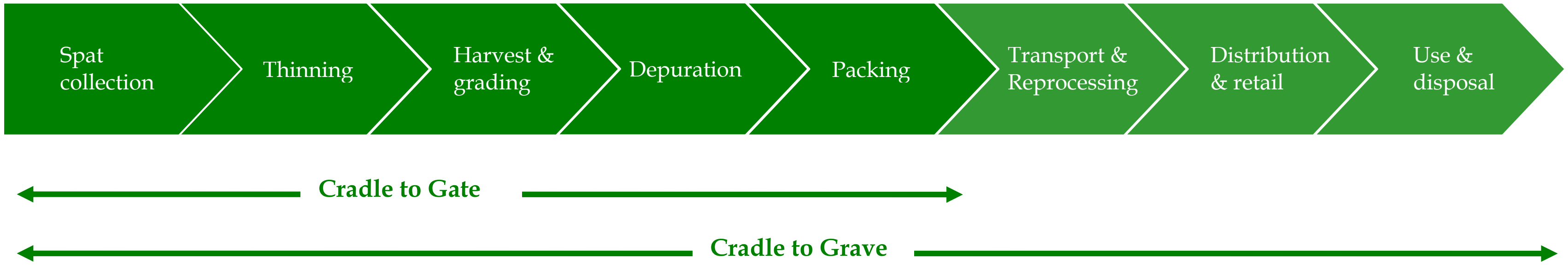
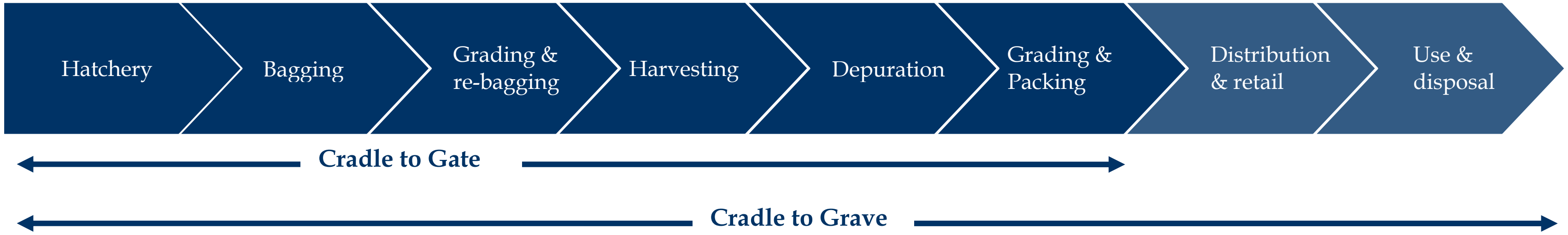


Figure 2.3 Process map and boundaries for calculating the cradle to gate carbon footprint for Scottish-produced intertidal oysters



3 CARBON FOOTPRINTING INVENTORIES

Four shellfish farmers provided data for this project: two mussel farmers; one oyster farmer; and one farmer producing both mussels and oysters. The characteristics of their operations are summarised in *Table 3.1* below.

Table 3.1 ***Shellfish farming characteristics***

	Mussels			**Oysters**	
	Farm A	**Farm B**	**Farm C**	**Farm B**	**Farm D**
2010 production (normalised)	100%	24%	141%	100%	464%
Average grow rate	2 yrs	2.5-3 yrs	3 yrs	5-6 yrs	3.5 yrs
Depuration during 2010	None	Always	Approx. 3 mths	Always	4 mths

Details of material and energy consumptions according to life cycle stage are provided below. Data collection, assumptions and emission factors are summarised in *Annex A*.

3.1 MUSSEL FARMING

3.1.1 Material consumption

The mussels are grown using the surface longline method. Spat is collected from the plankton in the water by suspending the coiled production ropes in the top two to three meters of water. There are various designs of rope in use, ranging from simple 'roughened' rope to specially designed area ropes aiming to maximise retention and yield.

Once the spat is firmly attached to the ropes, the ropes are lowered to their full extent. As the mussels grow, extra buoyancy is added to the longlines in order to avoid the line from sinking.

As the mussels grow, they are thinned to prevent overcrowding and to allow optimum growth conditions. Thinning involves extracting the mussels from their original rope, grading them, and enclosing them in a mesh 'sock' around a fresh production rope. The mesh 'sock' supports the mussels while they re-attach to the rope, and then gradually decomposes. Not all mussel farmers undertake thinning.

During thinning, specialist equipment is used, including rotating drums, conveyors, and grading machines.

The time required for the mussels to grow to the required size for harvesting depends on phytoplankton availability in the water. The average growth period reported by the farmers contributing to this study, varies from 2-3 years.

On harvesting, the mussels are extracted from the rope, separated, washed, and sorted into different grades. The same specialist equipment is used as during thinning.

If required, depuration is then carried out. This involves placing trays of mussels into a purpose-made tank filled with clean seawater treated by ultraviolet (UV) disinfection. The water is circulated through the UV system and returned to the tank via a cascade or spray bar that aerates the returning water to ensure good dissolved oxygen levels. The depuration process lasts 42 hours.

Table 3.2 *Material input in mussel cradle to farm gate*

Input	Amount	Unit
Ropes	13	kg per tonne
Buoys	4.4	kg per tonne
Pegs	3.5	kg per tonne
Mesh socks	2.3	kg per tonne

It should be noted that the amount of materials used by the three farmers varies considerably and may warrant further investigation in the future. For example, the amount of rope required per tonne of mussels harvested varies by a factor of 17. This significant variance may be due to differences in operating conditions (type of rope, nutrient level in water, strength of current, etc) or simply due to different approaches taken by the farmers in estimating their material use.

3.1.2 *Energy consumption*

Energy consumption is in the form of red diesel for vessels, vehicles (forklift) and generators, and electricity for seawater pumps, grading machine (unless stationed on the vessel), UV light for depuration, as well as general lighting and services.

The diesel and electricity required varies from farmer to farmer, depending on the distance from the sorting facilities to the mussel beds and the number of months of depuration.

Table 3.3 *Energy input in mussel cradle to farm gate*

Input	Amount	Unit
Electricity, excl. depuration	46	kWh per tonne
Fuel	28	litres per tonne
Oil & greases	0.94	litres per tonne

It should be noted that the energy used by the three farmers varies to some extent. For example, the electricity consumed per tonne of mussels harvested varies by a factor of 2.7.

3.2 OYSTER FARMING

3.2.1 *Material consumption*

The oysters are grown using the traditional bag and trestle method. Seeds are enclosed in small aperture plastic mesh bags and attached to steel trestles in the intertidal zone using cable ties or used inner tyres, depending on the farmer's preference. The seed size grade varies. One of the oyster farmers contributing to this project prefers them small, in the region of 6 mm in length. The other prefers them slightly larger, in the region of 15-20 mm in length. The weight of seeds per bag is 2.5 kg or less. The bags are turned frequently to reduce fouling on the upper surface of the bags and to redistribute the oysters in the bag to ensure optimal space for growth.

As the oysters grow, the oysters are re-graded at regular intervals and the size of the mesh aperture is increased progressively to allow maximum water flow and therefore to optimise growth. The maximum aperture used is restricted by the acceptable losses to oyster catchers.

Re-grading is carried out to provide growing space in the bag. As the oysters grow, the density of the stock within the bags is also reduced progressively. Oysters of similar size are combined to provide the best growing conditions. Faster growing oysters can, if not removed from the proximity of the smaller ones, make the smaller oysters become runts and stop growing.

During re-bagging, specialist equipment is used, including hoppers, conveyors, and grading machines.

The time required for the oysters to grow to the required size for harvesting depends on phytoplankton availability in the water. One farmer reported 3.5 years as the average growth period. Another farmer, who also farms mussels in the same loch, reported a growth rate to marketable size of 5-6 years.

On harvesting, the oysters are washed and sorted into different grades. The same specialist equipment is used as during re-bagging.

If required, depuration is then carried out. This involves placing trays of oysters into a purpose-made tank filled with clean seawater treated by ultraviolet (UV) disinfection. The water is circulated through the UV system and returned to the tank via a cascade or spray bar that aerates the returning water to ensure good dissolved oxygen levels. The depuration process lasts 42 hours.

