BIM
Ireland's Seafood Development Agency

SEAFOOD SUSTAINABILITY PROGRESS REPORT: AQUACULTURE 2025

Rialtas na hÉireann
Government of Ireland

Arna chomhchistiú ag an Aontas Eorpach
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ABBREVIATIONS

ASC – Aquaculture Stewardship Council

BIM – Bord Iascaigh Mhara

EBIT – Earnings before interest and taxes

ep-EROI – Edible protein energy return on investment

EU – European Union

EUMAP – European Union Multiannual Plan

FFDR – Forage Fish Dependency Ratio

FTE – Full Time Equivalent

GHG – Greenhouse Gas

GVA – Gross Value Added

GWP – Global Warming Potential

IPCC – Intergovernmental Panel on Climate Change

ISO – International Standards Organisation

KPI – Key Performance Indicator

LCA – Life cycle assessment

LCIA – Life Cycle Impact Assessment

PAS – Publicly Available Standard

PEFCR – Product Environmental Footprint Category Rules

WU – Water Use

GLOSSARY

Carbon Footprint (CF) – A total product carbon footprint is a measure of the direct and indirect greenhouse gas (GHG) emissions associated with all activities in the product's life cycle. Products are both goods and services. Such a carbon footprint can be calculated by performing (according to international standards) an LCA that concentrates on GHG emissions that have an effect on climate change (UNEP/SETAC, 2009).

Cradle to gate – An assessment that includes part of the product's life cycle, including material acquisition through the production of the studied product and excluding the use or end-of-life stages. (WRI and WBCSD 2010).

Global Warming Potential (GWP) – An index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing (defined by the IPCC).

Greenhouse Gases (GHGs) – Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Human-made GHGs include sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs); several of these are also O_3-depleting (and are regulated under the Montreal Protocol) (defined by the IPCC).

Gross Value Added (GVA) – GVA is the value that producers have added to the goods and services they have bought. When they sell their wares, producers' income should be more than their costs, and the difference between the two is the value they have added (CSO).

Hotspot – A life cycle stage, process or elementary flow which accounts for a significant proportion of the impact of the functional unit (UNEP)

Impact Category – Impact Categories are logical groupings of Life Cycle Assessment results of interest to stakeholders and decision makers (UNEP/SETAC, 2009)

Life Cycle Assessment – Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle. (ISO 2006)

Multiplier Effect – The multiplier effect is a term used to describe the impact that monetary supply from an activity can have on wider economic activity. When a company, government or person spends money it can have a trickle-down effect to other businesses and individuals. Multiplying the value of the initial spend through direct and indirect means.

Sustainability - Sustainability is the capacity to endure. In ecology, the word describes how biological systems remain diverse and productive over time. For humans, sustainability is the potential for long-term maintenance of well-being, which has environmental, economic, and social dimensions (UNEP).

EXECUTIVE SUMMARY

This inaugural report presents information on the sustainability performance of the Irish aquaculture sector. It baselines the performance of the sector across four dimensions of sustainability; (i) environment, (ii) economic, (iii) social and (iv) innovation. The data used in this report comes from a series of publications and reports published by Bord Iascaigh Mhara (BIM). This data has been analysed and assessed under a sustainability lens to develop and estimate the sustainability credentials and performance of the Irish aquaculture sector, using the years 2017 to 2019 as baseline years.

Some twenty four key performance indicators (KPI) were used to assess the sustainability of the aquaculture sector (salmon, rope mussel and oyster segments). Nine indicators were used to assess the environmental sustainability of the sector. These ranged from marine resource use (fish in fish out ratios and fodder fish dependency ratios), spatial use, greenhouse gas emissions, energy return on investment and contribution to food security. Much of the data used in the development of the environmental KPIs was derived from the BIM Carbon Footprint Report of the Irish Seafood Sector, the Aquaculture Bay Area Report, as well as the Annual Aquaculture Survey and in-house knowledge and expertise.

Seven economic indicators were used, and these focused on areas such as gross value added (GVA), full-time equivalent (FTE), running cost to turnover ratio, sales value, and productivity (output per FTE and unit of spatial use). These data and indicators are regularly reported within the Annual Aquaculture survey and made their inclusions and supporting data seamless. The social sustainability indicators focused on estimating the wider impacts and benefits of aquaculture within local coastal and rural communities, and various diversity metrics within the sector, as well as reviewing the age structure of the various segments. In total five indicators were used to assess the social sustainability of the sector. The use of innovation indicators as part of sustainability reporting has previously been carried out in Ireland and is used annually as part of Teagasc's' sustainability report for the agriculture sector. Three innovation indicators were selected which focused on new processes, new products and new forms of organisation. Innovation is a pillar of sustainability which can aid all other pillars by increasing efficiency, reducing burdens and increasing social license.

Each aquaculture segment was assessed independent of the other, as with their different biologies, inputs and requirements the results would not have been comparable. From an environmental perspective each of the segments is performing well, though there can be variance within years. There is also a need to raise awareness of the links between environmental and economic sustainability. At an operational level, these two pillars are linked and generally what is good for an operator's bottom line is also good for the environment (i.e., by viewing litres of fuel per hour as €/hour, reductions in carbon emissions can be achieved).

From an economic perspective the results were mixed between the segments. During the study years the salmon aquaculture sector saw decreased GVA and sales value but increased its sales value per tonne. The oyster sector saw reductions in its GVA and so its sales value per hectare increased, though the sales value per tonne saw no major increases. For the mussel sector sales value remained steady and saw increases in the tonnes produced per FTE.

The social sustainability indicators also had mixed results. All segments performed well in terms of multiplier effects for GVA, employment and wages. The diversity in genders was comparatively low for all segments with male workers dominating the workforce. International diversity was also comparatively low with Irish workers making up more than 85% across all segments. All segments had gaps in their age structures, which may indicate a lack of recruitment and succession.

The innovation indicators showed that certain segments perform better in certain areas of innovation. Greater work is needed to capture innovation data and to develop innovation indicators which better capture and reflect the dynamism which exists within the segments.

This report lays the baseline for which future sustainability gains and performance increases can be compared against. The closing section of the report identifies further opportunities and areas for work and increased data robustness. This would allow a deeper understanding of the sector to be gained and used to make more environmentally and sustainably informed decisions.

SALMON
SUSTAINABILITY SUMMARY

3.88 kg CO_2
eq./kg

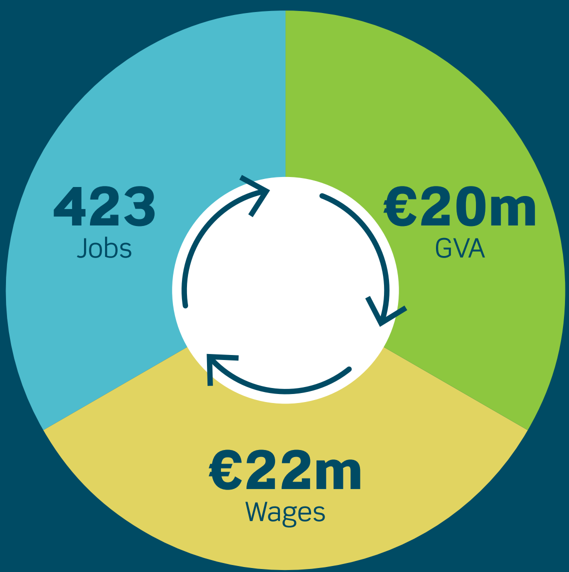
13 tonnes
/ha

12%
ep-EROI

86,446,545
meals produced

96%

4%



€8,260
/tonne

90 tonnes
/FTE

OYSTERS
SUSTAINABILITY SUMMARY

0.235 kg CO_2
eq./kg

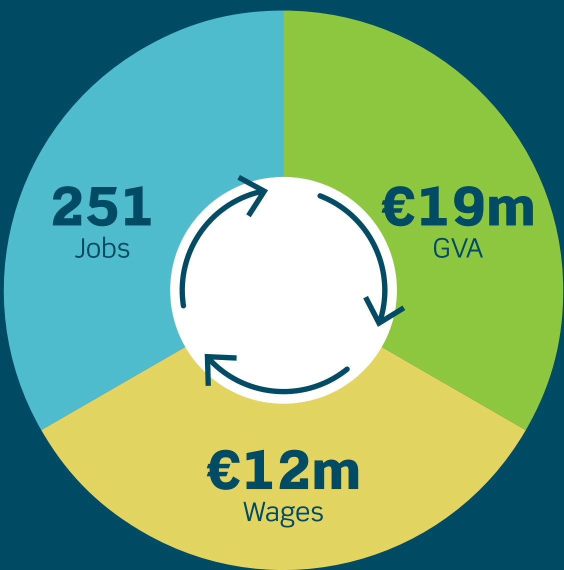
2.24 tonnes
/ha

13%
ep-EROI

26,105,000
meals produced

91%

9%



€4,357
/tonne

19 tonnes
/FTE

MUSSELS
SUSTAINABILITY SUMMARY

0.107 kg CO_2
eq./kg

3.3 tonnes
/ha

85%
ep-EROI

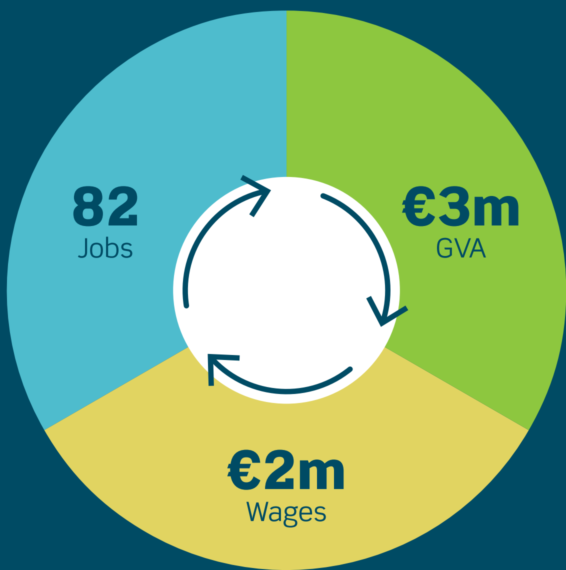
41,637,250
meals produced

91%

9%

€719
/tonne

62 tonnes
/FTE



1. INTRODUCTION
SUSTAINABILITY AND AQUACULTURE

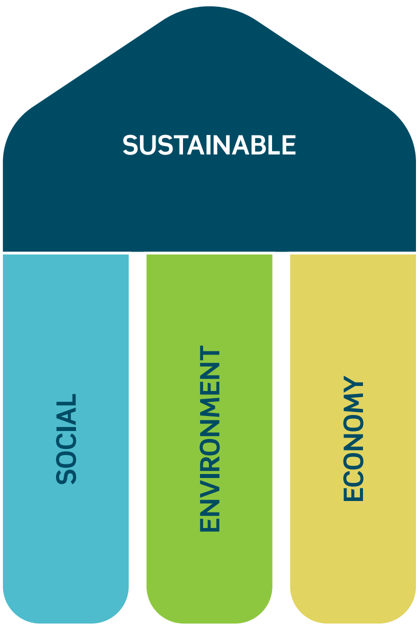
Sustainability is a wide-ranging term that covers several aspects and dimensions of the long-term viability of an activity. The classical definition used in the context of sustainable development is from the 1987 United Nations report (the Brundtland Report), "Our Common Future" – and defines it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainable development is now a key part of many policies and actions by governments, businesses, and individuals. The adoption of these approaches can help to avoid what has been termed the "tragedy of the commons." This tragedy is where a shared resource is overused by individuals to the detriment of all users. Currently we are seeing the effects of this tragedy in real time, with continuing overdemand on planetary resources and the effects of climate change becoming evident. Responsible use of the planet's resources, through successful management, stewardship and cooperation can lead to us all, as well as future generations, reaping the wealth of the commons.

Since the Brundtland Report, a new concept called the triple bottom line has come to the fore in terms of determining sustainability. This bottom line refers to the three pillars needed to ensure that something is environmentally sustainable, economically sustainable and socially sustainable. There needs to be equal consideration given to these pillars to ensure that an activity can provide employment, generate revenue and operate without undue impact on the environment (Figure 1A).

A more in-depth way of representing the sustainability of an activity is to view it through the intersection between the pillars (Figure 1B). This approach allows for the determination of whether the activity is bearable, equitable and viable across the different pillars of sustainability.

A



B

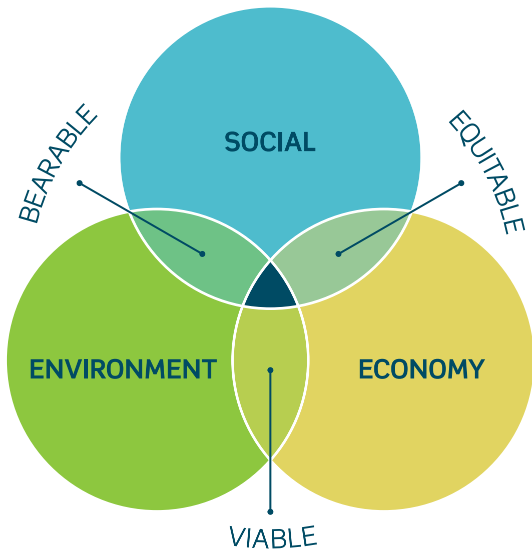


Figure 1:
A, The classical three pillars of sustainability.

B, the intersection of the three pillars is where/when an activity is sustainable.

Production of food in an efficient and sustainable manner has never been more important in human history. Pressures on planetary systems are resulting in global shifts in climate with greater instances of extreme weather events, the continuing deterioration in surface and ground waters due to societal and commercial activities. There are escalating losses in levels of global biodiversity due to changes in land use and resource extraction.

Beyond environmental impacts, social systems and patterns are also changing. Changes in production, use and consumption have pushed the terms sustainable and sustainability to the top of the agenda at all levels of society.

