Estimation of the carbon footprint of the Shetland fishery for Atlantic mackerel (Scomber scombrus)
Sandison, Frances

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Estimation of the carbon footprint of the Shetland fishery for Atlantic mackerel (Scomber scombrus)

Frances Sandison

2015
Estimation of the carbon footprint of the Shetland fishery for Atlantic mackerel (*Scomber scombrus*)

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Executive Summary

This study investigates the carbon footprint (CF) of the pelagic trawl Atlantic mackerel (*Scomber scombrus*) fishery of the Shetland Isles over the period 2012-2014. The study has found the Shetland Atlantic mackerel pelagic trawl fishery to have a comparably low CF at the point of landing in comparison both to other fisheries and terrestrial meat systems to a similar end point (0.41 t CO$_2$e per tonne of fish landed). This was found to be in keeping with other research which shows small pelagic species and pelagic trawl fisheries in general to have a low CF value.

Fuel consumption was found to be the single biggest contributor to the overall CF and thus any steps to further reduce fuel consumption will aid in lowering the fleet CF. Refrigerant leakage was also found to play a large part in the current estimation of CF for the Shetland fleet. However, this was caused by a minority of vessels and will no longer factor after the change in regulations in 2015 requiring the out-phasing of R22 as a refrigeration system. This will result in those vessels affected converting to the carbon neutral ammonia system utilised by the others, thus removing refrigeration leakage and further reducing the fleet CF value.
1. Introduction

1.1 Background

Today the fishing industry represents our last wild caught, large scale commercial foodstuff and produces a commodity that is traded globally (Smith, et al, 2010). Fisheries provide protein rich meat contributing to at least 15% of the average protein intake for half the global population (FAO Fisheries and Aquaculture Department, 2012). Of the fish landed or reared, only about 20% goes into uses other than direct human consumption (e.g. as fish meal or oil). Additionally, the fishing industry supports over 180 million jobs around the globe (FAO Fisheries and Aquaculture Department, 2010).

The increasing reliance on fish as a food source has largely been made possible by improving technology, although it has not come without its own problems (e.g. the collapse of commercial fisheries - Myers, et al, 1997; resulting changes in the behaviour of apex predators - Estes, et al, 1998: and extreme ecosystem shifts caused by the collapse of a foodweb - Pandolfi, 2005). As such, there are now numerous safe guards in place to try and minimise the negative effects of fishing and create sustainable and well managed fish stocks and marine environments (for example MSC certification, no take zones, international fishing quota). Despite this, one issue that has, up until recent years, been widely overlooked by measures of fishing sustainability is climate change. In recent years effects of climate change on various fisheries have been reported. For instance, climate change was reported as one of the contributing causes of the reduced sand eel population around Orkney and the Shetland Isles (RSPB, 2009). Future projections suggest this could have much greater effects on a variety of commercial fish species, with higher latitudes possibly seeing a 30-70% increase in catch potential and the tropics seeing a drop in catch potential of around 40% (Cheung et al, 2010).

As well as being affected by climate change, fisheries themselves may be a strong contributor to global warming emissions. Food production as a whole, including distribution and retail, is responsible for a significant overall proportion of a country’s net greenhouse gas emissions and general environmental impact (Foster, et al., 2006). The terrestrial meat industry alone, largely due to beef production, is known to be the second highest cause of global greenhouse gas
emissions after that of heating and electricity production (Rifkin, 2011). This ranks even above the contribution caused by worldwide transport. However, the focus for greenhouse gas emission has traditionally been on terrestrial meat production systems, and as a result there is to date no widely accepted figure for the aquatic food industry as a whole.

There is a growing consumer led interest in ethical food production and consumption, with 67% of UK consumers more likely to purchase a product with a low carbon footprint (Carbon Trust, 2012). There is also a growing political and scientific drive to sustainably manage resources. Growing consumer awareness on the state of fish stocks has also led to the development of indicators and certifications or labels that can help differentiate between sustainably managed fisheries and those that are not sustainably managed. One of the major labels for this is the Marine Stewardship Certification (MSC) of fisheries (MSC, 2011), which considers such factors as fishing pressure on stocks as a whole and various issues associated with fishing practices (e.g. as is seen in the Scottish North Sea haddock fishery (MSC, 2015). Such labels are often coveted as they can potentially increase the value and marketability of the resource in all aspects of retail. As it stands however, few if any of these measures of sustainability actually consider a fisheries’ carbon footprint.