Table 3.4 *Material input in oyster cradle to farm gate*

Input	Amount	Unit
Oyster bags	10	kg per tonne
Closures & ties	7.6	kg per tonne
Steel trestles	71	kg per tonne

It should be noted that the amount of materials used by the two farmers varies to some extent and may warrant further investigation in the future. For example, the amount of closures and ties required per tonne of oysters harvested varies by a factor of 25. This variance may be due to differences in operating conditions (density of mussels per bag, nutrient level in water, etc) or simply due to different approaches taken by the farmers in estimating their material use.

3.2.2 *Energy consumption*

Energy consumption is in the form of red diesel for vehicles (tractors, forklift) and generators, and electricity for seawater pumps, grading machine, UV light for depuration, as well as general lighting and services.

The diesel and electricity required varies from farmer to farmer, depending on the distance from the sorting facilities to the oyster beds and the number of months of the year for which a depuration stage is required.

Table 3.5 *Energy input in oyster cradle to farm gate*

Input	Amount	Unit
Electricity, excl. depuration	716	kWh per tonne
Fuel	48	litres per tonne
Oil & greases	1.6	litres per tonne

It should be noted that the energy used by the three farmers varies considerably and may warrant further investigation in the future. For example, the electricity consumed per tonne of oysters harvested varies by a factor of 17.

3.3 *CAPITAL BURDENS AND EMPLOYEE IMPACTS*

Capital burdens and employee impacts were outside the scope of this study and have not been included in the carbon footprint calculations.

Capital burdens in a carbon footprint relate to the embedded carbon in the larger equipment itself, spread over the life time. Capital equipment associated with shellfish farming includes stationary as well as mobile equipment. Stationary equipment for oyster farming includes hoppers, conveyors, grading machines, and depuration tanks and equipment. Mobile equipment includes tractors or other vehicles suitable for tidal bed traffic, forklifts, and vans/lorries for deliveries. Stationary equipment for mussel farming includes buoys, rotating drums, conveyors, grading machines, and depuration tanks and equipment. Mobile equipment includes vessels and forklifts and sometimes tractors.

4 RESULTS AND ANALYSIS

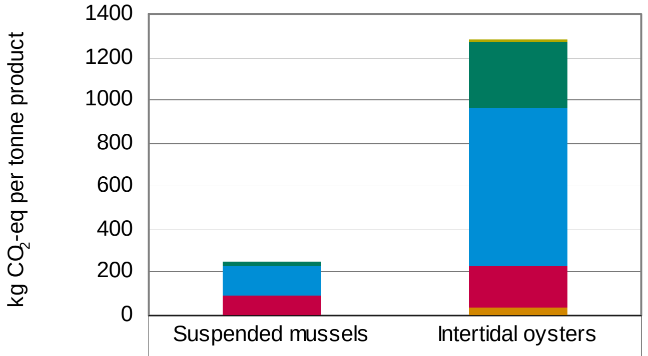
The cradle-to-gate carbon footprints of harvested shellfish were calculated to be 252 kg CO_2-eq per tonne of mussels and 1,281 kg CO_2-eq per tonne of oysters. Half or more of the carbon footprint is from farm operations, ie the electricity and fuel used. If depuration is included, the contribution from farm operations to the footprint is 62% or more.

Extrapolating across all Scottish mussel farmers, using the Scottish production data from *Table 1.1,* the carbon footprint of total Scottish suspended mussel and intertidal oyster production is 1,585,948 kg CO_2-eq and 297,264 kg CO_2-eq, respectively.

The carbon footprint numbers were calculated by analysing operational data for 2010 production collected directly from three mussel farmers and two oyster farmers. The farmers represent approximately 23% of total Scottish mussel production, and 37% of total Scottish Pacific oyster production. The data are considered to be confidential. *Sections 2* and *3* describe the method and inventories, and *Annex A* provides technical detail.

The cradle to gate footprints per tonne of harvested suspended mussels and intertidal oysters are presented in *Figure 4.1* below. In the following section, further details on each life cycle stage are provided for mussels and oysters separately.

Figure 4.1 ***Carbon footprint summary (per tonne of harvested shellfish)***

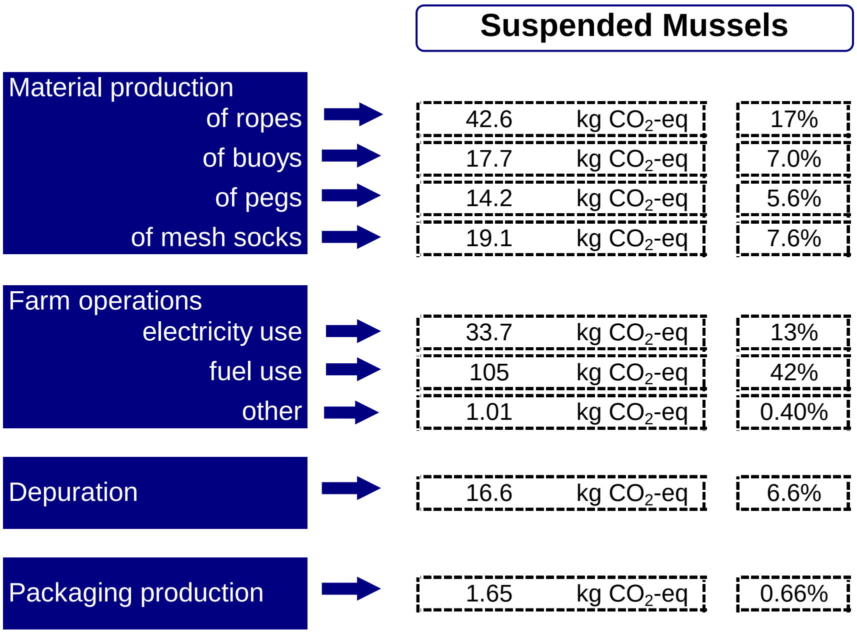


	Suspended mussels	Intertidal oysters
🟨 Packaging	1.65	11.2
🟩 Depuration	16.6	310
🟦 Farm operations	140	730
🟥 Materials	93.6	195
🟧 Hatchery	0.00	34.7

4.1 CRADLE TO FARM GATE CARBON FOOTPRINT OF SUSPENDED MUSSELS

As presented above, the cradle to farm gate carbon footprint of harvested mussels has been calculated to be 252 kg CO_2-eq per tonne. *Figure 4.2* below summarises the carbon footprint for suspended mussels, with further detail for material production and farm operations.

Figure 4.2 Cradle to farm gate carbon footprint summary for suspended mussels (kg CO_2-eq per tonne of mussels)



4.1.1 *Mussel cultivation and harvesting*

Mussel cultivation and harvesting comprise the components of material production and farm operations shown in *Figure 4.2* above. The carbon footprint of this life cycle stage is 233 kg CO_2-eq per tonne of mussels harvested. This is equivalent to 93% of the total cradle to farm gate carbon footprint. This is not surprising, as this life cycle stage accounts for the majority of operations associated with the production of suspended mussels. The significant contribution from this life cycle stage confirms this.

This stage can be sub-divided into materials and farm operations in the form of energy consumption. The production of ropes, pegs and mesh sock account for 40% of the life cycle stage, with the ropes accounting for more than 46% of the materials impacts.

60% of the life cycle stage is accounted for by energy consumption in the form of electricity, fuels, and oils and greases ('other'). Of these, fuel use accounts for the majority (three quarters).

4.1.2 *Depuration*

The carbon footprint of depuration is 16.6 kg CO_2-eq per tonne of mussels. This is equivalent to 6.6% of the cradle to gate carbon footprint.

It must be highlighted that limited depuration was required in 2010 for the three farmers contributing with data to this study. As such, this is also reflected in the contribution that this life cycle stage makes to the overall cradle to farm gate carbon footprint.

4.1.3 *Packaging*

The carbon footprint of the packaging used for transporting the harvested mussels to reprocessors or other customers is 1.65 kg CO_2-eq per tonne of mussels. This is equivalent to less than 1% of the cradle to farm gate carbon footprint.