A key area ready for disruption and embracing the sustainability agenda is the food production sector, particularly the seafood sector. Food production globally accounts for almost one third of greenhouse gas emissions (GHGs), almost half of all habitable land and 30% of global energy. With the global population expected to increase to nine billion by 2050, there will be a greater demand for food to feed this growing population. As a result, it is expected that global demand for seafood will increase by 50% in 2050. Much of this demand is expected to be met by aquaculture.

Aquaculture has been the fastest growing food production system in the world since the late 1980s. In Ireland, production has not increased and the sector is producing less than it did in the early 2000s. However, the value of aquaculture produce has increased. This production decline is multifactorial, however in recent years the sector has adapted and innovated. Ireland is a world leader in organic aquaculture and has embraced new modes of production, processes and organisation forms.

With this expected population growth and demand there is a drive to promote greater efficiencies in food production processes and food security. This increase without additional impact and improved security is the main objective of the EU Farm to Fork Strategy. Additional policy and funding support at EU level include the European Maritime Fisheries and Aquaculture Fund (EMFAF) and Blue Growth Strategy. Policies and supports provided by the Irish government to promote and support efficiency gains, food security and the performance of Irish food include FoodVision 2030 and the National Strategic Plan for the Sustainable Development of Aquaculture.

This report and its results underpin the National Strategic Plan for the Sustainable Development of Aquaculture. To baseline the sustainability credentials and performance of the Irish aquaculture it is crucial to begin the process of measuring and following KPIs related to the sector. This report aims to provide supports and insights into the seafood and aquaculture sector.

Key performance indicators across four dimensions of sustainability are used in this inaugural report. They are – environment, social, economic and innovation (Figure 1). Innovation as a pillar has been included within this framework as aquaculture has been widely regarded as one of the most innovative food sectors and to meet the challenges facing the sector innovative approaches and solutions are needed.

2. ASSESSING **SEAFOOD SUSTAINABILITY**

The dimensions of sustainability can have different data requirements and interpretations depending on the system or activity they are related to. Aquaculture is a diverse food production sector that covers both finfish and shellfish species which have quite different biologies and modes of life. These systems vary in terms of the level of energy, material and labour required to produce a viable food product at the end of their grow out cycle and have very levels of intensity and extensity. This makes it difficult to measure the sustainability of aquaculture. One of the most suitable mechanisms for measuring sustainability is by using indicators.

Indicators can allow for the monitoring of the sustainability performance of aquaculture activities over time and can help understand trends and patterns. These indicators must be relevant, robust, representative and identify patterns and trends both spatially and temporally.

The primary data sources used in this study were developed from the BIM Annual Aquaculture Survey (one of the suite of National Seafood Surveys), its publications and the research it supports through the EMFF. The annual aquaculture survey is one of the key reporting tools to the European Union on the performance and productivity of the Irish aquaculture sector. The survey is issued each year and aims to collect data from 315 aquaculture production units located in the country. The survey has been carried out since the mid-1990s and routinely reports on the trends and changes in the sector, its output, growth and value.

The survey results are broken down into the main types of aquaculture activities carried out in the country. They are: salmon, oysters, rope mussels, bottom mussels and other species. The survey, the data it collects and the time series available make this publication an ideal dataset to assess and monitor the sustainability credentials of the sector over time. To do that, it is necessary to develop a series of sustainability indicators.

3. AQUACULTURE
SUSTAINABILITY INDICATORS

Sustainability is complex to measure. Given the complexity and breadth of the topic, it is necessary to break it down and analyse parts of the system. These parts are classed as the three pillars mentioned above (environment, social and economic). Through the careful selection of relevant indicators, each part can be quantified and monitored.

Indicators are defined as values or measurements which can be measured repeatedly and can show trends or patterns over time. Sustainability indicators are specific indicators which are based on the concept of the three pillars – environmental, economic, and social (Figure 1). These indicators can be used to spot trends or measure the performance of an activity across the three pillars and allow for an approximation of its sustainability. They can also be useful to monitor, identify strengths and weaknesses, and allow comparison with other production systems and techniques, helping facilitate informed decisions that can move the activity towards higher sustainability.

Sustainability indicators need to be specific and relevant to allow for the robust measurement of the activity. They should incorporate science-based knowledge and methods and be easily communicable to all stakeholders. They should also present data and results in a manner that makes them relatable to operators, regulators, policy makers and the public. This selection and definition can pose a challenge, for sustainability in food production and seafood. By some estimates there are over 600 species of fish, shellfish, crustaceans, macroalgae cultured. In Ireland there are far fewer with 12 species cultured - salmon, oyster, rope mussel, bottom mussel, king scallop, native oyster, manila clams, rainbow trout, perch and the seaweeds Alaria, Laminaria and Saccharina. Each of these have different biologies, needs, processes and systems of production. Given these differences there are some indicators that are specific to finfish and shellfish which are presented in later sections.

Aquaculture sustainability indicators are required to be robust, but adaptable as farming techniques and best available practices can change. Given this, indicators may change in future versions of this report.

3.1 ENVIRONMENTAL INDICATORS

The environmental indicators selected as part of this report are based on some of the most crucial performance indicators for many food producing sectors. These are broken into greenhouse gas (GHG) emissions, resource efficiency and contribution to food security and human nutrition.

Like all food production activities, aquaculture can have an impact on the environment. In addition, it relies on the environment to produce its products – making environmental sustainability one of the most crucial pillars in achieving sustainable aquaculture systems. The initial suite of environmental indicators aims to capture the performance of this sector in terms of some of the most pressing policy, consumer and producer issues. These include greenhouse gas emissions, feed, ecosystem services and food security (Table 1).

Table 1: The environmental indicators, their units and the rationale for their inclusion.

Indicator	Units	Rationale
GHG emissions/segment	kg CO_2 eq./segment	Reductions in emissions are key as part of climate action
GHG emissions/ha	kg CO_2 eq./ha	-
GHG emissions/kg	kg CO_2 eq./kg of product	-
Energy related GHG emissions	Kg CO_2 eq./kg of product	-
Surface use	kg/ha	Spatial use is key indicator for the development of a sector
Fish in Fish out ratio	Ratio	The use of fish meal/oil are important resource indicators for the Irish aquaculture sector
Fodder fish dependency ratio	Ratio	The use of fish for fishmeal/oil are important resource indicators for the Irish aquaculture sector
Edible energy return on investment	Percentage of energy invested	Allows a measure of the energy invested in food production
Meals produced	Meals/ha, meals/FTE, total meals	Highlights the contribution to food security the sector makes

3.1.1 GREENHOUSE GAS EMISSIONS

3.1.1.1 Life cycle assessment

The life cycle assessments (LCA) used to generate the GHG, and life cycle values were carried out in accordance with the requirements of BS EN ISO 14040:2006, BS EN ISO 14044:2006, PAS 2050, PAS 2050-2:2012 which provides the supplementary requirements for the application of PAS 2050:2011 to seafood and other aquatic food products.

The LCA process requires four stages (Figure 2): goal and scope definition, inventory analysis, impact assessment, and finally interpretation of the results which takes place concurrently with the previous three stages (ISO 14040). The in-depth methodology used to estimate the emissions and life cycle data can be found in the Supplementary Materials of the Carbon Footprint report of the Irish Seafood Sector. A summary of the main points are presented below.

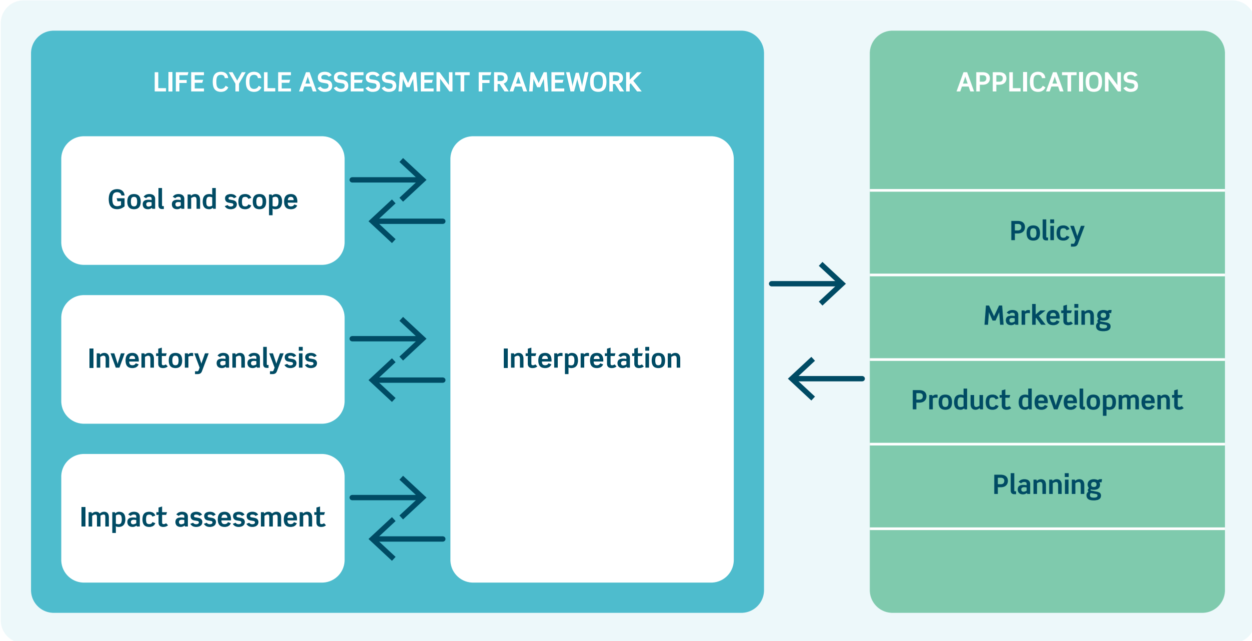


Figure 2: The stages of an LCA (adapted from ISO 14040).

3.1.1.2 Life cycle impact assessment

The impact category global warming potential (GWP) was assessed as part of the study. GWP is defined as the cumulative radiative forcing, both direct and indirect effects, over a specified time horizon resulting from the emission of a unit mass of gas related to some reference gas. As part of this assessment all the gases identified as GHGs under the Kyoto agreement (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) and two groups of gases (hydrofluorocarbons and perfluorocarbons) were analysed. These emissions were then characterised into their CO_2 equivalents (CO_2 eq.) using the relevant conversion factors. Once GHG emissions are calculated for each activity, convert to CO_2 eq. using the relevant global warming potential (GWP) factors from the most recent IPCC Guidelines for National Greenhouse Gas Inventories (currently refined in 2019).

To comply with PAS 2050-2, data must be collected over a period sufficient (for aquaculture, three years are required) to provide an average assessment of the GHG emissions associated with the inputs and outputs of fisheries, aquaculture, and processing that will offset fluctuations due to seasonal differences.

3.1.1.3 Goal and Scope

The aim of this LCA was to determine the life cycle environmental impacts of salmon, mussels and oysters farmed by the Irish seafood industry. These products are farmed and processed in Ireland prior to distribution for sale across the EU. The study was completed to support the Irish seafood sector in their efforts to identify and subsequently reduce their environmental impacts.

The system boundaries for each of the species production systems under consideration in this report are cradle-to-gate; in this case, “gate” refers to the harbour i.e., when the seafood is landed.

3.1.1.4 Functional Unit

The functional unit provides a reference against which inputs and outputs to a system are normalised to allow for multiple systems to be evaluated on a common basis (Figure 3). Therefore, it is crucial that the functional unit is clearly defined and measurable. Despite this, functional units tend to differ significantly, and therefore making comparisons between results can be difficult (Ruiz-Salmon et al., 2021).

In this study, the functional unit applied to each of the aquaculture systems is defined as "1 tonne of seafood to farm gate". This aligns with the goal and scope of the study which aims to support the Irish seafood sector in their efforts to identify and subsequently reduce their environmental impacts.

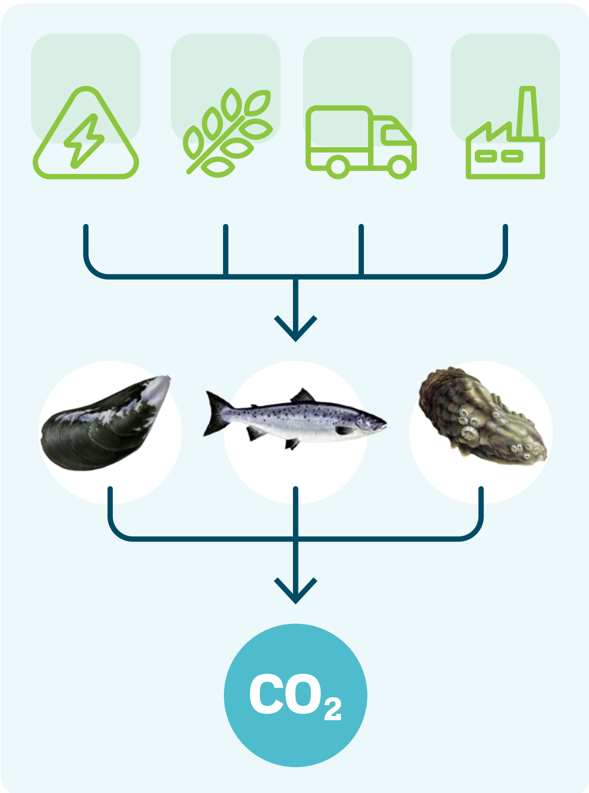


Figure 3: A simplified overview of the functional unit and system boundaries of the LCAs and carbon footprints of this report.

3.1.1.5 Life cycle Inventory

This study collected primary Life Cycle Inventory (LCI) data from active parties in the Irish seafood supply chain. The details of the data collection for each species are detailed in the BIM Carbon Footprint Report of the Irish Seafood Sector. This data is believed to reflect the normal operating conditions of the Irish seafood sector and therefore is considered to be representative. An assessment period of three years was applied to both the capture fisheries and aquaculture systems (PAS 2050-2). Data was collected between 2017 and 2019. All other background data were sourced from the LCI database, Ecoinvent v3.7.1 (2020).