1.2 An Overview of Carbon Footprinting and Life Cycle Analysis History
A ‘carbon footprint’ (CF) or carbon profile, is the term used to refer to the quantity of carbon dioxide and all other gas emissions that contribute to global warming, starting from the creation of a product right through until the end of its life including its disposal or eventual recycling. It is expressed in global warming potential (GWP) for every kilogram of gas emitted over a fixed period (typically 100 years). This allows for the total emissions from a product to be calculated and added together to give a single figure that can be directly compared to that of other products. A summary of some of the most common greenhouse gas emissions and their GWP over a century, based on the figures given by the IPCC (EPLCA 2009), is shown in Table 1. Greenhouse gas emissions are caused through many different processes, the most notable of which is the combustion of fossil fuels in heating and electricity production, transport and in agricultural processes (Rifkin, 2011).
Table 1 Greenhouse gases and their associated GWP over a hundred year period as reported by the IPCC (EPLCA 2009).

<table>
<thead>
<tr>
<th>Gas type</th>
<th>Chemical formula</th>
<th>GWP100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO$_2$</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH$_4$</td>
<td>25</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N$_2$O</td>
<td>298</td>
</tr>
<tr>
<td>HFCs</td>
<td>-</td>
<td>124-14800</td>
</tr>
<tr>
<td>Sulphur hexafluoride</td>
<td>SF$_6$</td>
<td>22800</td>
</tr>
<tr>
<td>PFCs</td>
<td>-</td>
<td>7390-12200</td>
</tr>
</tbody>
</table>

Life Cycle Assessment (LCA) is the standardized method for calculating environmental impact of any product or service from the beginning of its life to the end, including its CF. It is defined and outlined by the international organisation of standardisation, in their documents ISO 14044 and 14040 (BSI, 2006a; BSI, 2006b). Like a CF estimation, it follows a product through from obtaining the raw materials to final disposal or recycling of waste. However, rather than focus on the single impact category of global warming, it considers all possible environmental impacts associated with the product chain. This can range from GWP to habitat destruction, with a number of other impact categories in between. CF is considered an important category of LCA and one of the main constituents of the overall impact (BSI, 2011).

It is generally considered to be best practice when assessing the environmental impacts of any process to consider all possible impact categories over the entire lifespan of the product. Here an impact category is defined as the possible consequences that could affect human health, wildlife and sustainability. This prevents the shifting of burdens from one impact category to the other. For example; farmed shrimp have been found to have lower directly associated
greenhouse gas emissions than wild caught shrimp (Ziegler, et al., 2011). However, they are linked to the increasing destruction of mangroves which are considered an important habitat for many commercial fish species and thus may contribute to declining fish stock numbers, (Mangrove Action Project, 2013). Nevertheless, businesses tend to prefer the easier to understand and more marketable figure of a CF, which unlike the LCA, offers a single, unambiguous end figure. Fortunately, as GWP makes up a large proportion of environmental impact as a whole (Parker, 2012), a CF profile is accepted as a suitable first step in environmental analysis of a product (BSI, 2011). Both CFs and LCAs can be considered in their entirety (a cradle to grave approach) whereby the impacts/emissions of the product right from the beginning of its life, including any material capital goods, through to its eventual destruction or recycling are assessed. Alternatively, a segmented approach (cradle to gate) can be assessed whereby the impacts of a product are considered for only part of the life cycle, usually from the beginning of its life (including capital goods) through to the end of the first stage, where it passes into a different system. In the context of fishing, an accepted cradle to gate approach would consider the impacts of the fish from capture to landing or processing, leaving distribution and retail as separate stages in the assessment to be considered later (BSI, 2011). The latter is often preferred by businesses as it allows them to be accountable only for the emissions involved in their stage of the analysis, or it removes the issue of being unable to quantify possible emissions downstream of their involvement with the product.

1.3 Carbon Footprint Analysis in Capture Fisheries.
The traditional view of assessing environmental impact in capture fisheries has often been restricted to looking at fish stock levels, damage to the seabed, bycatch and effects of fishing down the foodweb (as discussed in Avadi and Freon, 2013). Unfortunately however this narrow focus has ignored several other important impacts, such as ocean acidification, toxicity and climate change, which, although not caused solely by capture fisheries, do represent important categories in a fishing LCA. LCA has been widely accepted as the more encompassing framework to assess a seafood product from its beginning to its end (Pelletier, et al., 2007). Creating carbon profiles for the fishing industry has gained interest and popularity over recent years, with LCA and carbon emission analyses starting in the late 1990s to early 2000s, (e.g.
Tharne, 2004; Ziegler, et al., 2003). However, a lack of standardisation and agreement on terms and scope has resulted in a multitude of LCAs of differing magnitude and methodologies. The release of the PAS 2050-2: 2012 (BSI, 2012) outlined specific guidelines for CF in the aquatic sector, meaning that there are issues with comparing LCAs prior to this.