The packaging used by the three farmers varies considerably, from reusable bulk tote bags and plastic containers to single use nets and cardboard boxes.

4.2 *CRADLE TO FARM GATE CARBON FOOTPRINT OF INTERTIDAL OYSTERS*

As presented above, the cradle to farm gate carbon footprint of harvested oysters has been calculated to be 1,281 kg CO_2-eq per tonne. *Figure 4.4* below summarises the carbon footprint for intertidal oysters, with further detail for material production and farm operations.

4.2.1 *Hatchery*

The carbon footprint of hatching of oyster seeds is 34.7 kg CO_2-eq per tonne of oysters. This is equivalent to 2.7% of the cradle to gate carbon footprint.

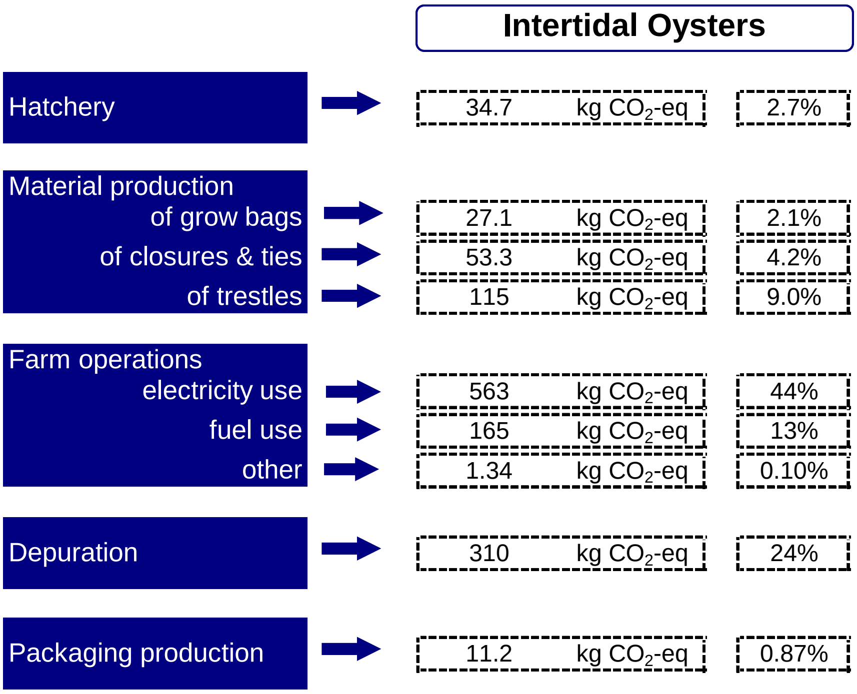
4.2.2 *Oyster cultivation and harvesting*

Material production and farm operations as shown in *Figure 4.4* comprise oyster cultivation and harvesting. The carbon footprint of this life cycle stage is 925 kg CO_2-eq per tonne of oysters harvested. This is equivalent to 72% of the total cradle to farm gate carbon footprint. This is not surprising, as this life cycle stage accounts for the majority of operations associated with the production of intertidal oysters. The significant contribution from this life cycle stage confirms this.

The stage can be sub-divided into materials and farm operations in the form of energy consumption. The production of oyster bags, closures, ties and steel trestles account for 21% of the life cycle stage, with the trestles accounting for more than 59% of the materials impacts.

79% of the life cycle stage is accounted for by energy consumption in the form of electricity, fuels, and oils and greases ('other'). Of these, electricity use accounts for the majority (more than three quarters). Electricity is used for sea water pumps, grading machine, and depuration. The data are not fully detailed for all of the oyster farms, but it seems that the majority of electricity consumed is used by sea water pumps. Depending on the extent of depuration, this can account for nearly the same electricity consumption as the pumps.

Figure 4.3 Cradle to farm gate carbon footprint summary for intertidal oysters (kg CO_2-eq per tonne of oysters)



	Intertidal Oysters	
Hatchery	34.7 kg CO_2-eq	2.7%
Material production		
of grow bags	27.1 kg CO_2-eq	2.1%
of closures & ties	53.3 kg CO_2-eq	4.2%
of trestles	115 kg CO_2-eq	9.0%
Farm operations		
electricity use	563 kg CO_2-eq	44%
fuel use	165 kg CO_2-eq	13%
other	1.34 kg CO_2-eq	0.10%
Depuration	310 kg CO_2-eq	24%
Packaging production	11.2 kg CO_2-eq	0.87%

4.2.3 *Depuration*

The carbon footprint of depuration is 310 kg CO_2-eq per tonne of oysters. This is equivalent to 24% of the cradle to gate carbon footprint.

The impact from depuration is dependent on the requirement for depuration during the period assessed. Of the two farmers contributing data, one always depurates its oysters and the other was required to depurate for four months in 2010. Compared with the mussels results, this shows how depuration, depending of the requirements, can come to represent a considerable proportion of the carbon footprint of the shellfish.

4.2.4 *Packaging*

The carbon footprint of the packaging used for transporting the harvested mussels to reprocessors or other customers is 11.2 kg CO_2-eq per tonne of oysters. This is equivalent to less than 1% of the cradle to farm gate carbon footprint.

The packaging used by the two farmers varies considerably. This is to a large extent due to one farmer delivering to the other for further processing and onward delivery to the final customer.

4.3 CAPITAL EQUIPMENT AND STAFF COMMUTING

Capital equipment in the form of vessels and machinery was excluded from the scope of this study. Capital equipment is regularly left out of carbon footprint studies as its contribution is generally found to be negligible when considering lifespan and production volumes over this period are considered. However, in the absence of feed inputs, and with presumed relatively modest fuel use, capital equipment could potentially contribute significantly to the overall mussel and oyster results. As such, one mussel farmer provided information about vessel and equipment use and this was assessed in the context of that farmer's individual carbon footprint.

Based on information provided by the farmer, capital equipment was found to represent 6% of the of the CO_2 emissions for that farm's cradle to farm gate carbon footprint. This can be deemed to have a moderate impact on the overall climate impacts. Staff commuting was found to represent 10% of the of the CO_2 emissions for that farm's cradle to farm gate carbon footprint and can be deemed to have a relatively significant impact.

4.4 CARBON SEQUESTRATION

There are three main ways in which shellfish production sequesters carbon:

a) in the shells of the mussels and oysters harvested and distributed for sale;

b) in the shells of the mussels and oysters that are dead on thinning/grading or harvesting; and

c) in the shells of the mussels that die at sea, detach and sink to the seabed.

Based on the data provided by shellfish farmers regarding loss rates and the shell to meat ratio as provided by a SARF member, the carbon sequestered in the shells of the mussels harvested (ie a) and b) above) amounts to 218 kg CO_2-eq per tonne of mussels harvested and 441 kg CO_2-eq per tonne of oysters harvested.

There appear to be considerable uncertainty with regard to c), ie the rate of mussels that die at sea, detach and sink to the seabed. This is further discussed in *Section A2.2* of *Annex A*. Based on assumptions of a drop off rate of 1% per month and a linear growth rate, the carbon sequestered in mussels that die at sea amounts to 12 kg CO_2-eq per tonne of mussels harvested.

Ocean acidity, the absorption of CO_2 in the ocean as the global average temperature increases, and the possible effect this may have on the ability of shellfish to grow shells, as well as the rate of degradation of shells, is outside the scope of this study.

The net carbon sequestered is a function of the carbon sequestered during growth and the carbon released following disposal. In the UK, a considerable proportion of the shells that are harvested for human consumption will end up in landfill sites, where the carbon that they contain will remain for a long period. In 2009/10, the split between landfill and incineration for municipal waste was 78% landfill and 22% incineration.

ERM considers that the acidity of a municipal landfill may result in the calcium carbonate ($CaCO_3$) of the shells reacting with this to produce an organic salt and water. Degradation to produce CO_2 is assumed not to take place.

However, on incineration, CO_2 is considered to be released. On combustion, the calcium carbonate of the shells will calcinate to produce calcium oxide (CaO) and CO_2.