3.1.2 GHG INDICATORS

Using the above methodology, the main GHG indicators used as part of this report were:

- Emissions per segment: this shows the total emissions per aquaculture segment.
- Emissions per unit of surface use (hectare): This indicator assesses the level of emissions associated with direct land/surface use for each of the aquaculture species/systems.
- Emissions per kg of product: This indicator will estimate the average amount of territorial greenhouse gas emissions (CO_2, N_2O, CH_4) associated with the production of a specific type of aquaculture product, expressed as kg CO_2 equivalent per kg of produce.
- Energy related emissions: This indicator measures emissions from electricity and fuel use associated with production activities on the farm. This provides an understanding of the role that energy inputs play in the GHG of Irish aquaculture. It also allows for a comparatively straightforward way to identify the fuel mix of energy inputs to the activity. This can also help better understand the pathways to decarbonisation for the sector.

3.1.3 FEED RELATED INDICATORS

Feed has been identified as a key driver in the environmental footprint of fed aquaculture systems. This is mainly due to the use and inclusion of fish meal and fish oil in the compound feed. These marine derived ingredients are favoured by feed manufacturers as they closely match the dietary requirements of farmed finfish (high in protein, similar amino acid profile, trace metals, and high omega 3 fatty acids). They are produced from whole fish, fish by-products or trimmings. Fish meal and oil are limited resources which are used and demanded by numerous sectors alongside the aquaculture sector. Fish meal and oil are used in direct human consumption, health products and in other animal feeds as well.

The use of meal and oil from reduction fisheries (i.e., wild caught fish) has reduced significantly in recent years, with a major shift to the use of by-products and sustainably managed wild fisheries for meal and oil (FAO, 2024). For example, in Norwegian salmon production, in 1990 it was estimated that almost 90% of feed comprised of marine resources from reduction fisheries. By 2020, inclusion levels had reduced to approximately 22%, with by-products accounting for 5% of total inclusion (Aas et al., 2022).

The organic salmon feed utilises a high proportion of fish meal and oil from by-products. In order for salmon to be classified as organic, very strict requirements must be met and traceability of ingredients and documentation forms a core aspect of organic certification. The BIM Carbon Footprint Report of the Irish Seafood Sector presented a breakdown of the dynamics of feed use in the Irish organic salmon sector. The report highlighted that "*the alternative to the valorisation of these trimmings for feed (either aquafeed, agriculture or pet food) is that they may instead be sent to waste and their nutritional value not recovered. By upcycling these nutrients and recovering them as an added value food product it helps to minimise nutrient loss and waste, while also promoting nutrient and resource efficiency. The inclusion of by-products, using nutrient recovery through animal nutrition, can promote a circular economy through reducing the volume of waste streams through adding value. In this regard organic feed production practices can help promote food system circularity". The report also discussed wider ingredient sourcing, "with the transition to organic aquaculture by the Irish salmon sector, there has been a marked change in the sourcing and transportation requirements of feed and feed ingredients. Fish meal and oil for organic aquaculture feed can only be sourced from either by-products and trimmings of fish or from sustainably certified fisheries. The bulk of the fish meal and oil used in Irish organic feeds is sourced from trimmings and processed at a fish meal and oil plant in Donegal. These products are then transported to Scotland where they are used in the formulation of organic feeds*". This change to organic standards has reduced the supply chains for salmon feed used in the Irish sector from a global one to a regional one.

Bearing in mind that this report deals only with production years 2017 – 2019, it is important to note that in more recent years that feeds have made greater use of other organic ingredients. In particular, there has been uptake in organic plant protein sources such as peas, beans, guar and sunflower. Alternative organic plant-based oils such as rapeseed oil and sunflower oil have also seen higher levels of inclusion. These organic plant proteins in recent feed formulations can make up between 24 – 37% of ingredients, depending on the growth stage of the salmon and the nutritional requirements.

These changes in feed formulations and the use of novel ingredients (other alternatives on the market include seaweed, insect, single cell (microalgae and bacteria), and plant) have reduced the levels of inclusion of fish meal and oil in aquaculture feeds globally, as well as domestically. Given the importance of feed in both an operational and environmental capacity, it is necessary to include indicators which can estimate its impact and sustainability credentials.

3.1.3.1 Forage Fish Dependency Ratio

Given the importance of feed and the recent changes in feed formulation and ingredient sourcing in Ireland it is important to measure the performance using of feeds and their ingredients. A metric that has been used by the IFFO (the Marine Ingredients Organisation) and the European Fishmeal and Fish Oil Producers (EFFOP) and in other sustainability and resource efficiency reports is the fodder fish dependency ratio (FFDR). It evolved from older metrics and places a focus on the ecological aspects of using ingredients from reduction fisheries. This metric has also found its way into third-party certification schemes (e.g., ASC). The FFDR is used to calculate the quantity of wild fish that is used in feeds, as a ratio of the quantity of fed fish production. In this way, it reflects the changes in feed formulations, as greater proportions of fish from by-products rather than reduction fisheries are used (Equation 1).

Equation 1 Forage fish dependency ratio (fish meal) FFDRfm where I is the inclusion rate and Y is the rendering yield for fish meal (fm).

$$FFDR_{fm} = \frac{I_{fm}}{Y} \times FCR$$

Equation 1

The use of FFDR to “communicate to the media and the consumers the need for sustainable sourced marine ingredients for fish feed (and that any other ingredient used in aquafeeds should also be assessed as critically)” has been recommended by the Aquaculture Advisory Council.

3.1.4 FOOD SECURITY

This indicator segment aims to assess the nutritional quality and the contribution to food security and human nutrition that the sector provides. The following suite of indicators are derived from tried and tested methodologies such as the edible protein energy return on investment (ep-EROI) approach and emerging trends in pairing environmental and nutritional aspects of food production systems (i.e., NEXUS approach and derivative works by Hallstrom et al., 2019 and Bianchi et al., 2022).

Nutritional data on seafood produced in Ireland can be sourced from publications such as the BIM Seafood Nutrition Handbook or from several European Food Composition Databases.

3.1.4.1 Edible protein energy return on investment

A metric which has been widely used to estimate the efficiency of seafood is the edible protein return on investment (ep-EROI) (Equation 6).

$$ep\text{-}EROI = (Energy\ inputs/Energy\ outputs)$$

Equation 2

The ep-EROI is used to estimate the energy efficiency of an activity and has been widely used in fisheries and aquaculture LCAs as a complementary metric (Vázquez-Rowe et al., 2014). At its core, the metric measures the energy input to food products and the edible energy that is returned.

The embodied protein content per edible portion of the species is approximated and multiplied by the energy content per kg of protein (16.73 MJ) to estimate the energy output. Data on edible yield can be sourced from food composition databases such as the Spanish database - Base de Datos Española de Composición de Alimentos (www.bedca.net) and other publications such as those from the Food and Agriculture Organisations (1989). Table 2 presents an overview of the ep-EROI values for commercially significant food animals.

Table 2: Edible protein energy return on investment (ep-EROI) values seafood and agriculture species.

Species	Fishing gear	ep-EROI (%)	Reference
Atlantic mackerel	Purse seining	68.6	NEPTUNUS project
Atlantic mackerel	Purse seining	17.8	(Vázquez-Rowe et al., 2014)
Chicken	United States	25	(Vázquez-Rowe et al., 2014)
Tuna	Purse seining	14.0	(Ramos et al., 2011)
Horse mackerel	Purse seining	14.9	(Vázquez-Rowe et al., 2014)
European pilchard	Purse seining	18.3	(Vázquez-Rowe et al., 2014)
European hake	Trawling	5.6	(Vázquez-Rowe et al., 2014)
Horse mackerel	Trawling	6.1	(Vázquez-Rowe et al., 2014)
Atlantic mackerel	Trawling	7.3	(Vázquez-Rowe et al., 2014)
Cattle	United States	2.5	(Vázquez-Rowe et al., 2014)
Sheep	United States	1.8	(Vázquez-Rowe et al., 2014)

3.1.4.2 Meals produced

This metric assesses the number of meals that were produced by the aquaculture segment. It uses the same edible yield co-efficient as the ep-EROI to estimate the meals produced. For salmon, a 110g darne was assumed to be representative, 100g of shelled mussels was regarded as a serving for one meal and a portion of oysters was regarded as six oysters with 15g of their live weight being edible (typically consumed as a starter or appetiser).

- Meals per segment: the meals produced per segment.
- Meals produced per full time equivalent: the number of meals produced per person employed in each of the segments.

3.2 ECONOMIC INDICATORS

The economic indicators used in this report are based on some of the key operational considerations in determining the economic viability and sustainability of aquaculture activity. These economic indicators use data that is documented and annually reported as part of BIMs Annual Aquaculture Report.

Some of the economic indicators presented below have been used routinely in this annual publication due to their reliability, robustness, and importance in conveying the economic performance of the Irish aquaculture sector. These indicators focus on key areas like (1) productivity or gross value added, (2) running cost to turnover ratio, (3) labour productivity and (4) net profit (Table 3).

Table 3: The economic indicators, their units and the rational for their inclusion.

Indicator	Units	Rationale
Gross Value Added/segment	€ GVA/segment	Measures contribution to the economy
Running cost to turnover	Ratio	Measures efficiency
Labour Productivity	€/segment	Measures average productivity
Net Profit	€/segment	Measures profitability
Sales Value and Net Profit per unit of surface use	€/ha	Measures value/profitability over spatial use
Sales Value per tonne of product	€/tonne	Measures the value per tonne of product
Output per FTE	Tonne/FTE	Measures the output per FTE

3.2.1 GROSS VALUE ADDED

Gross Value Added (GVA) has been used by BIM in its annual aquaculture and fisheries surveys for the last number of years. GVA measures the contribution of the sector or segment to the economy and is defined as the gross income from operating activities after adjusting for operating subsidies and indirect taxes.

It can be calculated from turnover, plus capitalised production, plus other operating income, plus or minus the changes in stocks, minus the purchases of goods and services, minus other taxes on products which are linked to turnover but not deductible, minus the duties and taxes linked to production.

Gross Value Added is calculated as:

$$\text{GVA} = \text{Turnover} + \text{Other Income} - \text{Energy costs} - \text{Livestock costs} - \text{Feed costs} - \text{Repair and maintenance} - \text{Other Operational costs}$$

Equation 3

3.2.2 RUNNING COST TO TURNOVER RATIO

Running Cost to Turnover Ratio, also known as cost revenue ratio, is a measure of the efficiency which compares the expenses of a company to its revenue and is represented as a percentage value (%). This indicator shows how much of the turnover (income) is consumed by production costs. Under the National Seafood Survey[1], the indicator is calculated as:

$$\text{Running cost to turnover ratio} = (\text{Energy costs} + \text{Wages \& salaries} + \text{Livestock costs} + \text{Feed costs} + \text{Repair \& maintenance} + \text{Other operational costs}) \times 100/\text{Turnover}$$

Equation 4

3.2.3 LABOUR PRODUCTIVITY

Labour productivity is calculated as the average output per worker or per time unit. It is a key indicator used to measure the efficiency of the Irish labour force and the performance of the Irish economy. It can be calculated as Gross Value Added (GVA) divided by Full Time Equivalents (FTE). This indicator describes the value added to the economy from the activity, in this case the value added to the economy by one FTE. Under the EUMAP, the indicator is calculated as follows:

$$\text{Labour productivity} = \frac{\text{GVA}}{\text{Persons employed FTE} + \text{Unpaid labour FTE}}$$

Equation 5

3.2.4 NET PROFIT

Net Profit is defined as total earnings minus the expenses incurred. It is a measure of a firm's profitability that includes the results of financial activity of the enterprise. The indicator is calculated as follows:

$$\text{Net profit} = \text{EBIT} - (\text{Financial Expenditure} - \text{Financial Income})$$

Equation 6

1 The National Seafood Survey is carried out in compliance with the European Union Multiannual Plan (EUMAP)

3.2.5 OTHER ECONOMIC INDICATORS

Less conventional indicators on the economic performance of the segments that make up the Irish aquaculture sector are presented here. These indicators capture the economic value that is derived from resources such as spatial use (land/water), the value of the products produced and the value and output by the people employed in the sector.

3.2.5.1 Sales Value and Net Profit per unit of surface use

This metric presents the sales value and net profit as a function of the total licensed area utilised by the aquaculture activities. It allows for the measurement of the productivity of the land/water/space used and occupied by aquaculture activities.

$$\text{€/ha} = \frac{\text{Sales Value or Net Profit}}{\text{Spatial Use}}$$

Equation 7

3.2.5.2 Sales Value per tonne of product

This indicator allows for the monitoring of sales value per tonne of aquaculture products per tonne. It allows for a spot check on the performance of the sector across a three-year average. In this report it is calculated as:

$$\text{€/tonne} = \frac{\text{Total Sales Value (€)}}{\text{Total production (tonnes)}}$$

Equation 8

3.2.5.3 Output per FTE

Output per FTE is a simple metric which can be used to highlight the productivity and relative output per FTE in the aquaculture segments. It focuses more on the physical sides of production than monetary but is a relevant metric in measuring the long-term performance of food production systems. It is measured as:

$$\text{Tonnes/FTE} = \frac{\text{Tonnes produced}}{\text{FTE}}$$

Equation 9

3.3 SOCIAL INDICATORS

Much of the focus on aquaculture over the past number of years has been on the economic and environmental impacts (and benefits) that it can have. Beyond these two pillars of sustainability, aquaculture activities have wider ranging impacts on communities and regions. It can have positive social impacts and can contribute to wider society. It can help maintain and develop coastal and regional communities, offering employment opportunities, access to locally produced food and increasing the viability and quality of rural life.

To reflect and estimate the contribution that aquaculture activities make towards coastal and rural life, several social sustainability indicators are used. These indicators aim to assess the wider benefits of that aquaculture makes to communities and region, through multiplier effects, the viability and maturity of aquaculture enterprises and the diversity that exists within the sector along gender, age, and nationality lines.