Many LCA studies of fisheries have shown that the capture process (summarised in Avadí & Fréon, 2013) is the most significant contributor to greenhouse gas emissions over the whole life cycle of the product. This appears to be overwhelmingly due to fuel emissions (Hospido & Tyedmers, 2005) and as a result the method and gear used to catch the fish has a significant effect on the overall CF, depending on their energy efficiency (e.g. Tharne, 2004; Tyedmers, 2000; Vázquez-Rowe, et al., 2010). Additionally some studies have found contributors such as refrigeration leakage also are responsible for a considerable proportion of the overall footprint (e.g. Zeigler et al, 2013; Vazquez-Rowe et al, 2010). The few studies that have not come to this conclusion tend to involve either air transport or value added products. Because of this correlation, Parker (2012) suggested that in studies without significant air travel or products involving the addition of ingredients with high CFs in their own right, fuel use could be used as a proxy for the CF of the overall product up to arrival at its intended destination.

The use of capital goods in studies, particularly with regards to vessel construction, has been found to have a negligible contribution to overall LCA values (e.g. Ziegler, et al., 2003; Hospido & Tyedmers, 2005; Hayman, et al., 2000) and, in line with PAS guidelines, it is often ignored from the analysis. There has been some debate as to whether this is an accurate representation, with some authors suggesting that the reported negligibility is due to an oversimplification of quantification of construction materials (Iribarren, et al., 2010). However, this argument is more aimed at other aspects of an LCA analysis, such as marine toxicity, than carbon footprinting.

A number of studies suggest that emission rates vary from fishery to fishery, depending heavily on the gear type used and the efficiency of the catch rate (e.g. Parker & Tyedmers, 2014; Madin and Macreadie, 2015; Ziegler, 2007) and that some can have a very high emission rate while others are particularly low (Madin and Macreadie, 2015). It is generally accepted that bottom
trawlers have the highest fuel consumption and emission rate (Winther, et al, 2009), especially in the shrimp and crustacean fisheries (Schau, et al., 2009). Research suggests that purse seiners are generally the most efficient of the mainstream fishing methods with regards to carbon emissions, and can be up to five times more efficient than bottom trawling in some fisheries (Driscoll & Tyedmers, 2010). However, it is noted by some that this is more reflective of their high rate of net haulage than actual fuel efficiency in terms of fuel combustion (Zeigler, 2007). Emission rates for pelagic trawls on the other hand are always significantly lower than bottom trawling, but vary from being twice as high as purse seining (Parker & Tyedmers, 2014) to being as efficient as it (Schau, et al., 2009). Zeigler et al, (2003) in particular warn against generalising about gear efficiency across fisheries due to such discrepancies. As such, results are best taken in context with other local fishing methods.

Artisanal fisheries have considerable variation in their carbon emission rate depending on method and species targeted (Ziegler, et al., 2011), but are largely perceived to be the lowest impact fishing method by the consumer. Little has been done on the emission rates in artisanal fisheries including handline fisheries, though some studies have suggested that handlining is no more efficient, or slightly less so than pelagic trawling or purse seining (Schau, et al., 2009). However, small pelagic fisheries are reportedly the single most energy efficient of the commercial fisheries (Parker & Tyedmers 2014).

1.4 Mackerel Biology and Stock Structure
Atlantic mackerel (Scomber scombrus) (Figure 1) is a small pelagic fish that is a member of the tuna family, Scombridae. A migratory fish, they spend the majority of their life travelling in large, fast moving shoals in mid-water, covering vast distances over the year as they move between overwintering, spawning and feeding grounds. Considered a high source of omega three fatty acids (NHS Choices, 2013) which are required by the fish for its high energy content to fuel their migration and spawning, they are considered to be a healthy source of protein and a valuable resource.
The North East Atlantic (NEA) mackerel stock is made up of three breeding populations – the Western component, the North Sea component and the Southern component, (Simmonds 2001). Only the Northern component is thought to be genetically distinct from the other two, although this distinction is debated by Jansen & Gislason (2013). The North Sea component of the mackerel stock showed a dramatic decrease in the late 1960-1970’s, which was generally believed to be the result of overfishing as well as indirect pressure on valuable prey species such as herring. Low recruitment continued thereafter, though a recent study by Jansen (2014) has suggested this is more reflective of a stock shift driven by changing water temperatures. The three components are treated as a single management unit, as intermingling between the populations make separate management impossible. As a result the stock is widely spread with several known spawning areas (Figure 2).
Mackerel from the North Sea component spend their winter months close to the Shetland Isles and along the Norwegian deep, before travelling into the central area of the North Sea in spring to spawn. The Western component however linger close to the continental slope (Scottish Pelagic Sustainability Group, 2014), spawning around Ireland and west of the UK between March-July, before travelling into the North Sea and Norwegian waters to mingle with the North Sea stock, (Figure 2). As with the North Sea component, over the years some clear shift in trends have been noted with the Western component and its migration time and path, moving later in the year and into deeper waters. Spawning areas have also seen an expansion further north and west of existing spawning grounds. ICES maintain that this is not reflective of changes in climate so much as it is of changes in stock size (ICES, 2005).