Where harvesting and grading takes place on harvesting vessels, shellfish that are dead or have broken shells, will generally be dumped in the sea. When graded on land, the shellfish are disposed off as waste. A small proportion may be crushed and given/sold to local chicken farmers, but this seems to be a minority use of the shells.

These shells, together with the mussels that die in the sea and drop to the bottom, will store the carbon in the shells in a more or less permanent form (depending on the local seawater pH). Over time, the shells may be covered with silt, more shells and other debris (Wolff and Beaumont, 2010).

Incorporating the end of life management of the shells from consumed shellfish, the net carbon sequestered is calculated to be 180 kg CO_2-eq per tonne of mussel and 359 kg CO_2-eq per tonne of oysters. If the carbon sequestered in the mussels that die at sea, detach and drop to the seabed is included, the net carbon sequestered in mussels is 192 kg CO_2-eq per tonne of mussels harvested.

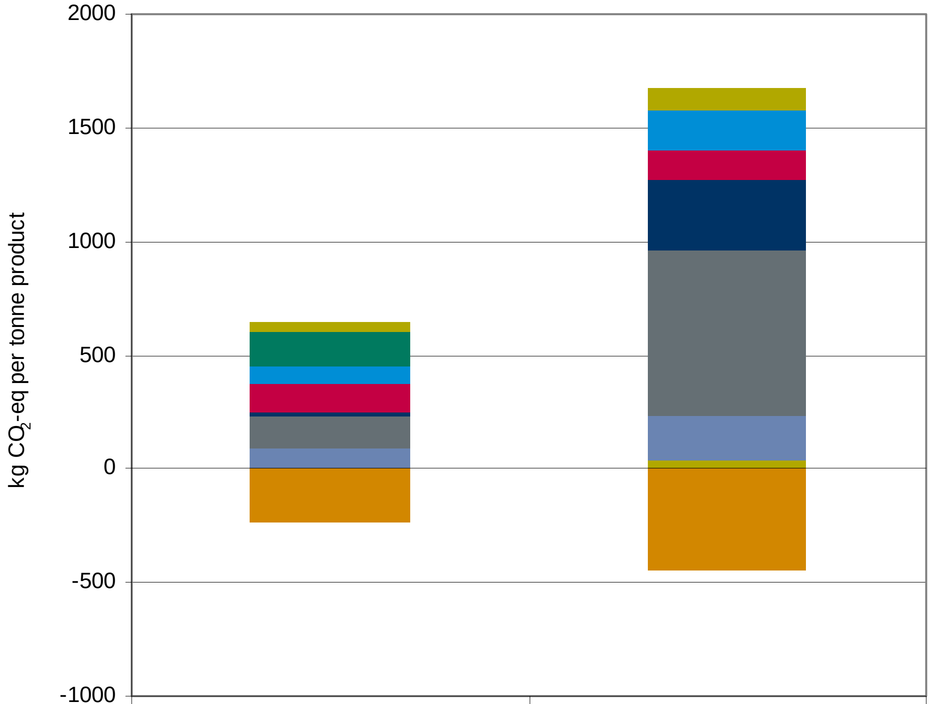
It must be noted that these calculations are based on assumptions and further research is advisable to confirm these results.

4.5 *CRADLE TO GRAVE CARBON FOOTPRINT*

This study has only considered the cradle to farm gate carbon footprint. This is partly because the subsequent life cycle stages, including transport of shellfish to processor, processing of the shellfish, distribution to market, consumption and end of life, are highly variable depending on farm location, market conditions, market demand etc. Each of these stages is discussed in *Table 4.1* and is presented below in order to estimate the scale of impact in comparison to the cradle to gate footprint. Further detail can be found in *Annex A4*.

Based on the various assumptions, the cradle to grave carbon footprint is calculated to be 649 kg CO_2-eq per tonne of mussels harvested and 1,685 kg CO_2-eq per tonne of oysters harvested. This does not consider any carbon sequestered. Including carbon sequestration in the harvested shellfish, the cradle to grave carbon footprint is calculated to be 430 kg CO_2-eq per tonne of mussels harvested (418 if including carbon sequestered in mussels dying at sea and sinking to the seabed) and 1,244 kg CO_2-eq per tonne of oysters harvested.

Figure 4.4 ***Cradle to grave carbon footprint summary, based on certain assumptions and including carbon sequestration (kg CO_2-eq per tonne shellfish harvested)***



	Suspended mussels	Intertidal oysters
End of Life	44.9	96.5
Use	155	0.210
Retail	75.0	178
Distribution	122	129
Sequestration	-230	-441
Depuration	16.6	310
Farm operations	140	730
Materials	93.6	195
Hatchery	0.0	34.7

For mussels, this amounts to 0.324 kg CO_2-eq per 500 g serving of mussels (edible content 112 g), and if including sequestration, 0.215 kg CO_2-eq per serving.

For oysters, this amounts to 0.726 kg CO_2-eq per half dozen serving of oysters (edible content 440 g), and if including sequestration, 0.532 kg CO_2-eq per serving.

Table 4.1 Cradle to grave discussion

Life cycle stage	**Discussion**	**Potential impact on carbon footprint - mussels**	**Potential impact on carbon footprint - oysters**
Processing	Processing may involve the cooking of the shellfish and repacking in the case of mussels, or simply repacking. No information has been made available for this life cycle stage. The process is likely to include sorting, washing and steaming or boiling, followed by rapid cooling. A proportion of the shellfish are likely to be discarded due to the shellfish having died prior to processing or the shell having broken during transport or processing.	Low to medium	Low
Distribution to market	Distance to market is highly variable (local, regional, national, international). As such, the impact of this life cycle stage varies considerably. Road transport seems to be the preferred mode of transport. For the international market, air transport may be used. Emissions from international airfreight are more than eight times more than those from road transport, whilst national airfreight are more than six times more than road transport. Product loss is also a considerable impact from this life cycle stage. Winther found that low edible yield had quite an impact on the overall carbon footprint (Winther *et al*, 2009). Of 1 kg of edible mussels delivered and consumed in Paris, 4.2 kg of washed and sorted fresh mussels leaving Norway was required (note, part of this product loss may have occurred during preparation). A scenario was created that assumed transport to London, via any processor used. No product loss was considered. Under these assumptions, this life cycle stage represents near to 20% of the total carbon emissions for mussels and near to 10% for oysters.	Low to high	Low to high
Retail	Retail will be of relevance to shellfish where the end user of the product is the general consumers. Retail impacts will mainly be related to the cooling of the shellfish to maintain freshness. No information was available that specified the average time shellfish spend in retail storage before purchasing. A scenario was created that assumed the shellfish products spent two days in store under chilled conditions. Under these assumptions, this life cycle stage represents more than 10% of the total carbon emissions for shellfish.	Low to medium	Low to medium