Table 4: The social indicators, their units and the rational for their inclusion

Indicator		Unit	Rationale
Multiplier Effects	GVA	€/segment	Indirect GVA stimulated by aquaculture
	Employment	Jobs/segment	Indirect employment stimulated by aquaculture
	Wages	€/segment	Indirect wages stimulated by aquaculture
Permanence of the farm in the activity	% of businesses operating over 10 years		A proxy for the long-term viability/ sustainability of a business in the activity.
Diversity Metrics	Gender	% male and female	Understand the gender balance of the activity.
	Nationality	% of each nationality in workforce	Understand the diversity within the segment.
	Age	% of each age group in workforce	Identify gaps in age cohorts in the segments.

3.3.1 MULTIPLIER EFFECTS

As part of the analysis of social sustainability of Irish aquaculture, the multiplier effect was selected as a key indicator. This metric is used to estimate the additional demand that is created further down the supply chain from a production activity. Broadly speaking it is used to estimate how much additional revenue is generated in the economy. In 2022, BIM published its first report on "The Economic Contribution of the Aquaculture Sector Across Ireland's Bay Areas". This report produced a set of multiplier values for the oyster, mussel and salmon sectors. It estimated multiplier effects for GVA, employment and wages.

3.3.2 PERMANENCE OF FARM IN ACTIVITY

This indicator is used to estimate the longevity and viability of an aquaculture enterprise by using data provided in the report mentioned previously (The Economic Contribution of the Aquaculture Sector Across Ireland's Bay Areas). The metric estimates how many enterprises have been in operation for over 10 years. This allows for the approximation of the long-term sustainability of an aquaculture enterprise.

3.3.3 GENDER INCLUSION

Gender diversity within the sector is useful to understand gaps and opportunities for additional recruitment and diversification within the sectors.

3.3.4 NATIONALITY DIVERSITY

Diversity of nationality is an important metric to monitor, as greater diversity in the workplace can lead to cultural innovation and a wider competitive advantage. Additionally, it can allow for knowledge exchange within and between businesses leading to greater production efficiencies, while increasing the knowledge and skillset base within a segment or sector. Other operational benefits which may arise from a diverse workforce can result in greater networking capabilities and potentially access to new and emerging markets.

3.3.5 AGE DIVERSITY

Age diversity is an important metric to account for as it measures the composition of the workforce within the respective sector. By monitoring and evaluating the age structure of the population it can allow for insights into gaps in the workforce which can lead to a shortage of skills and experience at certain levels of a business. Recent research has also indicated that businesses which have greater age diversity are often more productive than those that are not.

3.4 INNOVATION INDICATORS

Innovation is defined as the introduction of something new. Innovation can refer to new products, services, methods, and ways of doing business. For many food producing sectors, innovation often means doing more with less, and increasing process controls and efficiencies. In recent years innovation has also become synonymous with competitiveness, in order to keep pace with market demands and changes.

Teagasc in their inaugural Sustainability Report for the agriculture sector (Teagasc, 2013) used the following five types of innovation; new processes, new products, new organisational forms, entering new markets and using new supply sources, to develop a suite of innovation indicators. These forms of innovation are also used here in the development of innovation indicators for the Irish aquaculture sector.

These indicators will focus on new products, new processes, and new organisational forms.

3.4.1 NEW PRODUCTS

Product innovation is regarded as something new and improved over the product that it is replacing. There are two product innovations which have taken place in the Irish aquaculture sector which have helped to allow the sector to remain competitive in the market. The first of these is organic status for aquaculture products and central Marine Stewardship Council certification for the mussel sector.

- **Organic status**

In recent years there has been a trend for aquaculture products and in particular finfish (salmon) to achieve organic status. Organic aquaculture products must comply with EU Organic Regulations and be certified by an approved organic certification body. The drive behind this is the need to differentiate Irish aquaculture products and achieve a better price for products, due to the comparatively high operating costs in Ireland. Other aquaculture segments which have seen growth of organic practices and certification are rope mussels which has helped them to secure markets.

- **Marine Stewardship Council Certification**

Marine Stewardship Council (MSC) Certification is one of the worlds most recognised brands and frameworks for sustainability and responsibility in seafood management. Since 2019, Irish mussel fishery has been certified as sustainable by the MSC. This certification makes all mussel producers in Ireland eligible for MSC, once they apply and are accepted. The opportunities that this may bring include enhanced reputation, better visibility of products, improve dialogue and transparency with stakeholders, a pathway for improvements, and access to new markets, secure markets and promotional opportunities.

This metric expresses the number of businesses which have transitioned to these practices as a percentage of total businesses. This metric can be used to monitor the growth of these and other product innovations in the sector.

3.4.2 NEW PROCESSES

Process innovation can be regarded as new or improved process that can improve resource efficiency, increase social license, increase food quality and safety and sustainability credentials. There are two processes that have been used by the aquaculture sector which have provided frameworks which act as vehicles for increased sustainability and food safety. These are Bord Bia's Origin Green programme and BIM's Certified Quality Aquaculture (CQA) standard.

- **Origin Green**

Origin Green is Ireland's national food and drink sustainability programme which aims to drive sustainability improvements throughout the food and drink supply chain. The seafood sector makes up a high rate of the Origin Green membership and through the programme has demonstrated its commitment to sustainability. The programme was launched in 2012, with primary producers from aquaculture joining in 2015. The programme is unique in that as part of its frameworks, it requires companies to set targets across the pillars of sustainability that they must meet if they are to maintain their accreditation. Origin Green provides a structure around which companies must innovate and increase their sustainability.

- **Certified Quality Aquaculture**

As Ireland's seafood development agency, BIM is the standard holder for the Certified Quality Aquaculture (CQA) Scheme. The CQA Farm standard covers several areas of production which contribute to increased sustainability in aquaculture production. This includes the implementation of environmental management systems, process controls for food safety and quality, protection of nature and the environment, as well as personnel and operation standards. This multifaceted approach and requirements incentivise scheme members to improve and innovate as part of their day-to-day activities.

New processes and reporting frameworks can act as powerful promotors of innovation and efficiency. This metric is measured in the same manner as new products.

3.4.3 NEW ORGANISATIONAL FORMS

New organisational forms are a form of innovation that has historically been associated with large, corporate businesses and indeed the bulk of research and work on this form of innovation has been focused on these types of organisations. However, the lessons learned and the tools available can also bring value and innovation to other sectors, like aquaculture.

Innovation can be driven by links between structural forms and relationships. By bringing together different actors and players within sectors increased understanding, the creation and exploitation of new knowledge can lead to innovation. Within this context innovation can be considered as the capacity to respond to changes in the market and to shape and influence the market to the response.

In this regard, support has been provided by BIM to develop industry working groups, to facilitate a forum for the aquaculture sector. To date, one group has been established for the oyster sector, with other groups to be formed. This means that for this indicator only one segment of the aquaculture sector can be included. Future iterations of this report should be able to report on this indicator for the salmon and mussel segments.

- **Irish Oysters Packers Group**

The Irish Oyster Packers Group is an industry working group facilitated by BIM. The core members of the group consist of producers interested in retaining the value of their products themselves by packing and adding value to their products before distribution. The group also works to address common issues which were affecting the segment. This innovation allowed the companies to use collective effort to explore and develop new export markets, receive a direct return, and allow the promotion of Irish oysters while increasing the overall reputation and value of the industry.

This metric expresses the volume and value of the member companies as a total of the oyster sector.

4.

RESULTS

Using the above suite of indicators to baseline estimates on the sustainability credentials of the Irish aquaculture sector consisting of the three segments with sufficient business maturity, data and segment size are investigated.

These segments are:

- The organic salmon segment (marine stage)
- The pacific oyster segment and
- The rope mussel segment.

4.1 SALMON SUSTAINABILITY

4.1.1ENVIRONMENTAL

Between 2017 and 2019, it was estimated that **total emissions for the organic salmon sector** were in the region of 54,273 tonnes of CO_2 eq. (tCO_2 eq.). Average annual production during this period was 13,984 tonnes of salmon to the farm gate. Most of these emissions arose from the production and use of feed inputs. The second highest driver of emissions for the sector was energy use, followed by transportation and consumables (Figure 4). When looked at from a product perspective these results estimate a total of **3.88 kg CO_2 eq. emitted per kg of salmon** to the farm gate.

Energy from the electrical grid contributed 27% of GHGs emitted or 1.01 kg CO_2 eq./kg of salmon. If expanded to include fuel for vehicles and vessels the energy related emissions increase to **40% of GHG emissions or contributes 1.54 kg CO_2 eq./kg of salmon**.

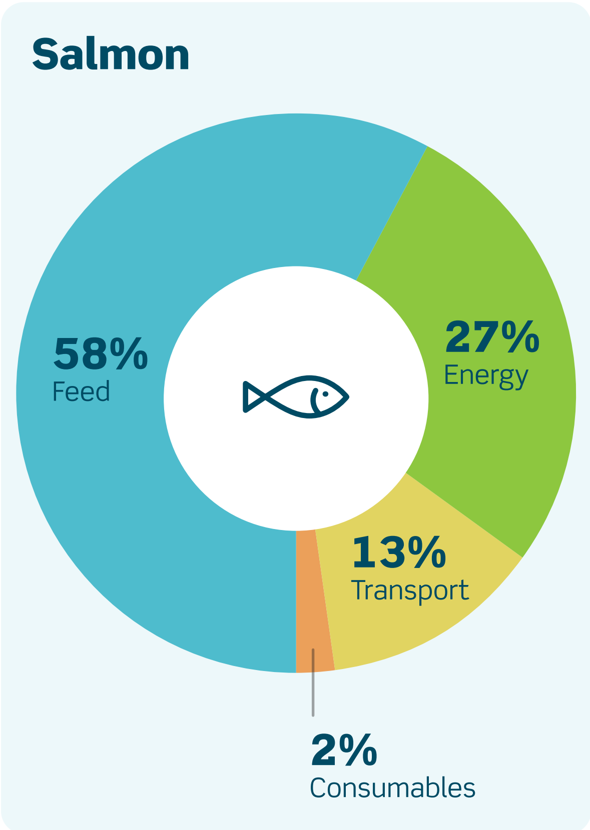


Figure 4: A breakdown of the main contributors to the carbon footprint of Irish organic salmon.

13 tonnes
/ha

The total licensed area for salmon production in Ireland is estimated to be 1,090 ha. However, it is worth noting that a proportion of licensed area is not being utilised due to older sites being no longer suitable for modern farming techniques or being left to fallow in accordance with licensing requirements. From a productivity perspective the yield or amount of product produced per hectare of surface area used by salmon culture was **12.83 tonnes of salmon per hectare**. Using the total sectoral emissions and dividing them by the total licensed area for salmon aquaculture, it is estimated that 49.8 tCO_2 eq./ha were emitted during 2017 – 2019.

The use of these levels of marine ingredients is driven by the **organic** certification of the sector. Within organic standards, for the feed to be organic, it must use ingredients that are organic, have been sourced from fisheries certified as sustainable, or from trimmings, by-products and offcuts from fish for human consumption, or fish not used for human consumption (Regulation 2018/848 of the European Parliament). Organic salmon feed manufacturers instead utilise fish meal and oil from sustainably certified fisheries or from by-products from fish processing. This use of by-products, which would otherwise go to waste or to petfood, but is instead used to produce human food (i.e., organic salmon) can be regarded as playing a role in the circular economy, as it is nutrient recovery through animal nutrition. Marine resources accounted for an average of 62% of the feed ingredients for organic salmon during this period.

The average percentage of fishmeal in the feed was 44% and fish oil at 18%. Additionally, the fodder fish dependency ratio (FFDR) for the sector was also estimated. FFDR assesses the amount of marine ingredients, in the form of fish meal and oil, that was sourced from fodder fish species and reduction fisheries. For the study periods the **fishmeal FFDR (FFDRm) for Irish organic salmon sector was 0.97 and the FFDR for oil (FFDRo) was 0.67**. These values reflect the use of sustainable fisheries, trimmings and by-products in organic salmon feeds. The FFDRm in other countries during this period was 0.6, and the FFDRo was 2.2. This indicates that Irish organic salmon feed sources much of its fishmeal from sustainable fisheries and its fish oils from trimmings and by-products.

Feed formulations can fluctuate from batch to batch in terms of each ingredient inclusion level. The use of fish meal and oil can also fluctuate depending on availability (e.g., seasonality), but also the market dynamics at the time, with feed producers sourcing cost competitive ingredients. Another dimension to consider with feed for the Irish salmon sector is its organic status. This status places additional constraints and requirements on the sourcing of feed ingredients from organically certified/ compliant suppliers.

Table 5: The level of feed use associated with the Irish organic salmon sector between 2017 and 2019. Food conversion ratios are also presented for each of the years along with specifics on feed formulation and performance of the feed used.

	2017	2018	2019	3 Year Average	Standard Deviation	Coefficient of Variance (%)
Operational data						
Feed used (tonnes)	21,106	13,968	18,802	17,959	3,643	20%
Stock produced (tonnes)	18,342	12,044	11,567	13,984	3,781	27%
FCR	1.15	1.16	1.63	1.31	0.27	21%
Feed Specifics						
FM%	44				-	-
FO%	18				-	-
Total marine ingredients (%)	62				-	-
FFDR						
FFDRo	0	0.7	1.3	0.67	0.65	98%
FFDRm	0.8	0.9	1.2	0.97	0.21	22%

FCR: food conversion ratio, FM%: fish meal percentage, FO%: fishoil percentage, FFDRo: fodder fish dependency ratio fish oil, FFDRm: fodder fish dependency ration fish meal.

12%

ep-EROI

It was estimated that the **edible protein energy returned on investment (ep-EROI) for salmon production was 12%**. This value was derived assuming an edible yield of 68% from a salmon carcass and a protein content of 20.4%. Energy input per ton of production was estimated to be 19,227 MJ with the edible energy estimated to be 2,320 MJ. This 12% value places Irish organic salmon aquaculture well within the range of global salmon production for ep-EROI and highlights the relative efficiency of it as a food product.