1.5 The Scottish Mackerel Fishery
In recent years Atlantic mackerel has become the single most valuable species to the Scottish fishing industry, making up about one third of the value of the total landings. In 2012 catches totalled over 134,000 tonnes, valued at £131 million (Scottish Pelagic Sustainability Group, 2014), and it is still considered one of the healthiest commercial fisheries in Europe. Catches by
the Scottish fleet largely consist of removals from the Western and North Sea components of the stock. There are two main aspects to the fishery, the first being the much larger trawl fishery which operates on a seasonal basis, from January-February targeting mackerel along their migration route (with the west component of the stock moving from the continental shelf where they overwinter towards the south and west of the UK and Ireland, and the North Sea component moving from the Norwegian deeps into the central North Sea – Scottish Pelagic Sustainability Group, 2014) and from October–November in Scottish waters. The second aspect is the inshore fishery, which operates only a single season running from June-October.

Fishing is mainly conducted by pelagic trawl where a large trawl net is towed through the water at the mid-water level. Unlike the better known bottom trawling method, this form of trawling does not impact upon the seabed as it does not touch the sea floor and has a relatively low bycatch rate. This is mainly due to the shoaling behaviour of the mackerel which allows pelagic vessels to target a single shoal at a time. Shoals are mainly ‘relatively clean’, i.e. they consist of only mackerel, but at different times of the year shoals may either be less dense or have higher percentages of bycatch species within them. Wheelhouse equipment (sonar and echosounder) enable the fishers to identify those shoals of mixed species and allows for them to be avoided, resulting in a minimum bycatch (MSC, 2014).

The fish from the Scottish fishery are used solely in human consumption and transported to be sold worldwide. In January 2009 the Scottish Pelagic Sustainability Group gained Marine Stewardship Council (MSC) certification of the North East Atlantic mackerel fishery against the MSC’s standard for environmental and sustainable fishing (Seafish, 2013). This label was suspended in 2012 after Iceland and Faroe allegedly compromised the sustainability of the stock by increasing their quotas markedly without international agreement. International debate continued until 2014 when an agreement was finally made between Faeroe, Norway and the EU, with allowance made for Iceland should they wish to join later. This initial agreement was set for five years during which time a long term management plan, agreed on by the respective nations, is to be assessed by ICES in the hope of regaining MSC certification (MSC, 2014).
Unlike other national pelagic fleets, purse seining does not feature largely in the Scottish fleet, instead it is predominantly undertaken by pelagic trawl. The eight vessels that make up the Shetland pelagic trawler fleet are all refrigerated seawater vessels and make up a notable proportion of the Scottish fleet. In these vessels the catch is pumped into large chilled seawater tanks to keep it fresh prior to landing. The inshore fishery also adds to the mackerel quota uptake, though at a considerably lower level, operating smaller handline or jigging vessels. Mackerel caught by the Shetland trawlers are predominantly landed at processing plants in Shetland, North East Scotland and in Norway. Shetland itself possesses one large scale processing plant, Shetland Catch, which due to its proximity to seasonal shoaling pelagic fish attracts landings from national and international vessels as well as some from the local fleet. Smaller boats typically land their catches to the traditional fish markets on the island (Leiper, S., pers. comm.).

1.6 Aims and objectives of Project

Within the Scottish mackerel fishery the Shetland fleet is of relative importance, being awarded a sizeable proportion of the quota – over quarter (26.89%) of the Scottish quota for the Western component of the mackerel stock in 2014 (Shetland Fish Producers’ Organisation, pers. comm.). Fishing takes place during October and November mainly in Scottish waters (referred to herein as ‘late season’); and in January - February when stocks are on their feeding migration (referred to herein as ‘early season’), which results in fishing activity moving as far as south-west Ireland by February. There is an assumption within the pelagic sector in Shetland that the mackerel fishery based in Shetland will have a relatively low CF given the modern nature of the fleet and the use of high-tech equipment.