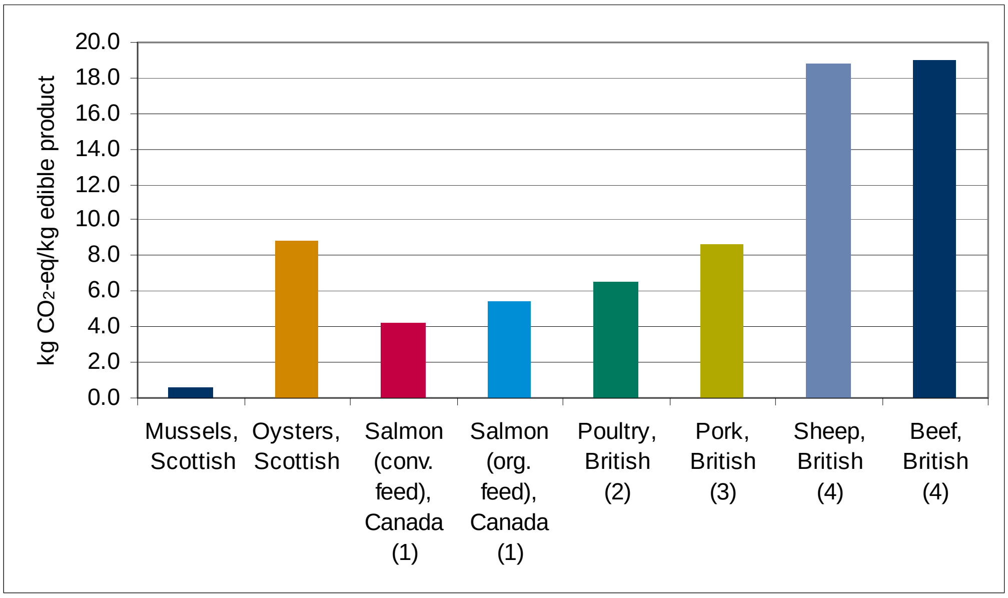
Life cycle stage	Discussion	Potential impact on carbon footprint - mussels	Potential impact on carbon footprint - oysters
Use	The use phase entails the storage, preparation and cooking of the shellfish. If eaten un-cooked, as is the case for the majority of oysters consumed, the impact will be considerably lower. A scenario was created that assumed storage in the fridge for one day before consumption. For the mussels, it was assumed that these were cooked on the hob by boiling for 5 minutes. Under these assumptions, this life cycle stage represents less than 1% for the total carbon emissions for oysters. For mussels, the contribution is considerably higher, accounting for approximately a quarter of the total carbon emissions.	Medium	Low
End of life	The disposal of shellfish in a municipal landfill has limited impact on the carbon footprint since no degradation to CO_2 is considered. Only the impact of refuse collection is considered. A scenario was created that assumed general UK municipal disposal, which in 2009/10 was 78% landfill and 22% incineration without energy from waste, and 50km waste lorry transport. Under these assumptions, this life cycle stage represents less than 10% for the total carbon emissions for shellfish.	Low	Low

4.6 COMPARISON WITH COMPETING PRODUCTS

Protein sources competing with mussels and oysters in the market include other fish products as well as meat products such as beef, lamb, pork and poultry. Various data sources (EBLEX 2009, ERM 2009, Defra 2006, Pelletier and Tyedmers 2007) were consulted and the figures were converted into similar units to enable a level of direct comparison.

The comparison of mussels and oysters with meat products is shown in *Figure 4.5* below. The sources have not been compared with regard to the methods applied for determining the carbon impacts. However, the data suggest that shellfish perform favourably against meat products and that mussels specifically can justifiably be promoted as a low-carbon food product.

Figure 4.5 Carbon footprints of seafood and meat products



(1) Pelletier and Tyedmers 2007(2) Defra 2006
(3) ERM 2009
(4) EBLEX 2009

4.7 CARBON CREDITS AND THE SHELLFISH SECTOR

Carbon credits and carbon markets are a component of international, national and voluntary attempts to mitigate the growth in concentrations of greenhouse gases in the atmosphere. By purchasing carbon credits, one conceptually 'neutralises' the emission of a quantity of CO_2-equivalents in one location by avoiding the emission of the same quantity of CO_2-equivalents elsewhere.

The carbon market involves both a compliance and a voluntary carbon market (House of Commons 2007). The compliance carbon market is governed by the Kyoto Protocol, which establishes legally-binding targets for greenhouse gas reductions by those countries that ratified the Protocol. To enable compliance, the Protocol established Flexible Mechanisms for meeting the targets by trading carbon credits or emission reduction units (Kyoto Protocol 1998). These mechanisms are: the Clean Development Mechanism (CDM); Joint Implementation (JI); and Emissions Trading. In addition, several countries and regions have developed their own trading mechanisms, most notable amongst these being the European Emissions Trading Scheme (EU-ETS).

The voluntary carbon market has developed independently of government targets and policies and allows businesses, NGOs, and individuals to participate in carbon offsetting to meet their own objectives. Carbon credits are also created in the voluntary market, but unlike the compliance market where credits are tradeable, credits in the voluntary market are not tradeable between schemes.

Under the CDM, carbon reduction projects are set up in developing countries generating tradable credits called Certified Emissions Reductions (CERs), which can be used by industrialised nations to offset carbon emissions at home and meet their Kyoto reduction targets. Carbon credits are generated through four types of projects: renewable energy; energy efficiency; fugitive emissions capture; and carbon sequestration. The JI is based on the same principles as the CDM, but in this case it allows developed countries, particularly those in transition to a market economy, to host carbon-reducing project funded by another developed country. The credits generated, called Emission Reduction Units (ERUs), go to the investor country while the emission allowances of the host country are reduced by the same amount. No such geographical restrictions apply to projects under the voluntary carbon market.

The defining characteristic of carbon credits (offsets) is 'additionality'. Additionality means that the project must provide emission reductions that are additional to those which would have occurred under a business-as-usual scenario. In other words, if a wind farm would have been built or trees planted, regardless of the sale of the carbon credits then the projects are not additional and cannot be counted as carbon offsets. Additionality can be demonstrated in various ways, for example by showing that a project would not be profitable enough without the sale of the carbon credits or that a certain technology would not have otherwise been adopted.

Additionality is a challenging issue and a difficult concept to explain not by virtue of its actual definition, but because of its application in practice. Designing rules effectively to test whether offsets are additional can be challenging. There are numerous possible approaches, but in general the evaluation should be done in accordance to explicit and verifiable criteria. Ongoing monitoring and verification are key components to ensure actual reductions are real and have long-term perspectives.

Under carbon sequestration, currently only afforestation and reforestation are considered additional activities under the Kyoto Protocol. This means that, at present, shellfish farming projects would not be eligible for carbon credits.

At a future Conference of the Parties to the Kyoto Protocol, this could potentially be expanded with research and sound arguments to include aquaculture projects. These would then need to demonstrate additionality to be eligible.

Within the CDM framework, one obstacle may prove to be achieving consensus on the inclusion of living organisms. Another is likely to be providing evidence of the permanence of the carbon sequestration in the shells. A similar issue has been observed for forestry. The result is that the credits (so-called Certified Emissions Reductions, CERs) issued by the CDM Executive Board for forestry projects are only temporary credits, ie the offsets are not permanent and they eventually expire. As a consequence, the price of forestry credits compared to renewable energy credits etc is much lower and has not created significant demand from investors.

The voluntary market, which would be the most likely avenue for any potential future aquaculture carbon credit projects, follows the same criteria for additionality. For example, voluntary schemes such as the Voluntary Gold Standard (VGS) (1) and Verified Carbon Standard (VCS) (2) have similar strict additionality criteria. However, where they differ are on less stringent criteria to permanence.

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(1) http://wwf.panda.org/what_we_do/how_we_work/businesses/climate/offsetting/gold_standard/
(2) www.v-c-s.org

5 CONCLUSIONS AND RECOMMENDATIONS

The cradle-to-gate carbon footprints of harvested shellfish were calculated to be 252 kg CO_2-eq per tonne of mussels and 1,281 kg CO_2-eq per tonne of oysters.

Extrapolating across all Scottish mussel farmers, the total carbon footprint of all Scottish suspended mussel and intertidal oyster production for 2010 is 1,585,948 kg CO_2-eq and 297,264 kg CO_2-eq, respectively.

The carbon footprint numbers were calculated by analysing operational data for 2010 production collected directly from three mussel farmers and two oyster farmers. The farmers represent approximately 23% of total Scottish mussel production, and 37% of total Scottish Pacific oyster production. The data are considered to be confidential.

5.1 CARBON HOTSPOTS

More than half of the cradle to farm gate carbon footprint for both suspended mussels and intertidal oysters is from farm operations, ie the electricity and fuel used to cultivate and to harvest the shellfish. If depuration is included, the contribution from farm operations to the footprint is 62% for mussels and 81% for oysters. Depuration can constitute a significant proportion of the cradle to gate carbon footprint.

Scenarios were developed to determine the potential significance of the full cradle to grave carbon footprint of the shellfish. The destination of the shellfish (place of consumption) and the format it is delivered in (fresh or pre-cooked) determines the level of processing the shellfish undergoes, the distance it travels and the mode of transport, the loss rate along the supply chain, the preparation of the shellfish and possibly also how the shells are disposed of after consumption. The life cycle stages of distribution, retail, and use can all have a significant impact on the overall carbon footprint of shellfish. For mussels, processing also can have a significant impact.