86,446,545

meals produced

The **organic salmon sector produced 86,446,545 individual meal sized portions**. These values assume that there is 68% yield off a carcass and that a 110g portion is used per meal. The salmon sector during this time had 166 FTE, dividing this into the meals produced equals on average **478,486 meals produced per FTE.** Expressing the meal productivity for the sector as a function of the spatial use occupied by the salmon sector during this time on average **the sector produced 72,699 meals/ha**. These values may seem high, and it does not account for supply chain losses or recovery of edible material during processing. This metric highlights the contribution that this small but culturally and economically significant form of aquaculture plays in food security and human nutrition.

4.1.2 ECONOMIC

Between 2017 and 2019 the **average output for the Irish organic salmon sector was 13,984 t**. The greatest output from the sector was in 2017 with 18,342 t. The lowest level of output was in 2019 at 11,567 t. **The average sales value for the sector during this period was €113,269,057.** The highest value was observed in 2017, with 2018 reporting sales value of €97,282,392 (Table 4).

The average sales value per tonne of salmon was €8,260. There was a degree of fluctuation between the study years but overall, an upwards trend in the price per ton of salmon. The sales value per hectare of spatial use, however, saw a downwards trend with an overall average of €103,917. Farmed salmon output volume in Ireland experiences a repeating cyclical fluctuation over time. This is caused by a combination of factors; the limited licenced capacity available for on growing salmon, the requirements of space per fish and fallowing of sites as per organic production specifications plus the limited capacity to produce smolts for on growing sites. The trend is also influenced by the wider environmental factors such as jellyfish swarms, phytoplankton blooms and periodic appearance of pathogenic and parasitic organisms whose effects impact production and are becoming more pronounced with climate change.

The average FTE reported in the salmon sector was 166. An upwards trend in FTE was observed from 2017 with an FTE of 131 to 195 in 2019. The **average output was 90 t/FTE**, with a coefficient of variance of 49%. **The average gross value added for the salmon sector during this time was estimated to be €21,770,800**.

The average GVA was skewed through an exceptionally high value in 2017, as a result this indicator has a coefficient of variance of 167% - indicating a high level of variance. The GVA values oscillated due to the real effects of varying output volume, set against the more constant trend of increasing costs. There are also the skewing effects of sampling where there are few companies involved and these vary greatly in size and overall contribution to the segment. For certain costs data therefore, the sample may not have been fully representative for the segment, and this would impact on economic indicator values such as for GVA and Net Profit.

The running cost to turnover ratio was 99.78%. Over the three years of observation, salmon product output and therefore turnover has declined significantly while costs have not matched in proportion. Certain costs such as wages/salaries and other operating costs increased at unit purchase level.

Labour productivity was estimated to be €162,758 on average. However, there was a high degree of variance in the data set with the coefficient of variance of 171%. This was impacted by a labour productivity of €480,618 in 2017.

A significant variance in labour productivity is caused by the periodic fluctuating rate of production output of the sector against the backdrop of relatively stable employment. The extent of the fluctuation depicted in the data may however be skewed by a difficulty of extracting employment purely associated with the production sector for companies who are also employed in other parts of the value chain such as processing.

Net profit for the Irish organic salmon sector between 2017 and 2019 was **estimated to be €32,171,574**. Like GVA and labour productivity there was a high degree of variance in the data set with a coefficient of variance of 88%. **The Net Profit/ha was €29,515** (coefficient of variance was recorded for this indicator). These high values reported in 2017 influenced the indicator.

Table 6: The results of the economic indicators for the organic salmon sector between 2017 to 2019. Averages, standard deviations, and coefficients of variance for each of the indicators highlight the trends and fluctuations in the sector.

Indicators	2017	2018	2019	3 Year Average	Standard Deviation	COV* (%)
Tonnes	18,342	12,044	11,567	13,984	3,781	27%
Sales Value (€)	€133,519,265	€97,282,392	€109,005,515	€113,269,057	€18,490,838	16%
FTE	131	171	195	166	32	20%
GVA	€62,960,947	-€5,876,237	€8,227,689	€21,770,800	€36,362,087	167%
Running cost to turnover ratio	81	118	101	100	18	19%
Labour Productivity	€480,618	-€34,465	€42,121	€162,758	€277,925	171%
Net Profit	€62,241,336	€6,174,221	€28,099,165	€32,171,574	€28,254,535	88%
Sales value/ Tonne	€7,279	€8,077	€9,424	€8,260	€1,084	13%
Sales value/Ha	€122,495	€89,250	€100,005	€103,917	€16,964	16%
Net Profit/Ha	€57,102	€5,664	€25,779	€29,515	€25,922	88%
Tonnes/FTE	140	71	59	90	44	49%

* Coefficient of Variance

4.1.3 SOCIAL

The multiplier effect for GVA for the salmon sector was estimated to be 1.9. This means that for each euro added by the salmon sector an additional €0.9 is generated indirectly. Based on the average GVA for the salmon sector between 2017 and 2019, of €21,770,800, this would support an additional GVA of €19,593,720.

Table 7: The multiplier effects for the salmon sector. The actual values of the sector for GVA, employment and wages are presented alongside the indirect multiplier values.

Salmon	GVA	Employment	Wages and Salary
Multiplier Effect	1.9	3.3	3.2
Sector Values	€21,770,800	188	€9,195,416
Multiplier Value	€19,593,720	432	€20,229,916z
Total Sectoral Value (Sector Value + Multiplier Value)	€41,365,520	620	€29,425,332

The multiplier effect for employment in the salmon sector was estimated to 3.3. This means that for every direct salmon aquaculture related job present, 2.3 jobs are sustained indirectly elsewhere. FTE has been reported in the economic section, but within this context total employment is a more appropriate figure. Total employment in the sector throughout the study years was on average 188. With the multiplier effect, this would result in indirect employment of 432 jobs in the wider community.

The multiplier effect for wages for the salmon sector was 3.2. This means that 2.2 times that number of wages was generated indirectly through salmon aquaculture. While not actively considered as an indicator as part of this report, wages and salaries in the salmon sector for 2017 to 2019 were on average €9,195,416/annum. This would place the indirect value of wages and salaries at €20,229,916.

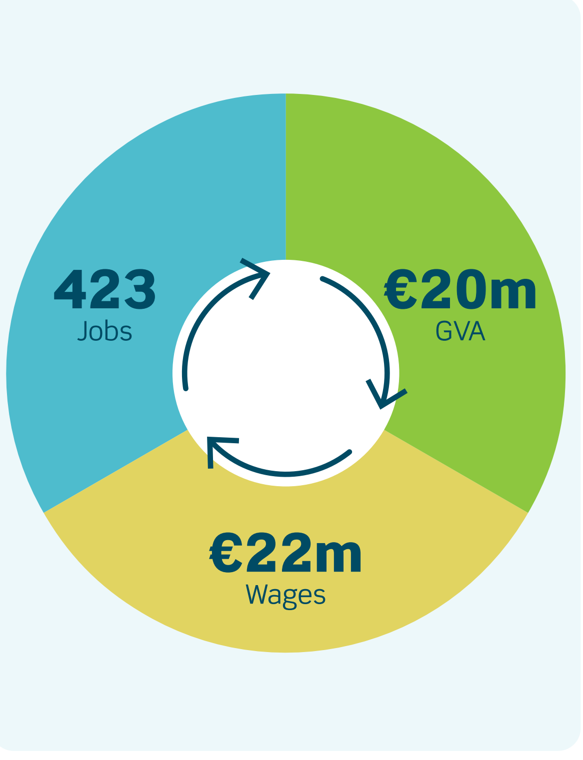
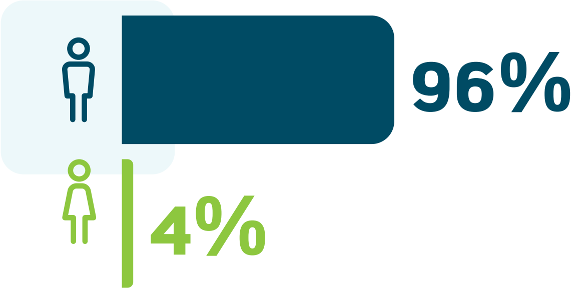


Figure 5: The Irish organic salmon sector supports indirectly, 423 jobs, €20m in GVA and €22m in wages.



Gender diversity in the salmon sector was low. Most people employed in the sector were male (96%), with only a very small percentage of the workforce being female (4%). In 2019, the percentage of women in the salmon sector increased to almost 6%, an increase of 1.6% on the previous year.

Irish nationals were the largest cohort employed in the salmon sector at 87%. The remainder of the workforce was made up of nationalities from other EU countries. No other nationalities were recorded.

The age diversity in the salmon sector was well distributed between the age classes. There was no one in the sector who was aged 65 and over according to the data submitted to the Annual National Aquaculture Survey for the years 2017 to 2019. There was on average 13% of the workforce in the 55-64 age category and 25% in the 45-54 category. The next two categories were roughly equal with 35-44 year olds accounting for 20% of the population and the 25-34 cohort accounting for 20%. The 16-24 age group was 16% of the salmon sector workforce. These results indicate that the salmon sector workforce is aging, and that **additional recruitment of younger individuals is needed** to sustain the workforce going into the future. Additional recruitment and retention of younger people would allow for greater retention of knowledge and skills within the salmon sector. It would also maintain important business relationships leading to lower levels of disruption when senior staff retire. This issue of succession planning is something which all food producing sectors are currently facing in Ireland.

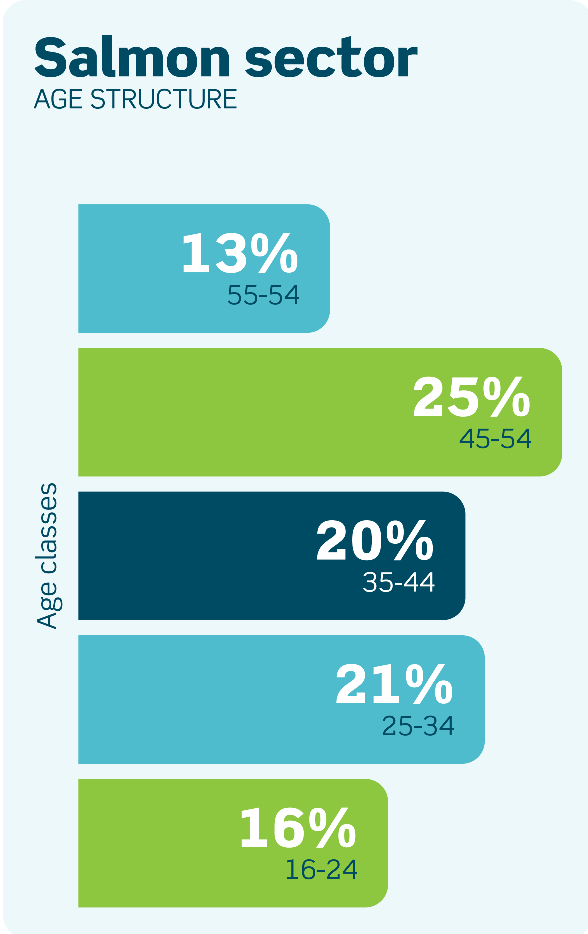


Figure 6: The average age structure of the Irish organic salmon sector between 2017 – 2019.

The permanence of the farm in the activity is a useful metric which highlights the maturity and resilience of an aquaculture business. It also highlights the value and placement of these businesses as sources of employment/ career opportunities and their wider social and economic impact (i.e. multiplier effects, jobs, food). In this report, this metric relied upon data generated as part of the BIM Bay Area study and its summary report. Data on the permanence or maturity of salmon businesses is not available for use from that report. However, given that the sector has seen consolidation and amalgamation during the 2017 to 2019 period and beyond, it can be presumed, that the sector does have a high degree of permanence in the activity. This is because the vast majority of existing salmon farming sites and businesses have been in operation or licensed for more than 10 years.

4.1.4 INNOVATION

The salmon sector during the reference years of this report were in the process of transitioning from conventional salmon production to organic husbandry methods. In total, for marine salmon production there were 5 companies in operation. **In 2018, all of the salmon sector achieved organic certification**. This move allowed the sector to command a price premium against the higher operating costs incurred (when compared to other salmon production nations), while reducing pressure on the natural environment through reduced stocking densities and a high level of animal welfare and veterinary care.

From a new processes perspective, during 2017 to 2019 the salmon sector engaged in both the Origin Green and the CQA schemes. There was a **participation rate of 40% of the companies** in the segment in both schemes. While not possible to present in this report, their participation in these schemes would have introduced sustainability targets and improvements in process efficiency that would have contributed to an increased culture of sustainability within the companies.

4.2 OYSTER SUSTAINABILITY

4.2.1 ENVIRONMENTAL

Between 2017 and 2019, it was estimated that **total emissions for the oyster sector** were in the region of 2,404 tCO_2 eq. Average annual production during this period was 10,215 tonnes of oysters to the farm gate. The main driver of emissions for oyster production was fuel at 56% of emissions, processing at 31% with transportation and other production inputs making up the remainder of emissions. The estimated emissions for **1 kg of oysters to the farm gate was 0.235 kg CO_2 eq.**

0.235 kg CO_2 eq./kg oysters

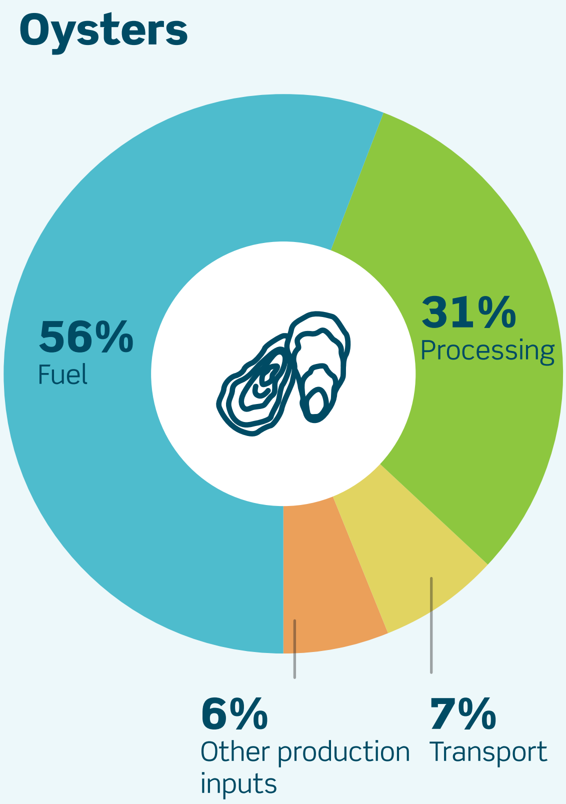


Figure 7: A breakdown of the main contributors to the carbon footprint of Irish oysters.