The aims of this project are as follows;

- To investigate the CF of the mackerel fishery undertaken by Shetland’s pelagic trawl fleet
- To contrast the CFs of the pelagic trawl fleet in the two intra-annual mackerel seasons
- To compare the CF of Shetland’s mackerel fisheries with that of terrestrial meat systems and other commercial fisheries
To investigate the CF of the smaller inshore Atlantic mackerel fishery and to contrast this against the pelagic trawler CF

While a full LCA analysis should be considered for the future to prevent improvements in one sector inadvertently causing higher impacts in another, at this stage a carbon profile is felt to be the best first step for the analysis of the Shetland mackerel fishery.

2 Methods

2.1 Data Collection

For the initial stage of this study a cradle to gate CF study is proposed, focusing on the capture-landing phase of the Shetland Atlantic mackerel fishery. In this instance the gate is defined as the factory door, with only ship related emissions considered.

Both aspects of the Shetland fishery were intended to be included; the large scale pelagic trawl fishery and the smaller handline fishery, with a retrospective approach used examining record data to calculate the carbon footprints for the fisheries over the past three years (as in keeping with the PAS guidelines). However it was discovered on implementation that this was not feasible for the handline aspects of the fishery as the smaller vessel skippers did not typically keep records to the detail required for a reliable estimation. For this reason, exploration of the handline Atlantic mackerel fishery in Shetland was eliminated from this stage of the analysis.

For the pelagic trawler aspect, focus was primarily given to the overall carbon footprint. The contrast between the two intra-annual fishing seasons was also explored to see if there was any significant difference between them.

PAS guidelines (BSI 2012) suggest that for a fleet this size, all vessels should be included in analysis for an appropriate confidence interval. However, as one of the vessels was registered between two different ports, it was removed from further analysis to avoid unnecessary complication.

The following data were collected for the seven suitable vessels;
Fishing inputs

- Consumables;
  - Nets
  - Rods/lines/hooks
  - Ropes
  - Metals
- Cooling materials
  - Refrigerants
- Fuels/ Energy
- Materials used for maintenance
  - Lubricating oil
  - Anti-fouling agents
  - Cleaning agents

Fishing outputs

- Catch
  - Landed bycatch
- Emissions
  - Loss of refrigerants to atmosphere
  - Emissions from fuel combustion

This data was obtained from primary sources, through interview/correspondence with the skippers/engineers of the vessels as well as their shipping agents, and in some cases (as with the details on nets – weight and consumption, and for the details on antifouling) companies used for purchase of materials. Permission was obtained for access to ship records to allow analysis of the raw data, either passed on through the shipping agents/companies or by access to their online e-log records.

Where secondary data was required in the absence of reliable raw data (e.g. refrigerant leakage), the range suggested by the Seaﬁsh carbon footprint analysis tool was used (Seaﬁsh,
n.d.). A worst case scenario approach taken to allow for a conservative estimation (in keeping with suggestions made by the PAS for unknown data) and the highest suggested figure used.

2.2 Data Analysis

In order to calculate the end figure of CF, landings per year for each of the vessels as well as estimation of fuel spent per year were calculated the latter being taken from fuel purchase records. For this an approximate quantity of litres purchased per year were calculated using base price figures obtained from the fishing agent. These were then validated by comparison of the calculated figures with a random selection of invoices. All compared figures were found to be within acceptable parameters and thus deemed appropriate for use. The issue of fuel purchased not directly equalling fuel spent was considered, however as averages were taken over the full three year period, it was felt that any discrepancies between the two would equal out overall.

From the total fuel spent over the year, this was allocated by percentage of landings (mass of landed fish) between the different fish species, as per the PAS guidelines. The total fuel was split between all species landed as a proportion of total landings for the time period looked at, in order to account for emissions caused by the lengthy non-fishing periods and activities in which auxiliary engines were continuously run to keep the main engines in working order or where the ship was moved from port to port.

By allocating fuel with this method, landed bycatch could be removed from the analysis as it had been already accounted for by subdivision of the landings and related emissions. Additionally, as the fish were landed whole no calculation of percentage yield to fish caught was necessary. Litres spent per tonne of mackerel landed could therefore be calculated with relative ease. This was done at different levels dependent on the focus – per vessel, per trip, per season, per year and average over the time period.

For consumables, estimates were obtained through the engineers and skippers and calculated to give yearly averages, with the figures split again by allocation to each species percentage of total landings for the year/time period and then calculated per tonne of mackerel landed. As
this had a very low contribution to the analysis, estimations were deemed suitable without further validation.