5.2 GREATEST POTENTIAL FOR ENVIRONMENTAL IMPROVEMENT

The results suggest that efforts to reduce the impacts of climate change from shellfish production should focus on increasing energy efficiency. The construction and maintenance of the vessels and equipment are outside the scope of this study, but are fundamental in reducing fuel consumption and therefore to lowering the carbon footprint. Operating vessels only when required and combining multiple tasks, as well as using appropriately sized vessels, all helps to promote fuel efficiency. Using harvesting vessel contractors, or farmers sharing vessels, may help reducing impacts as well as resulting in the vessels being more fully utilised, with upgrading likely to be achieved more quickly. Efficiency in stationary equipment may be achieved through the promotion of non-idle operation and depuration only when the full capacity of the tank is used. Installing renewable forms of electricity generation is another option for footprint reduction.

One of the main benefits of suspended mussel and intertidal oyster farming is proximity to shore, which minimises fuel consumption. Therefore, compared to other shellfish or fish products, mussel and oyster production is a low fuel-intensity means of production.

Although of less significance than energy use, material use is also a considerable contributor to the carbon footprint. Prolonging the life of materials and using materials that achieve high yield through minimal material use will aid in reducing the carbon footprint.

Another measure for achieving a lower carbon footprint could be to assess the requirements for increasing the edible yield reaching the consumer.

Considerable variation is seen between the farmers contributing data to this study. Data collection was conducted iteratively, and in some cases the variation was reduced. However, a considerable range remains in many instances. It has not been possible completely to clarify the reason for this. It seems that in part it is due to different estimates of lifetime for various materials, as well as production achieved and therefore the nutrient level of the waters. However, it may also spotlight areas of best practice, which could aid the industry in identifying further efficiencies.

5.3 CRITICAL DATA POINTS

Accurate electricity and fuel use data is most critical to calculating a carbon footprint for shellfish, as the majority of the footprint arises from energy used during cultivation, harvesting and depuration.

Considerable differences are seen between the shellfish farmers contributing data to this study. This may be a natural variance due to different water conditions and nutrient levels, as well as possible differences in farming methods used. However, it might also warrant further investigation by SARF.

Operational changes on at least one farm have influenced the results for 2010. This is likely to have influenced the estimated materials required for producing a tonne of shellfish for the particular farm, ie the material use is likely to be higher per tonne shellfish harvested in 2010 than under normal operation. However, the operational changes may not have led to a linear decrease in fuel use as well.

5.4 CARBON FOOTPRINTING – FOR WHAT USE?

The carbon footprint of a product might be measured for a number of different reasons and to fulfil many different needs. The intended use of the footprint data will determine the requirements of the study. For example, for labelling the carbon footprint of a product under PAS 2050, specific requirements apply to the quality of the data, and certification of data is required. Product labelling is not an outcome sought from this project.

There are a number of potential applications for the footprint data for mussels and oysters, which include:

- an aid in prioritising efforts to reduce the contribution made by mussels and oysters production to climate change;
- a basis for developing criteria for environmentally preferable and sustainable shellfish farming;
- a basis for consumer information;
- a basis for business to business communication and collaboration (eg. reducing the carbon footprint of prepared foods);
- a foundation for developing shellfish cultivation methods and vessels with lower carbon footprints per kilogramme shellfish; and
- a contribution to the marketing of shellfish products (for example, through further research comparing with other protein sources).

This report provides the basis for moving on to creating a more sustainable and competitive shellfish sector in Scotland, should the industry wish to take any of the above potential uses further.

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Annex A

Technical Detail

A1 DATA COLLECTION

This streamlined carbon footprint uses a combination of: primary data collected from a small selection of Scottish shellfish farmers; and secondary or generic data from industry sources and publications. Data were collected through a series of site visits, telephone interviews, bespoke questionnaires and industry reports and represents best estimates for the 2010 production year for the farmers involved.

The primary data obtained from the shellfish farmers were for:

- electricity and fuel consumption by task;
- material consumption;
- packaging consumption;
- growth rate and stocking density; and
- tonnage of shellfish harvested as well as loss rates.

Data for a complete year of operation have been used in order to take into account seasonal differences. Data for several years of operation were considered, but it was decided that one year of operation was suitably representative for the purposes of this study.

At SARF's request, capital equipment in the form of vessels and machinery was excluded from the study. Capital equipment is regularly left out of carbon footprint studies as its contributions are generally found to be negligible when lifespan and production volumes over this period are considered. However, in the absence of feed inputs and with presumed relatively modest fuel use, capital equipment could potentially contribute significantly to the overall mussel and oyster results. As such, one mussel farmer provided information about vessel and equipment use and this was assessed in the context of that farmer's individual carbon footprint.

Secondary data have been used for:

- material production for ropes, bags, etc;
- electricity and fuel production;
- transport processes; and
- waste management processes.

Data were obtained from the life cycle inventory database, ecoinvent, and Defra GHG emissions data.

A2 DATA ASSUMPTIONS

Key assumptions related to the data used in this study are listed below.

- The results are derived from the data supplied by four shellfish farmers: two mussel farmers; one oyster farmer; and one farmer producing both mussels and oysters. Although the results are extrapolated to estimate the total carbon footprint for Scottish-produced suspended mussels and intertidal oysters in general, caution should be exercised when drawing conclusions for Scottish production as a whole.
- Since materials in the form of grow ropes, oyster bags etc have a life span of many years, the purchase of new materials and the generation of waste varies considerably from year to year. To account for this, average annual material consumption and wastage was calculated based on the farmers' estimations of stock held and lifespan of the materials.
    - Ropes are assumed to have a lifespan of 10-20 years. The ropes are assumed to be made from virgin polypropylene (PP) or polyethylene (PE) depending on rope type.
    - Buoys are assumed to be produced from virgin high density polyethylene (HDPE) and have a lifespan of 10-15 years.
    - Oyster bags are assumed to be produced from virgin high density polyethylene (HDPE) and have a lifespan of 20-25 years.
    - Steel trestles are assumed to last 10 years before having degraded to a non-useable state.
    - The same quantity of material required for the production of a tonne of shellfish is also assumed to be disposed off.
- Transport:
    - Oyster seeds are assumed to be transported to the oyster farmer at ambient temperature.
    - Transport distances to London include any reported transport to processors. Transport to the processors has been calculated as chilled or ambient transport depending on the information provided by the farmers. Chilled transport from the processors to London is assumed.
    - The rate used for loss of shellfish during distribution and retail is based on estimations by SARF members.
- End of life data assumptions:
    - Refuse collection was assumed to be 50 km by waste lorry.
- The weight of the vessel associated with the capital burden calculations uses the gross weight provided by the shellfish farmer.
- Transport calculations associated with staff commuting use the distances per staff as provided by the shellfish farmer.

A2.1 *EXCLUDED DATA*

A2.1.1 *Staff commuting to site*

Based on information from one of the mussel farmers, a scenario was created for staff commuting to work. On average, the core staff members drive 14 miles (round-trip) to work five days per week. Another member of staff drives 30 miles (round-trip) to site three days per week, and another 3 miles (round-trip) to site also three days per week. Using a Defra / DECC 2011 greenhouse gas conversion factor for an average car, unknown fuel (0.38876 kg CO_2-eq per mile) (Defra / DECC 2011), the total emissions for the seven staff were calculated to be 9,922 kg CO_2-eq per year. This represents 10% of the CO_2 emissions of that farm's cradle to farm gate carbon footprint and can be deemed to have a relatively significant impact.

A2.1.2 *Capital equipment*

Based on information from one of the mussel farmers, a scenario was created for including capital equipment. The farm has one large vessel, a smaller vessel, and a rigid inflatable boat (RIB). Harvesting and grading takes place onboard the larger vessel. Based on assumptions regarding the weight of the vessels, their material composition and lifespan, and using greenhouse gas conversion factors for these (confidential), the total emissions for the capital equipment were calculated to be 5,615 kg CO_2-eq per year. This represents 6% of the CO_2 emissions for that farm's cradle to farm gate carbon footprint and can be deemed to have a moderate impact.

A2.2 *IN-WATER MORTALITY*

While suspended in the water column, a proportion of the mussels on the ropes will die, detach and sink to the seabed. Limited information about mussel mortality has been identified.