Energy related emissions for oyster production were dominated using fossil fuels in the form of diesel at 55.7% energy from the grid contributed 30.8% of emissions. The remaining 13% of emissions arose from consumables. Combined these inputs contribute 0.203 kg CO_2 eq./kg of oysters.

2.24 tonnes
/ha

The total licensed area for oyster production in Ireland is estimated to be 4,555 ha. From a productivity perspective the yield per hectare was 2.24 t. Using the total sectoral emissions and dividing them by the total licensed area for oyster production it was estimated that 0.53 tCO_2 eq./ha were emitted during the 2017 – 2019 period.

13%
ep-EROI

It was estimated that **the ep-EROI for oysters in Ireland was 13%**. This value was derived assuming an edible yield of 23% from a single oyster and a protein content of 10.8%. Energy input per ton of production was estimated to be 3,093 MJ with the edible energy estimated to be 416 MJ/t. This 13% positions Irish oysters well within the global range of pacific oysters ep-EROI values (global range: 11%-26%).

26,105,000
meals produced

The oyster sector produced an estimated 26,105,000 meals on average between 2017 and 2019. This value assumes that there is a 23% edible yield from an individual oyster and that the average consumer has six oysters as part of a meal. The oyster sector between 2017 and 2019 had an FTE of 545. The meal productivity of the oyster sector was **47,886 meals/FTE**. The productivity of the sector for producing meals when assessed by spatial use was **5,731 meals/ha**. This metric demonstrates the contribution that oyster aquaculture makes towards human nutrition as well as food security.

4.2.2 ECONOMIC

The average output of the Irish oyster sector between 2017 and 2019 was 10,215t. The greatest output from the sector was in 2019 with 10,460 t. The lowest level of output was in 2017 at 9,990 t. During this period there was a positive upwards trend in production output with an increase of 470 over the three years. **The average sales value for the sector during this period was €44,505,971**. The highest sales value was observed in 2019, following the same upward trend as the tonnes produced (Table 5).

The average sales value per ton of oysters was €4,357. There was a marginal degree of fluctuation between the study years with a 1% coefficient of variance observed, with an overall upwards trend in the price per tonne of oysters. **The sales value per hectare of spatial use was on average €9,771**. This value increased in line with the other sales value-based indicators and saw a 1% deviation. This value increased in line with the other sales value-based indicators and saw a 1% deviation. The segment has seen steady growth in both output volume and average unit sales value due to strong market demand. The rate of increase in average unit sales value however, slowed over the three-year period and overall turnover increase was driven by increasing output volume.

The average FTE in the oyster sector was 545. There was a degree of fluctuation in FTE in the three years, with a rise to 598 in 2018 from 527 in 2017, before closing with an FTE of 541 in 2019. The average production average output 19 t/FTE, with a coefficient of variance of 4%. **The average GVA for the oyster sector was €30,923,023**. GVA was steady throughout the sample years with a coefficient of variance of 5%. Though the GVA was lowest in 2019 at €29,337,818. The segment grew at a steady rate of output volume and value, keeping ahead of rising costs, making for a steady economic performance as seen in the GVA values. The sample data obtained for the segments costs over the period was large and representative.

The average running cost to turnover ratio for the oyster sector was 66%. There was a general increase in the running cost to turnover ratio between 2017 and 2019 for the oyster sector. Over the period, most running costs have increased at a greater rate than has turnover, causing the margin between income and cost to narrow. Therefore, costs are taking a greater proportion slice of revenue generated and increasing the running cost to turnover ratio.

Average labour productivity for the oyster sector was estimated to be €56,751. There was a low degree of variance in the data set with a coefficient of variance of 5%. There was a downward trend in labour productivity in the sample years with a decrease of €5,149 between 2017 to 2019. Wages/salaries are one cost that has risen significantly for the segment over the period and at a greater rate than the revenue generated from sales. Increased productivity by unit sales per employee was negated by the increased labour cost per worker. That increased cost, along with other unit costs increases, negatively impacted labour productivity.

Net profit for the oyster sector between 2017 and 2019 was estimated to be €19,047,935. This indicator had the highest degree of variance in the data set with a coefficient of variance of 18%. This variability was introduced through a decline in the net profit for the oyster sector. Between 2017 and 2019 net profit reduced by €6,010,411. **The Net Profit/ha was €4,182** and saw a similar level of decrease to that of Net Profit and variance (an 18% coefficient of variance). Essentially turnover has not kept pace with increasing costs for the segment. While output sales and volume have continued to grow, this has been at a slowing rate, whereas costs such as wages, salaries and juvenile input costs have continued to rise at a faster rate. The profit margin is linked to this narrowing gap between income and cost values.

Table 8: The results of the economic indicators for the oyster sector between 2017 and 2019. Averages, standard deviations, and coefficients of variance for each of the indicators highlight the trends in the sector.

Oysters	2017	2018	2019	3 Year Average	Standard Deviation	Coefficient of Variance (%)
Tonnes	9,990	10,196	10,460	10,215	236	2%
Sales Value (€)	€43,727,845	€44,609,884	€45,180,186	€44,505,971	€731,725	2%
FTE	527	568	541	545	21	4%
GVA	€31,293,726	€32,137,525	€29,337,818	€30,923,023	€1,436,195	5%
Running cost to turnover ratio	58	65	76	66	9	14%
Labour Productivity	€59,419	€56,563	€54,270	€56,751	€2,580	5%
Net Profit	€22,931,422	€17,291,371	€16,921,011	€19,047,935	€3,368,293	18%
Sales value/ Tonne	€4,377	€4,375	€4,319	€4,357	€33	1%
Sales value/Ha	€9,600	€9,794	€9,919	€9,771	€161	2%
Net Profit/Ha	€5,034	€3,796	€3,715	€4,182	€739	18%
Tonnes/FTE	19	18	19	19	0.73	4%

4.2.3 SOCIAL

The multiplier effect for GVA for the oyster sector was estimated to be 1.6. Which means that for each euro that is added by the oyster sector that an additional €0.6 is sustained indirectly. Based on the average GVA for the oyster sector between 2017 and 2019, of €30,923,023 this would support an additional GVA of €18,553,814.

Table 9: The multiplier effects for the oyster sector. The actual values of the sector for GVA, employment and wages are presented alongside the indirect multiplier values.

Oysters	GVA	Employment	Wages and Salary
Multiplier Effect	1.6	1.3	1.8
Sector Values	€30,923,023	838	€14,671,805
Multiplier Value	€18,553,814	251	€11,737,444
Total Sectoral Value (Sector Value + Multiplier Value)	€49,476,837	1,089	€26,409,249

The multiplier effect for employment in the oyster sector was estimated to 1.3. This means that for every direct oyster aquaculture related job, 0.3 jobs are sustained indirectly elsewhere. Total employment in the sector throughout the study years was on average 838. With the multiplier effect, this would result in indirect employment of 251 jobs in the wider community.

The multiplier effect for wages for the oyster sector was 1.8. This means that 0.8 times that amount of wages was generated indirectly through oyster aquaculture. While not actively considered as an indicator as part of this report, wages and salaries in the sector for 2017 to 2019 were on average €14,671,805/annum. This would place the indirect value of wages and salaries at €11,737,444.

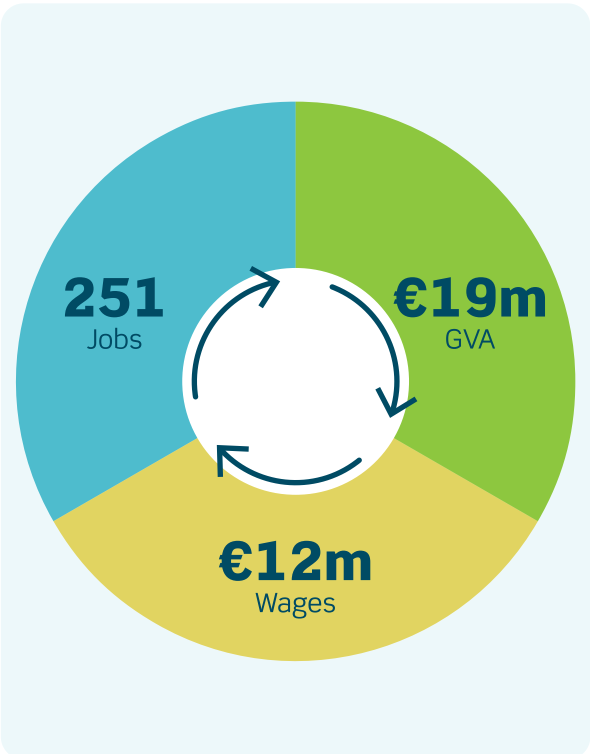


Figure 8: The Irish oyster sector supports indirectly, 251 jobs, €19m in GVA and 122m in wages.

Gender diversity in the oyster sector was low. Most people employed in the sector were male (91%). With the remaining 9% of the workforce being female. In 2019, the percentage of women in the oyster sector increased to almost 10%, which was an increase of 1% on the previous years.

Irish people were the largest cohort employed in the oyster sector at 84%. Much of the remainder of the workforce were from nationalities within the European Union at 14%. Other nationalities accounted for an average of 1% of the workers.

The age diversity in the oyster sector was well mixed between age classes. The segment had an average of 51% of the workforce in the 16-24 age class, which indicates that there is a very high level of young people in the sector who can sustain the workforce going forward. This younger cohort help to mitigate some of the issues presented in the salmon section, with regards to maintaining business relationships, and a higher potential for effective succession planning. The other five ages classes; 25-34, 35-44, 45-54, 55-64 and 65+ were more uniformly distributed with 12%, 14%, 14%, 13% and 8% respectively.

While this is positive, there is a high degree of variability within the age categories between the study years. The 16-24 category accounted for 75% of the workforce in 2017, before declining to 26% in 2018, before rising to 28% in 2019. This variability is mirrored in the other ages categories with coefficients of variance across ranging from 61% (55-64) to 149% (35-44). This indicates that there is likely a very high degree of staff turnover, which is due to the seasonality of the work and the physical nature of the jobs.

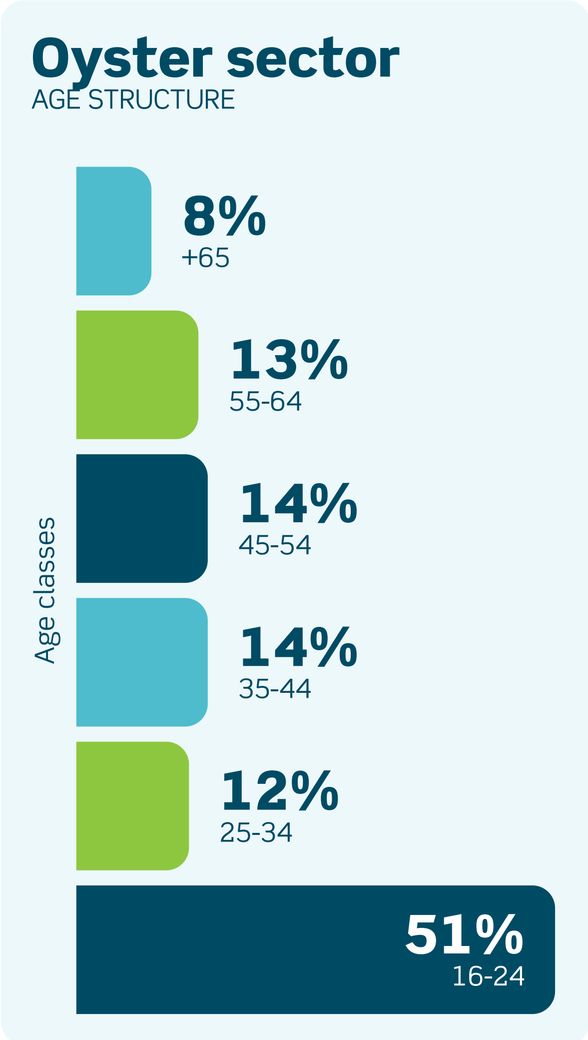


Figure 9: The average age structure of the oyster sector between 2017 – 2019.

The permanence of the farm in the activity for the oyster sector was estimated to be 83.3%. This indicates that there is long term viability in the oyster aquaculture sector for businesses. There was also a high level of newer businesses in the oyster sector with 1.9% of businesses operating for more than five years, 9.3% operating for more than three years, 3.7% operating for more than one year and 1.9% operating less than one year.

This indicates that there is growth and opportunity for new oyster enterprises within the sector which indicate positive growth and a high degree of permanence in the activity.

4.2.4 INNOVATION

During 2017 to 2019, there were on average 141 oyster businesses. During this time 15 oyster businesses were involved in Origin Green. This new process required companies to set environmental and sustainability reduction targets that they were required to meet to maintain their certification under the scheme. These targets likely resulted in reductions in energy and material use while contributing to greater awareness of sustainability and process efficiency.