The calculation of actual carbon footprint was done by the Seafish online emission profiling tool, though the final figure (given in kg of CO₂ equivalent emitted per tonne of fish landed) was then converted to tonne of CO₂ equivalent (t CO₂e) per tonne of fish landed to allow for easier comparison with other studies. Assessment was made of the overall fleet average figures, individual vessel average figures and both individual and fleet average figures per year. For the seasonal comparison, fuel spent over the collective fishing seasons over the study period was contrasted with landings per species within the specified season. The Pearson correlation test was used to determine if there was a significant relationship between the end carbon footprint and: landings; fuel consumption; fuel intensity, as well as between fuel consumption and landings.

3 Results

3.1 Fleet Analysis

An overall estimated carbon footprint for the Shetland pelagic trawler fleet’s Atlantic mackerel fishery was calculated by accumulating the data for all seven vessels followed in the study over the three year period and then averaging. The estimated average carbon footprint is shown in Figure 3.
The average estimated carbon footprint for the entire Shetland pelagic trawler fleet between the years of 2012 and 2014 is 0.407 t CO$_2$e. Of this, the majority (0.283 t CO$_2$e) is caused by the fuel consumption in the fishery. The contribution of the refrigerants in the overall footprint is notable. However, upon closer inspection this contribution is caused solely by two of the seven vessels in the fleet (Figure 4). In contrast the contribution to the footprint by the vessels fishing gear and maintenance is minimal (0.002 t CO$_2$e).

**Figure 3** Estimated average footprint for the Shetland pelagic trawler fleet 2012-2014.
Figure 4 Estimated overall average carbon footprint for the Shetland pelagic trawler fleet 2012-2014.

There is clear inter-vessel fluctuation in CF, with the lowest carbon footprint belonging to Vessel 4 (0.287 t CO\textsubscript{2}e) and the highest to Vessel 6 (0.645 t CO\textsubscript{2}e). However both Vessel 6 and 7’s comparatively higher overall footprint is caused largely by the emissions from refrigeration leakage. Emissions caused purely by fuel combustion places them below all five other vessels (0.215 t CO\textsubscript{2}e and 0.204 t CO\textsubscript{2}e respectively), with refrigeration leakage adding an additional 0.429 t CO\textsubscript{2}e /0.426 t CO\textsubscript{2}e respectively to their overall CF figure.

Annual inter-vessel fluctuations in CF for the period 2012 to 2014 are shown in Figure 5. There are notable fluctuations in CF across vessels and years. No real trend can be seen between the initial two years of the study (2012-2013) as some vessels’ annual footprints increase while other’s decrease, with the overall averages being quite similar (0.455 t CO\textsubscript{2}e and 0.448 t CO\textsubscript{2}e). However, there is a marked reduction in the average for 2014 (0.356 t CO\textsubscript{2}e) and, with the exception of Vessel 7, all vessels show a clear reduction in CF for this year. In 2014 fuel
consumption emissions are lower for all vessels except vessel 7, explaining its overall increase in CF.

Vessel length did not have a considerable effect on CF, however refrigeration was found too. The two oldest vessels (Vessels 6 and 7), built prior to a change in refrigeration policy in 2000, were still utilising the R22 refrigeration method over the study period, resulting in much higher refrigeration figures than the other vessels.
Figure 5 Estimated individual carbon footprints for the Shetland pelagic trawler fleet 2012 (top), 2013 (middle) and 2014 (bottom)
3.2 CF Individual Component Analysis

This section explored the individual components that were used to calculate the end carbon footprint levels. The overall fuel consumption attributed to mackerel fishing per vessel per year is shown in Figure 6. Inter-vessel fluctuations are seen quite clearly with Vessel 4 possessing the highest fuel consumption in all but one year (2012), and Vessel 6 showing low emissions for all three years. However, there are also clear intra-vessel fluctuations (e.g. Vessel 4), although for some this is relatively minor (e.g. Vessel 1). While the similar averages in years 2012-2013 are possibly evidence of natural fluctuations, the slightly higher average in 2014 suggests an overall increase in fuel consumption in this year for the majority of vessels. There was no correlation between fuel consumption and overall CF ($P>0.05$).

![Fuel allocated to mackerel fishing for the Shetland Pelagic Trawler fleet](image)

**Figure 6** Fuel allocated by mass to the mackerel fishing 2012-2014 for the Shetland pelagic trawler fleet.
Figure 7 shows the total weight of mackerel landed per vessel per year. The trends reflect the same pattern seen with fuel consumption, with the exception of Vessel 5 in 2012 which shows a lower landing than expected from the high fuel consumption. Overall there is little fluctuation seen between the years 2012 and 2013 although a much higher average is evident in 2014. A significant relationship is seen between total yearly landings and overall CF ($P=0.02$).