Two literature studies were found (Karayücel and Karayücel 1999, Stirling and Okumus 1994), although they considered mussels reared in lantern nets – not rope-grown. Karayücel and Karayücel found that one-year old rope-grown mussels, held in experimental lantern nets at 2 m and 6 m depth in Loch Kishorn, Scotland, for a period of 15 months showed a natural cumulative mortality rate of 13.6% at 2 m and 16.7% at 6 m. Stirling and Okumus found that one-year old rope-grown mussels, held in experimental lantern nets and cross-transplanted between Loch Etive and Loch Leven, Scotland, for a period of 12 months showed a mortality rate of 6% to 7%. Taking into account both study findings, this would suggest an annual mortality rate of between 6% and 13%.

For a recent SARF project (Tom Wilding 2011), up-to-date mortality rates were sought. A mussel farmer source estimated this to be 1% per day for one-year old mussels until harvesting.

This suggests considerable variation, or possibly uncertainty. A 1% mortality rate per day would mean that sequestration in shells for mussels dying at sea and sinking to the seabed would completely outweigh the carbon impacts of mussel farming since the quantity of dead mussels would be several magnitudes higher than the quantity harvested. For example, for the mussel farmers contributing to this study, the weight of dead mussels sinking to the seabed is estimated to be between 23 and 603 times higher than the weight harvested. The range is due mainly to different grow-out rates. This large difference between harvested and in-water lost mussels seems somewhat unrealistically high.

To give an indication of the potential quantity of carbon sequestered in shells from mussels dying at sea, detaching and sinking to the seabed a mortality rate of 1% per month has been assumed. It must be stressed that this is only an assumption and further evidence of the mortality rate would be needed in order for it to be of sufficient robustness to support conclusions being drawn on sequestration based on in-water mortality.

A3 LIMITATIONS

This study relies on a combination of primary data collected from shellfish farmers and secondary and generic data from industry and literature sources. The farmers contributing to this study are a group of four shellfish farmers, representing approximately 23% of total Scottish mussel production and 37% of total Scottish Pacific oyster production. Although considered to be representative of Scottish shellfish production, some caution should be exercised when drawing conclusions for Scottish-produced suspended mussels and intertidal oysters in general due to the limited coverage of the sample.

With regard to the data, accurate electricity and fuel use data is most critical to calculating a carbon footprint for shellfish, as the majority of the footprint is from energy used during cultivation, harvesting and depuration. Considerable differences were seen between the shellfish farmers contributing data to this study and, as a consequence, the figures provided were double-checked.

Average data and variance is shown for a number of factors in *Table 3.1* to *Table 3.3*. For example, the amount of rope required per tonne of mussel harvested varies by a factor of 17.

Table 3.1 Material input in mussel cradle to farm gate

Input	Unit	Amount	Factor variance
Ropes	kg per tonne	13	17
Buoys	kg per tonne	4.4	16
Pegs	kg per tonne	3.5	56
Mesh socks	kg per tonne	2.3	1.5

Table 3.2 Material input in oyster cradle to farm gate

Input	Unit	Amount	Factor variance
Oyster bags	kg per tonne	10	2.3
Closures & ties	kg per tonne	8	25
Steel trestles	kg per tonne	71	4.6

Table 3.3 Energy input in oyster cradle to farm gate

Input	Unit	Mussels		Oysters	
		Amount	Factor variance	Amount	Factor variance
Electricity, exc depuration*	kWh per tonne	46	0.7	716	17
Fuel	litres per tonne	28	2.0	48	13
Oil & greases	litres per tonne	0.94	5.2	1.6	2.7

* Assumptions have been made with regard to sea pump use for depuration.

The variation observed may partly be natural differences due to water conditions and nutrient levels affecting shellfish growth, as well as possible differences in farming methods used and distance to growing area. However, the variation might also be due to different approaches in estimating material and energy use by the individual farmers. On the other hand, it may also spotlight areas of best practice, which could aid the industry in identifying further efficiencies.

The variations found suggest considerable differences in practice between shellfish farmers, especially between oyster farmers. To get a better understanding of the representativeness of the results generated, future work could include an increase in the number of participating farmers to achieve higher representation of Scottish shellfish production.

Operational changes on at least one farm have influenced the results for 2010. This is likely to have influenced the estimated materials required for producing a tonne of shellfish. However, the operational changes may not have led to a linear decrease in fuel use as well.

A4 CRADLE TO GRAVE CARBON FOOTPRINT

This study considered the carbon emissions of suspended mussel and intertidal oyster farming that occur up to the point at which shellfish leave the farm. Shellfish processing, distribution to market, consumption and end of life are highly variable, depending on farm location, market conditions, market demand and various other factors. Each of these stages is discussed below in order to estimate the scale of impact in comparison to the cradle to gate footprint.

A4.1 SHELLFISH PROCESSING

Processing relates to the further packaging of shellfish, or mainly in the case of mussels, the cooking of products entering the market as pre-cooked (eg vacuum packed pre-cooked mussels). No information was collected for this life cycle stage. However, it is likely to include sorting, washing and steaming or boiling, followed by rapid cooling. A proportion of shellfish are likely to be discarded as part of the process due to having died prior to processing or to the shell having broken during transport or processing.

A4.2 DISTRIBUTION

Being to a large extent fresh produce, fast delivery times are required. Therefore, next day delivery via road or air freight is often used for fresh shellfish. Fast delivery is not a factor for processed pre-cooked mussels. Therefore, these enter the general food supply chain. The different transport modes have a varying carbon footprint per tonne km travelled. The emission factors in *Table 4.1* indicate the scale of difference between each mode of transport.

Assuming transport to London via road, distribution to a London customer accounts for 19% of the cradle to grave carbon footprint for mussels, and 8% for oysters. Product loss during distribution and retail has been estimated by SARF members to be 20% for mussels. The loss rate is significantly less for oysters, down in single figures. For the purposes of this project, a loss rate of 8% has been assumed for oysters.

Table 4.1 Onward transport to user of shellfish

Transport mode	**kg CO_2-eq per tonne per km travelled**
Road (rigid, >17 tonnes)	0.23644
Air (domestic)	2.07910
Air (short-haul international)	1.59643

Source: Defra, 2011

Promotion of transport by road can help reduce the carbon impact of this life cycle stage. It is acknowledged that, in some circumstances, using road transport would not be possible due to the distance and thereby time required for delivery.

A4.3 *RETAIL*

Retail is of relevance where the end user is the general consumer. Retail impacts will be related mainly to maintaining the shellfish at a temperature that ensures and prolongs freshness.

A scenario was created that assumed the shellfish spend two days in store under chilled conditions. Under these assumptions, retail account for 12% of the cradle to grave carbon footprint for mussels, and 11% for oysters.

A4.4 *USE*

The use phase entails the storage, preparation and cooking of the shellfish. If eaten un-cooked, as is the case for the majority of oysters consumed, the impacts will be lower.

A scenario was created for mussels assuming that they were stored in the refrigerator for one day and subsequently cooked on the hob for 5 minutes. Product loss is estimated by SARF members to be anywhere from 0% up to 5%. This loss was not considered as part of this project. Using ERM's database emission factors (confidential) the carbon impacts of the use phase was found to account for 24% of the cradle to grave carbon footprint for mussels. For oysters, which were considered to be eaten un-cooked, this life cycle stage account for significantly less than 1% of the cradle to grave carbon footprint.

A4.5 *END OF LIFE*

Since shellfish are most likely to be consumed either in the home or in a restaurant (or other catering service), routes for the management of waste need to be considered.

Mussel or oyster shells from shellfish consumption in the home may end up in the general household bin or, if food waste is collected separately, in the food waste bin (although a quick Internet search resulted in only one council, Dorset, specifically suggesting shells be included in the food waste bin). In 2009/10, the split between landfill and incineration for municipal waste was 78% landfill and 22% incineration.

Catering waste, ie waste food from restaurants, catering facilities and kitchens, are regulated under the Animal By-Products (Enforcement) (England)

Regulations No. 2011/881. The regulations categorises animal by-products into three groups of which category 3, low risk materials, include catering waste. Category 3 wastes can go to landfill for disposal.