Assessing innovation through new organisational forms, the oyster sector was the only segment during this to innovate through this medium. The Irish Oyster Packers Group during this time consisted of on average 13 member companies which represented 9% of primary production companies. These organisations were collectively responsible on average for €11,860,265 of sale value which accounted for 27% of total sales value for the oyster sector. From a production perspective these companies produced 2,319 tonnes of oysters which accounted for 24% of oyster production. The average sales price per ton of oysters sold through the group was €4,744. This value is 8% higher than the average sales value for a ton of oysters for the whole sector (€4,357). When accounting for employment figures (using total employment rather than FTE), the Irish Oyster Packers Group employed 232 individuals or 28% of people in the sector.

4.3 MUSSEL SUSTAINABILITY

4.3.1 ENVIRONMENTAL

During the study years (2017 - 2019), it was estimated that the rope mussel sector produced on average 9,463 t/annum. It was estimated that the rope mussel sector emitted 984 tCO_2 eq./annum. The main driver of emissions for rope mussel production was fuel use in vessels, which accounted for 85% of emissions. The second greatest contributors to emissions were consumables and packing which both contributed 7%. The estimated emissions for **1 kg of mussels to the farm gate was 0.107 kg CO_2 eq**.

Rope Mussels

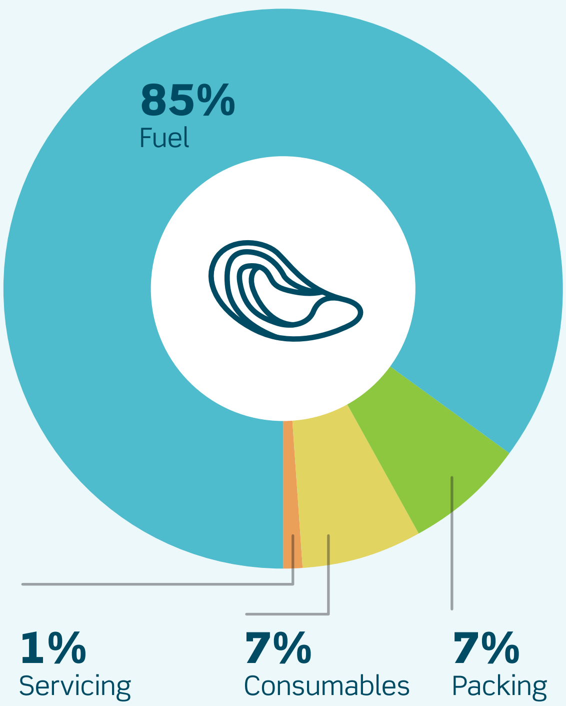


Figure 10: A breakdown of the main contributors to the carbon footprint of Irish rope mussels.

0.107 kg CO_2 eq./kg mussels

Energy related emissions for mussel production were dominated by fossil fuels at 85% of emissions. The main fossil fuel used was diesel in vessels at 48.5% of emissions. This was followed by diesel in vehicles at 20%, petrol in boats accounted for 15% and electricity contributed the remaining 2%. These **emissions accounted for 0.092 kg CO_2 eq./kg of mussels**.

3.3 tonnes
/ha

The total licensed area for rope mussel production was 2,828 ha. The average yield per hectare during this time was 3.3 t. From an emissions perspective it was estimated that **0.35 tCO_2 eq./ha was emitted**.

85%
ep-EROI

The ep-EROI for rope grown mussels in Ireland was estimated to be 85%. This value is very high and brings focus to the low energy inputs associated with rope mussel production in Ireland. These values were estimated using a 44% edible yield for mussels and assumed an average protein content of 12.1%. Energy inputs per ton of mussels were estimated to be 1,049 MJ with an edible energy content of 891 MJ. This value of 85% is higher than has been previously reported for mussel aquaculture. Ep-EROI is a production and sustainability metric that is not widely used in measuring the performance of mussel aquaculture, but these results highlight the energy efficiency of this form of aquaculture.

41,637,250
meals produced

It was estimated that on average the rope mussel sector produced on average **41,637,250 meals**. This value is based on 44% edible yield and that an average consumer would consume 100g of mussels in a meal. During 2017 to 2019 the mussel sector had an FTE of 186. These FTEs produced **223,516 meals/FTE**. The total spatial use by the mussel sector was 2,828 ha. Per hectare **the sector produced 14,723 meals/ha**.

4.3.2 ECONOMIC

The average output of the Irish rope mussel sector between 2017 and 2019 was 9,463 t. The greatest output from the sector was in 2019 with 10,290t. The lowest level of output was in 2017 at 8,559 t. Like the oyster sector, there was a positive upwards trend in mussel production with an increase of 1,731 t over the three years. **The average sales value for the sector during this period was €6,753,948**. The highest sales value was observed in 2017 (€7.257.465), which decreased in 2018 before increasing in 2019 (Table 7).

The average sales value per ton of mussels was €719, with a decline in the price across the sample years. The sales value per hectare of spatial use was on average €2,388 and followed the same trend as other sales value-based indicators. Average unit sales value suffered from weakening market demand for Irish product over the period.

The average FTE in the oyster sector was 166. There was a decrease in FTE in the three years, with a decrease from 228 in 2017 to 133 in 2019. The average production average output was 62 t/FTE, with a coefficient of variance of 33%. **The average GVA for the mussel sector was €4,588,773**. GVA was one of the more variable indicators with a coefficient of variance of 48% across the sample years. GVA saw a three year low of €2,109,313 in 2018 before increasing again in 2019 to a level that was more comparable to 2017. There was a net increase in costs and a decrease in turnover for the segment, over the period, producing a net decrease in GVA.

The average running cost to turnover ratio for the rope mussel sector was 74%, with a coefficient of variance of 37%. This variance was introduced through the ratios changing from 43 to as high as 94 within the three-year period, indicating high increases in running costs.

Significant increases in personnel, energy, maintenance and other operational costs, combined with decreases in turnover over the period have directly and negatively impacted the ratio by narrowing the gap between these competing values.

Average labour productivity for the oyster sector was estimated to be €276,850. There was a degree of variance in the data set with a coefficient of variance of 45%. Labour productivity increased in 2019, having decreased in 2018 from 2017 values.

Net profit for the mussel sector between 2017 and 2019 was estimated to be €1,562,232. This indicator had the highest degree of variance in the data set with a coefficient of variance of 152%. This variability was driven by losses in 2018 and low levels of profit in 2019, when compared to 2017. Between 2017 and 2019 net profit reduced by €2,807,080. The Net Profit/ha was €552 and saw a similar level of decrease to that of Net Profit and variance (152% coefficient of variance).

Table 10: The results of the economic indicators for the mussel sector between 2017 to 2019. Averages, standard deviations and coefficients of variance for each of the indicators highlight the trends in the sector.

Mussels	2017	2018	2019	3 Year Average	Standard Deviation	Coefficient of Variance (%)
Tonnes	8,559	9,541	10,290	9463	868	9%
Sales Value (€)	€7,257,465	€6,069,065	€6,935,313	€6,753,948	€614,608	9%
FTE	228	136	133	166	54	33%
GVA	€6,244,054	€2,109,313	€5,412,953	€4,588,773	€2,187,115	48%
Running cost to turnover ratio	43	94	84	74	27	37%
Labour Productivity	€27,405	€15,548	€40,597	€27,850	€12,530	45%
Net Profit	€4,066,135	-€638,494	€1,259,054	€1,562,232	€2,366,922	152%
Sales value/ Tonne	€848	€636	€674	€719	€113	16%
Sales value/Ha	€2,566	€2,146	€2,452	€2,388	€217	9%
Net Profit/Ha	€1,438	-€226	€445	€552	€837	152%
Tonnes/FTE	38	70	77	62	21	34%

4.3.3 SOCIAL

The multiplier effect for GVA for the mussel sector was estimated to be 1.6. This means that for each euro that added by the mussel sector, an additional €0.6 is sustained indirectly. Based on the average GVA for the mussel sector between 2017 and 2019, of €4,588.773 this would support an additional GVA of €2,753,264.

Table 11: The multiplier effects for the mussel sector. The actual values of the sector for GVA, employment and wages are presented alongside the indirect multiplier values.

Mussels	GVA	Employment	Wages and Salary
Multiplier Effect	1.6	1.2	1.8
Sector Values	€4,588,773	410	€2,217,538
Multiplier Value	€2,753,264	82	€1,774,031
Total Sectoral Value (Sector Value + Multiplier Value)	€7,342,037	492	€3,991,569

The multiplier effect for employment in the mussel sector was estimated to 1.2. This means that for every direct mussel aquaculture related job, 0.2 jobs are sustained indirectly elsewhere. Total employment in the sector throughout the study years was on average 410. With the multiplier effect, this would result in indirect employment of 82 jobs in the wider community.

The multiplier effect for wages for the oyster sector was 1.8. This means that 0.8 times that amount of wages was generated indirectly through oyster aquaculture. While not actively considered as an indicator as part of this report, wages and salaries in the sector for 2017 and 2019 were on average €2,217,538/ annum. This would place the indirect value of wages and salaries at €1,774,031.

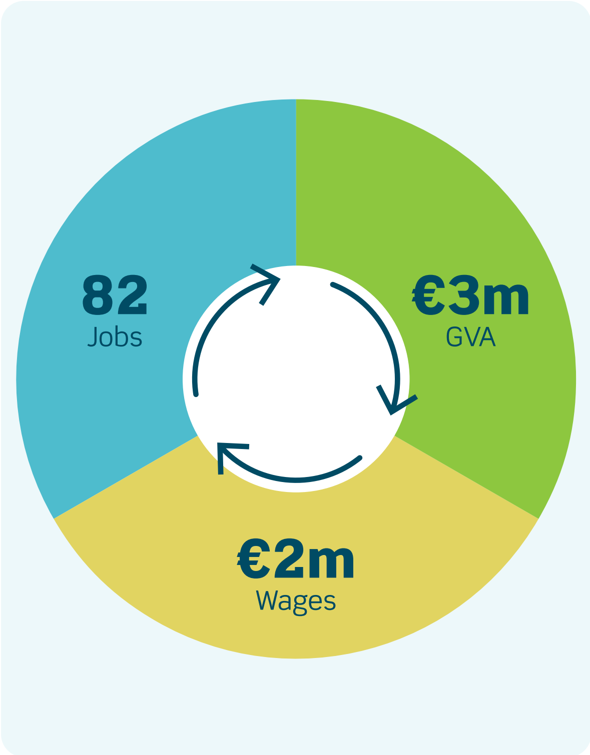


Figure 11: The Irish mussel sector supports indirectly, 82 jobs, €3m in GVA and €2m in wages.

Gender diversity in the mussel sector was low and similar to the oyster sector. Most people employed in the sector were male (91%), with the remaining 9% of the workforce being female. The percentage of women in the mussel sector increased from 6% in 2017.

Irish nationals were the largest cohort employed in the mussel sector at 83%. Most of the remainder of the workforce were from nationalities within the European Union at 17%. No other nationalities were recorded as working in the sector.

The age diversity in the mussel sector was mixed between age classes but was weighted towards an older workforce. The 16-24 age class had the lowest level in the sector at 4%. This indicates there are issues with recruitment into the sector. The 25-34 age category was the tied third largest age class at 19%. And shared the same value with the 55-64 and 65+ age cohorts. The largest percentage of the work force was found to be in the 45-54 age class at 30%. This places 68% of the work force at over 44 years of age.

This indicates that the mussel sector workforce is aging, and that additional recruitment of younger individuals is needed to sustain the workforce into the future.

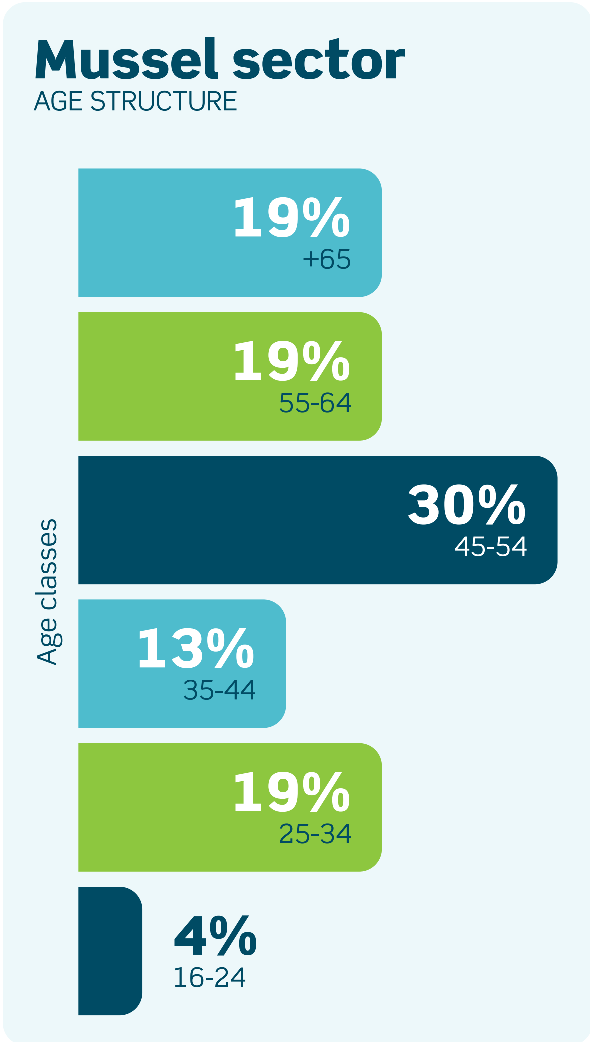


Figure 12: The average age structure of the mussel sector between 2017 – 2019.

The permanence of the farm in the activity for the mussel sector was estimated to be 96.4%. This indicates that there is very high long-term viability for businesses in the mussel sector. The remainder of the business in the sector, 3.6%, were less than one year in the sector, which indicates that there are opportunities for new mussel enterprises within the sector which indicates growth and a high degree of permanence in the activity.