**Figure 7** Total annual landings for the Shetland pelagic trawler fleet 2012-2014 by vessel.

Fuel spent per tonne of mackerel landed for each vessel per year is shown in Figure 8. Fluctuations are seen between vessels and between years, with no clear trend overall between years 2012 and 2013 (reflected in the similar averages). However, in 2014 the majority of vessels spent less fuel per tonne of mackerel (the exceptions being Vessel 7 in 2013 and Vessel 3 in 2012). This was reflected in the lower fleet average value of 76.2 litres spent per tonne of mackerel landed.
A strong positive linear relationship is seen between litres spent per tonne of mackerel landed and the overall CF for the year. In Figure 9 two distinct groups of results can be seen – those that follow the main linear trend, and a smaller subset that follow a linear trend at more elevated CF values. The elevated values represent figures from the two vessels with the relatively high refrigeration leakage values. The overall relationship was not found to be significant ($P>0.05$). However, the removal of the elevated outliers from the analysis resulted in a highly significant correlation ($P<0.01$). The relationship between fuel spent and fish landed was also explored. Again a significant positive relationship is seen between the two variables ($P<0.01$).

![Litres of fuel spent by the Shetland Pelagic Trawler fleet per tonne of Atlantic mackerel landed](image)

**Figure 8** Litres of fuel spent per tonne of Atlantic mackerel landed by individual vessels in the Shetland Pelagic trawler fleet from 2012-2014.
Figure 9 Litres of fuel spent per tonne of Atlantic mackerel landed by the Shetland pelagic trawler fleet against the resulting carbon footprint over the entire study period.

3.3 Seasonal Analysis

The effect of fishing season on overall CF values was explored by separating early season landings from late season landings (Figure 10).
Generally, more fish are landed overall in the late season than in the early season. Despite this there is considerable inter-vessel variation with a marked difference between seasons for some vessels (e.g. 5 and 6) and little difference for others (e.g. Vessel 3).

Figure 11 shows the total fuel spent for each season. Overall there is an increase in the late season, however there are some deviations from the trend seen in Vessel 7 and Vessel 2. There was also considerable variation between vessels.
Figure 11 Total fuel consumption for Atlantic mackerel fishing over entire study period by season landed.

In order to put these figures into perspective, litres spent per tonne of fish landed (fuel intensity) was calculated and is shown in Figure 12. There was no noticeable trend evident. For some vessels fuel usage is higher in the late season, while with others the reverse is true, with only one (Vessel 5) showing similar fuel usage between the two seasons.
Figure 12 Litres of fuel spent per tonne of Atlantic mackerel landed per season over the entire study period.

Table 2 shows the frequency of landings for each port used by the vessels. While Shetland was one of the most frequently used ports (second equal with Selje, Norway, coming after Alesund, Norway), Norway as a whole is frequented much more than the UK. This is true regardless of season, though it is slightly more pronounced in the late season.

Table 2 Frequency of landings in each port for the entire study period.
4 Discussion

4.1 Discussion of Study Results

The results of this study show that the majority of emissions in the CF for the Shetland pelagic trawler fleet are caused by fuel combustion, as is in keeping with the findings of others (summarised in Parker, 2012). Similarly, vessel maintenance and consumables are typically low.

Various studies (e.g. Irribarren, 2011; Vazquez-Rowe 2010) have also found refrigeration to have a significant contribution to the overall figure, and indeed this is also seen in this study, with refrigeration emissions raising the CF figure considerably. The variation in refrigerant emissions is essentially due to the different refrigeration techniques. Vessels 1-5 in this study, being more modern and built post 2000 and the implementation of the Ozone Regulations (IOR, 2007), use Ammonia as a refrigeration system, which is known to have little environmental impact, while Vessels 6 and 7, being older and built before the 2000 regulations, still utilise R22 as a refrigerant. R22 is known to have a very high global warming potential and as a result was banned by the 2000 regulations from being used in new build ships, with a view to phasing it out completely from existing vessels by 2015. With this in mind the large contributions of the refrigeration emissions for these two vessels are put into context.