ERM considers that the acidity of a municipal landfill may result in the calcium carbonate ($CaCO_3$) of the shells reacting with this to produce an organic salt and water. Degradation to produce CO_2 is estimated not to take place.

$$\text{acid} + \text{alkaline} = \text{organic salt} + H_2O$$
$$RCOOH + CaCO_3 = RCOOCa + H_2O$$

However, on incineration, CO_2 is considered to be released. On combustion, the calcium carbonate of the shells will calcinate to produce calcium oxide (CaO) and CO_2.

$$CaCO_3 = CaO + CO_2$$

A scenario was created for the management of waste mussel shells assuming 78% disposed in landfill with no degradation taking place and 22% managed through incineration with calcination taking place. Only shells were considered, disposal of any potential shellfish meat was not considered. In addition, refuse collection was included, assuming an average distance travelled of 50 km, as well as the management of the packaging known to be disposed of in the household.

Note that, in practice, more packaging is likely to be associated with the purchasing of shellfish by the consumer. Using ERM's database emission factors (confidential) the carbon impacts of the end of life phase was found to account for 7% of the cradle to grave carbon footprint for mussels, and 6% for oysters.

A5 DATA COMPARISON

The mussel carbon footprint calculated in this study is lower than that reported by Winther *et al* for Norwegian-produced mussels (Winther *et al* 2009). Winther *et al* calculated a footprint of mussels based on data from a select group of Norwegian mussel farmers, to be 2.54 kg CO_2-eq per kg edible product at the wholesaler (in Paris). Converting the results of this study to 'per kg edible product' results in a footprint of 0.61 kg CO_2-eq for mussels (this includes the natural water content of the mussels). If excluding the natural water content, the footprint is 1.7 kg CO_2-eq per kg edible product.

There are several factors that have contributed to the difference in footprint. *Table 5.1* presents an effort to compare the material and energy input data for the Winther *et al* study and this assessment. In addition, Winther *et al* has included capital goods in its calculations. As can be seen, fuel consumption is about half for this current study, whereas material inputs are more than three times as high. Electricity consumption is the same, and packaging use is considerably lower (partly due to this study not covering all packaging use).

However, the main difference is the quantity of live, unsorted mussels assumed required in order to provide 1 kg of edible product at the wholesalers. In Winther *et al*, this is 7.3 kg, whereas this study assumes 2.05 kg, based on estimates regarding loss rates during distribution. If excluding the natural water content of the mussels as part of the meat weight, the quantity of live, unsorted mussels required is 5.68 kg.

Table 5.1 Material and energy input comparison

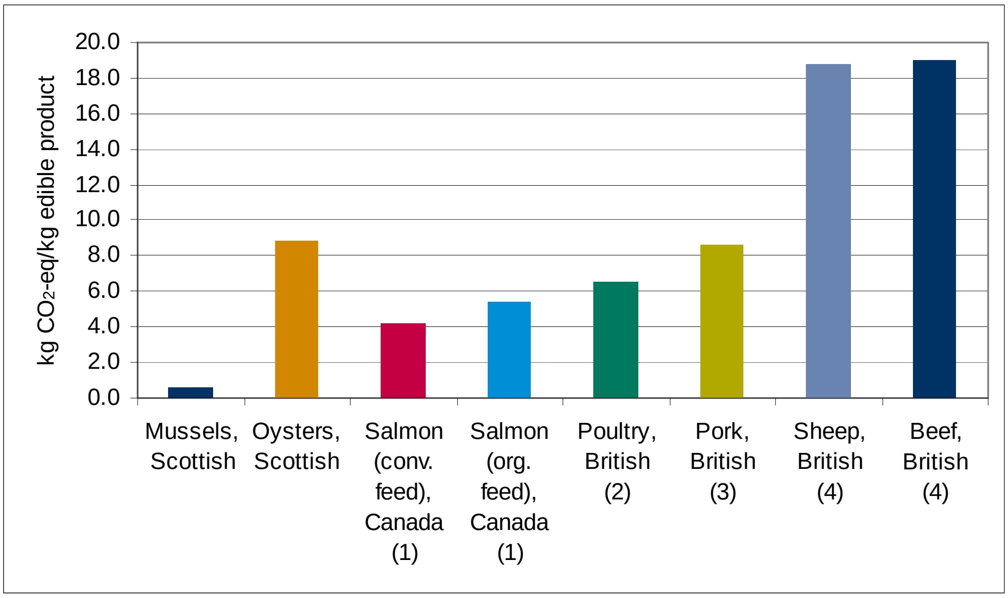
Input	Unit	Winther et al	Current study
Cultivation			
Fuel	kg/kg raw product	0.047	0.0233
Plastics	kg/kg raw product	0.0063	0.0212
Cotton	kg/kg raw product	-	0.0023
Iron	kg/kg raw product	0.0088	-
Transport			
Distance	km	200	7-800
Ice	kg/kg raw product	0.3	chilled trp
Processing, Packaging			
Electricity	kWh/kg product	0.046	0.046
Packaging	kg/kg product	0.063	0.0082

No comparative study was identified for oysters.

Comparison of mussels and oysters with meat products is shown in

Table 5.2 below. The sources have not been compared with regard to the methods applied for determining the carbon impacts. However, the data suggest that shellfish perform favourably against meat products and that mussels specifically can justifiably be promoted as a low-carbon food product. In order to support this conclusion, an attempt at converting the figures into similar units to enable a level of direct comparison, as shown in *Figure 5.1*, has been made.

Figure 5.1 ***Carbon footprints of seafood and meat products***



(1) Pelletier and Tyedmers 2007
(2) Defra 2006
(3) ERM 2009
(4) EBLEX 2009

Table 5.2 Cradle to gate carbon footprint for shellfish and meat

Shellfish/meat	Unit	Carbon footprint	Reference	Assumptions used for conversion	Unit	Carbon footprint
Beef, British	kg CO_2-eq/kg carcase	13.89	EBLEX 2009	Assumed 73% of the carcase is saleable meat (1)	kg CO_2-eq/kg edible product	19.0
Sheep, British	kg CO_2-eq/kg carcase	14.64	EBLEX 2009	Assumed 78% of cut lamb is saleable meat (2)	kg CO_2-eq/kg edible product	18.8
Pork, British	kg CO_2-eq/kg edible product	8.6	ERM 2009		kg CO_2-eq/kg edible product	8.6
Poultry, British	kg CO_2-eq/kg product	4.57	Defra 2006	Assuming 70% meat yield (3)	kg CO_2-eq/kg edible product	6.5
Salmon (conv. feed), Canada	kg CO_2-eq/kg live weight	2.1	Pelletier and Tyedmers 2007	Assuming 50% meat yield (4)	kg CO_2-eq/kg edible product	4.2
Salmon (organic feed*), Canada	kg CO_2-eq/kg live weight	2.7	Pelletier and Tyedmers 2007		kg CO_2-eq/kg edible product	5.4
Mussels, Scottish	kg CO_2-eq/kg edible product	0.61	Current study		kg CO_2-eq/kg edible product	0.61
Oysters, Scottish	kg CO_2-eq/kg edible product	8.8	Current study		kg CO_2-eq/kg edible product	8.8

* Including the natural water content.

** Organic crop ingredients / fisheries by-product meals and oil.

(1) Source: http://www.eblex.org.uk/documents/content/returns/brp_b_beefactionforprofit31-betterreturnsfromunderstandingkillingoutpercentage.pdf. This is based on the grid system for grading saleable meat.. Based on http://www.eblexretail.co.uk/assets/documents/EUROP_classification_grid.pdf, 73% has been assumed as a slightly optimistic yield.

(2)Source: http://www.eblex.org.uk/documents/content/returns/brp_l_31betterreturnsfromunderstandingkillingoutpercentage.pdf. This is based on the grid system for grading saleable meat, using the mean.

(3) Source: http://www.ukagriculture.com/livestock/broiler_chickens.cfm

(4) Source: http://www.mjseafood.com/fishipedia-seafood-guide/buying-storing-and-cooking/cuts-and-portions/

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