4.3.4 INNOVATION

Approximately 34% of the rope mussel sector innovated through new products during 2017 to 2019 as organic status. This transition to organic status allowed producers to secure markets. Organic mussels accounted for 58% of segment value and had a sales value of €666/tonne, which was 7% lower than the segment average. Organic production also accounted for 62% of mussel production by volume during this time.

During this time, the Irish mussel fishery was nationally accredited through the MSC as sustainable. This allowed producers of rope mussels to join the client group and use the MSC logo and enter higher value processors. The initial client group formalised in 2019 consisted of 35 producers or 59% of mussel producers.

Also, during this time, the mussel sector innovated through new processes with 15% of production companies taking part in the CQA scheme and 3% taking part in the origin green program. There were approximately 59 businesses in operation during the study years. Like other segments, the inclusion and uptake of these certification schemes and programmes allowed companies to set reduction targets and foster cultures of sustainability within their organisations.

4.4 SECTORAL SUSTAINABILITY

The following section reviews and discusses the sustainability performance of each of the aquaculture segments. The aquaculture segments were not compared against each other as they have very different biologies (fed vs unfed, finfish vs shellfish), culture systems (intensive vs extensive) and production requirements (infrastructure and equipment), which makes a fair comparison very difficult. Future versions of this report will be able to compare the performance and progress of each of the segments against this baseline report.

4.4.1 SALMON

The organic salmon sector was the highest volume and value segment within the Irish aquaculture sector. The salmon segment operates with a low carbon footprint and as has been demonstrated by this report and previous publications by BIM, with a high degree of resource efficiency. As reported in the Carbon Footprint Report of the Irish Seafood Sector, Irish organic salmon is below the global average emissions for salmon production.

The sector also operates with a high ep-EROI. This metric highlights the resource efficiency and return on edible energy that salmon aquaculture provides.

The report publishes for the first-time data and breakdowns on feed, feed composition and FFDR for the Irish salmon sector. These metrics are regularly reported by the salmon aquaculture industry themselves in public disclosures and their wider disclosure and publication has been recommended by the Aquaculture Advisory Council.

Feed is one of the major inputs into fed finfish aquaculture and is also one of the more contentious areas of salmon production. It is also an area of aquaculture that has received one of the highest levels of research, development, scrutiny, and advancement.

By sharing and highlighting the low level of marine resource use more accurate and representative information can be introduced into public discourse.

The ingredients that go into feed are agricultural and seasonal in nature, which means that the level of inclusion in ingredients can change from year to year and indeed batch to batch. Feed manufacturers need to meet the minimum nutrient requirements of the feed, remain cost competitive and meet organic status requirements and environmental goals. These fluctuations in pricing and ingredient availability and sourcing can help explain the marginal increase in marine ingredients inclusion in feeds in Table 5.

This information, however, needs to be considered within the wider picture of sustainability and sustainable development. The data used in this publication does not reflect changes in feed composition and ingredient sourcing witnessed in the last number of years (post 2019). Since 2019, there has been a greater inclusion of plant-based proteins (relieving stress on marine sources), greater use of byproducts from seafood processing rather than from reduction fisheries (circular economy) and the increased use on microalgae and single cell protein sources (alternative proteins).

Economically, there was a degree of fluctuation in GVA, labour productivity and net profit for the salmon sector between 2017 and 2019. During this period, their operational costs rose and the margin of profitability decreased. However, the sector does remain profitable.

From a social perspective the salmon segment is a net contributor to the economy and local communities, as evidenced by the multiplier effects. There remain challenges with regards to the age structure of the workforce and succession planning. The segment contributed 86 million meals and is a positive contributor to food security.

4.4.2 OYSTERS

The oyster segment was the second largest by volume and value within the Irish aquaculture sector between 2017-2019. The oyster segment operated with a very low environmental impact. It was estimated that the carbon footprint for one tonne of oysters was 235 kg CO_2 eq. This value places Irish oyster production squarely within the average global range. Fossil fuel was identified as the main driver of GHG emissions at 56%. With rapid advancements in low carbon alternatives to fossil fuel such as biofuels like hydrotreated vegetable oil (HVO) and other alternative technologies reaching maturity, the oyster sector is well placed to reduce its already low carbon footprint even further.

The oyster segment was also highly productive with 2.24 t/Ha of oysters produced across the study years. The ep-EROI for oysters was estimated at 13%. This value as mentioned in the main text is within the global range of values, but this range is from a small number of studies. The oyster segment also demonstrated a high contribution to food security with an estimated 26.1 million meals produced in an average year.

From an economic perspective there was growth in the oyster segment with annual tonnage increasing across 2017 to 2019. This growth was also mirrored in sales value, price per tonne and sales value per hectare for the segment. Other economic indicators were also relatively steady across this period.

The multiplier effects for the oyster segment highlighted the indirect contributions that this type of aquaculture makes towards coastal and rural communities. These multiplier effects can play a strong role in contributing to the sustainability of coastal communities. Across the different diversity metrics that were assessed, men made-up the bulk of the workforce with most workers being of Irish extraction with roughly one in ten workers coming from outside the island.

Across the aquaculture sector there are several issues regarding the age structure of the workforces. The oyster segment has the highest proportion of people aged 16-24 in all the aquaculture sector. At face value this appears positive but greater scrutiny is required in future reports to ascertain the level of seasonal and occasional work within this cohort. Overall, the oyster segment appears to have a well distributed makeup of workers. However, it is important that recruitment into the workforce is maintained to ensure the viability of this segment.

From an innovation perspective, the oyster segment has been active in pursuing new processes through Origin Green. Initially it may look that the level of engagement with the scheme is low at 15 businesses. However it is important to understand that the majority of the 141 businesses in the oyster segment are comparatively small operators whose main business is producing half grown or bulk product. The oyster segment during this period was the only segment to see innovation through new organisational forms. This new organisational form saw an increase of 8% in the value of their oysters over non-members. There is a need for greater investigation and validation what the group can bring to its members and how similar groups can generate additional value for the rope mussel and salmon segments.

4.4.3 MUSSEL

The mussel segment of the Irish aquaculture sector performed with a very low level of emissions. These emissions were estimated to be 107 kg CO^2 eq./tonne. This level of emissions per tonne is one of the lowest of all farmed products. The mussel emissions profile is driven by fuel use at 85% of GHGs. The same options and opportunities for decarbonisation and emissions reduction for the oyster segment apply to the rope mussel segment.

In an average year, the rope mussel segment produces 3.3 tonnes of product per hectare. The 85% ep-EROI for rope mussels is one of the highest recorded to date. This indicates a very high return on energy investment and highlights the low energy input for mussel production and the high energy content that mussels have as a food product. On average the mussel segment produced 41.6 million meals per annum, which highlights the contribution to food security and human nutrition that the segment makes.

The mussel segment performed well within the study years, with positive growth recorded in volume. There was variance in the average sales value for the segment and in the GVA. Overall, this segment performed as well if not better in 2019 as it did in 2017, in several different economic categories. FTE saw a significant change in the years though it did stabilise, and because of this change the output per FTE increase by almost 100%.

Like the other aquaculture segments the mussel segment performed very strongly with multiplier effects. The segment indirectly supported 82 additional jobs, almost €1.8 million in wages and salary and €2.7 million in GVA. Like the other segments the mussel segment had a higher male proportion of the workforce and saw a similar level of the workforce indicating their nationality as Irish. The mussel segment had a very low level of younger workers and a high proportion of aging workers. To maintain the viability of the segment there will need to be additional recruitment of younger workers into the workforce. With over 90% of mussel farms operating for more than 10 years the long-term viability and sustainability of these enterprises is very high.

The mussel sector also demonstrated high levels of innovation through the collective certification of rope mussels through MSC. This innovative action has allowed the sector to enter new markets and attract new consumers.

5. FUTURE WORK

The importance and need for sustainability and sustainability reporting is just starting. The European Union recently brought forward its Corporate Sustainability Reporting Directive and there are a number of other articles in development such as the proposed Green Claims Directive, which will increase the threshold for sustainability claims. This report forms a baseline which uses over 20 indicators to monitor the performance of the Irish aquaculture sector over the sustainability pillars of economics, environment, social and innovation.

There are several areas and issues that need further support, research, development and validation to more comprehensively monitor the sustainability performance and progress of the Irish aquaculture sector.

From an environmental sustainability pillar, an additional area which should be considered within future sustainability assessments is the wider ecosystem services that shellfish aquaculture can have. These species of shellfish have been shown to have high remediation potential for coastal waters that are experiencing high levels of nutrient input. This additional nutrient input comes from activities that take place higher in catchments. These nutrients can enter surface waters through heavy rainfall or land run off and ultimately end up in coastal and transitional waters. These excess nutrients can lead to eutrophication and harmful algal blooms. Shellfish can play a role in ameliorating this additional pressure on the marine environment. Shellfish such as oysters and mussels can sequester carbon in their shells through biomineralisation. The carbon that is bound in the shells is relatively inert and it is thought that this can act as a long-term storage system for excess carbon. This wider assessment of ecosystem services is an ongoing area of research, both nationally and internationally. With this strong research effort to better understand sequestration of carbon and nutrients, and the wider interaction between the environment and shellfish aquaculture, it is possible that these outputs may results in useable KPIs for future reports.

Another area of environmental sustainability that should be included in future reports is biodiversity. Biodiversity is an important part of an ecosystem, but under the current frameworks of sustainability (life cycle assessment and systems thinking), it is one of the most difficult parts to represent and account for. Biodiversity typically is represented as consisting of three levels: species, genetic and ecosystem. Each of these levels are linked and influences the others. The complexity, time and expense in attempting to categorise and reflect the interactions that an activity can have is a common gap in all food related sustainability initiatives. Like the ecosystem services work, this is an area of ongoing and emerging research which has not yet reached a level of maturity with which it can be included as a part of this study.

The economic sustainability of Ireland's aquaculture sector hinges on informed decision-making and robust policy development, both of which are fundamentally supported by accurate and comprehensive data collection. There is a need to improve data collection methodologies and systems, which can provide the foundation for more resilient and robust economic KPIs.

To ensure consistency and reliability in data collection, there needs to be additional development and implementation of standardised data collection protocols across the aquaculture industry. A unified approach to data collection will allow for better comparability and aggregation of data from diverse sources. By creating a centralised database, BIM can store, manage and analyse data effectively, making it accessible for research, policy formulation and operational decision-making.

There is a need for greater collaboration between stakeholders to facilitate comprehensive data collection and utilisation. By fostering a culture of collaboration, development agencies such as BIM can ensure data collection efforts are not siloed but rather contribute to a collective understanding of industry challenges and opportunities.

Data-sharing agreements can be developed to protect proprietary information while allowing for the aggregation of critical data for broader analysis. Through this, BIM can create platforms that enable farmers, researchers and policymakers to share data and insights. Increasing the awareness of how monitoring economic KPIs can provide insight into financial trends and the economic sustainability of their enterprise.

By focusing on improving data collection methodologies and systems, BIM can significantly enhance the economic sustainability of Ireland's aquaculture sector. Standardised protocols, advanced technologies, collaborative platforms, capacity building and sophisticated analytics are all critical components of a robust data collection strategy. Through these efforts, decision-makers and policy makers can be better informed by more accurate, comprehensive, and timely data, ultimately supporting the growth and resilience of the aquaculture industry.

Social sustainability is an area of sustainability which can be difficult to capture and represent. The social indicators used in this report were leveraged from a 2018 publication[2] which presented 56 indicators to assess the sustainability of aquaculture systems (22 environmental, 14 economic and 20 social). The data used for the social indicators were from the annual aquaculture survey, which is a reporting tool for the European Union. While a useful data source, the data collected as part of that initiative does require more comprehensive and in-depth data than is required in its current form. Data for the multiplier effects were sourced from another BIM publication, which had higher data needs than is required for the EU. Work will be carried out to more efficiently mine the data for that and how it can be used to assess the social sustainability of the aquaculture sector.

2 Valenti et al. (2018) https://www.sciencedirect.com/science/article/abs/pii/S1470160X17308646

Another area of social sustainability that has emerged in the past five to six years is social license to operate. An indicator which gauges and monitors the level of social license available to the sector to operate would prove useful in resolving stakeholder conflict and increasing consensus.

Innovation is an area which future versions of this report should strive to capture more robustly. This report was not able to represent the contribution and level of activity that the Irish aquaculture sector plays in terms of research output and engagement. At any given time, there are several aquaculture businesses involved in research either as project partners, stakeholders, or data contributors in EU, Interreg or government programmes. This research requires industry time, human resources, expertise and operational knowledge to succeed. Many of these projects can be applied in nature and benefit industry through new equipment, machinery, or systems of production. However industry does engage heavily with higher level research projects which gather information and data to inform policy. This engagement with researchers and higher education institutes is often a reciprocal relationship, with knowledge transfer which can instigate new processes, products and forms of production. This reciprocal relationship lays a strong foundation for innovation and is something which needs to be reflected in future versions of this report. The pillar of innovation is particularly noteworthy when considering that industrial aquaculture such as that practiced in Ireland today only commenced in the 1970s. The level of progress and process efficiency that the sector has witnessed in its 50 to 60-year existence is something which needs greater recognition and acknowledgement.

Finally, there is a need to expand the scope of this report to other aquaculture species such as abalone, trout, perch and seaweeds. These segments of the aquaculture sector have their own strengths, weaknesses and opportunities for sustainable development and expansion. It is important to baseline these segments under a sustainability lens so that appropriate support and action can be taken to ensure their viability and sustainability.

This report drew from data held by BIM and from BIM publications that covered 2017 to 2019. These years saw changes in process and production methods and saw years in which the effects of climate change were felt throughout the sector. Through this exercise data gaps were observed. The identification of these gaps will allow BIM to collect and collate more relevant sustainability data which can be used to develop more comprehensive and holistic indicators. These indicators will help to better monitor and target supports that will improve the sustainability performance and credentials of the Irish aquaculture sector.

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