Despite this, two key points should be borne in mind when interpreting these results; first, as refrigeration could not be directly measured nor was leakage information known, estimated refrigeration values are based on the likely reference range offered by Seafish in their GHG Emissions Profiling tool (Detailed – V2: Seafish, n.d.). Also, following basic guidelines given by the PAS (BSI, 2012), a worst case scenario was assumed and the uppermost of the suggested range calculated for all vessels. This may or may not be reflective of true leakage values, however, the vessel engineers were not aware of any significant leakage from their vessels. Zeigler et al (2013) noted that modern vessels typically had only low levels of leakage suggesting that the value estimated in this study might be higher than the true value. Another important issue to consider is the date of the out-phasing of R22 as a refrigerant. While the profile presented here is considered to be representative of the study period, correspondence with the skippers of the vessels in question has confirmed that they will now be using the
ammonia method. As such, the contribution of refrigerants from their individual and overall fleet CF would be considerably reduced from 2015 onwards.

No correlation was seen between vessel size and fuel emissions, suggesting that vessel size does not play any significant effect on a vessels’ overall CF. The overall decrease in CF in 2014 is almost certainly due to the increased quota that was awarded in 2014 following the agreements between the Faeroe Islands, Norway and the EU (MSC, 2014). While an increase in fuel consumption was also seen, the resulting litres of fuel spent per tonne of fish landed was overall reduced.

Due to the small dataset, significant trends should be interpreted with caution. Despite this, a number of conclusions can be considered. While total fuel spent had no clear bearing individually on the overall CF, fuel intensity shows a clear significant relationship with it. This supports Parker’s (2012) assertion that fuel use can be used as a proxy indicator for CF, at least for the Shetland pelagic trawler fleet, providing that the landing rate is known and ammonia is the refrigerant used. This enables consideration of seasonal differences to simply focus on litres spent per tonne of fish landed, as all other contributions (consumables, fuel used in non-fishing periods, refrigeration leakage) would be allocated either as a 50/50 split or by mass of landings per species.

A partial positive correlation was found between fuel spent and quantity of fish landed with more variation than in litres per tonne and CF. This may be expected as an increase in fuel spent suggests more time at sea with the potential to catch more fish. However additional external factors would also have an affect here because fluctuation in the size of catches and the ease of locating fish.

In keeping with the expected, the larger catch was seen to be taken in the late season when the fish are passing nearby to Shetland and thus easier to access. A higher fuel consumption was also seen. Despite this no clear tread is seen in fuel intensity, with prominent inter- vessel fluctuations seen, some vessels favouring the early season while others favoured the late. Although it may be expected that catches of mackerel closer to Shetland would result in lower fuel intensity, this discrepancy is possibly explained by the tendency of the Shetland fleet to
land their catch outside of Britain. While Shetland is one of the most commonly used ports in Europe, UK ports collectively are notably less used than the collective ports of Norway. Landing outside the UK would remove any potential fuel savings from catching the fish close to Shetland.

Caution must be taken when considering the results for this stage of the analysis as accuracy of fuel purchased cannot be guaranteed to be representative of fuel spent. For the study as a whole this was not felt to be an issue as any discrepancy between fuel used and fuel bought would very likely even out over the study period. However when looking at such small and exact timescales as is seen when splitting by season, this becomes a possibility for inaccuracy.

4.2 Comparison of Results with Other Aquatic Meat Studies

On the whole the findings of this study are in keeping with the trends found in similar studies. As illustrated in Table 3, the results of this study indicate that the Shetland mid-water mackerel fishery has a considerably lower CF than that of demersal fish such as haddock, cod and farmed salmon. This is in keeping with the general trend for small pelagics to have one of the lowest CFs of all fish in general, and for pelagic trawling to have a lower footprint than demersal trawling.

**Table 3** Carbon footprint values for tonne of live fish caught or produced at farm gate expressed in tonne carbon dioxide equivalent (t CO\(_2\)e) over a 100 year period.

<table>
<thead>
<tr>
<th>Meat type</th>
<th>Place of study</th>
<th>Authors</th>
<th>Year of publication</th>
<th>Fishing method</th>
<th>Carbon Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Mackerel</td>
<td>Shetland</td>
<td>This Study</td>
<td>2015</td>
<td>Pelagic trawl</td>
<td>0.41</td>
</tr>
<tr>
<td>Atlantic Mackerel</td>
<td>Galicia</td>
<td>Irribaren et al</td>
<td>2011</td>
<td>Pelagic trawl</td>
<td>0.88</td>
</tr>
<tr>
<td>Atlantic Mackerel</td>
<td>Galicia</td>
<td>Irribaren et al</td>
<td>2011</td>
<td>Purse seine</td>
<td>0.61</td>
</tr>
<tr>
<td>Farmed salmon</td>
<td>UK</td>
<td>Pelletier et al</td>
<td>2009</td>
<td>Farmed</td>
<td>3.27</td>
</tr>
<tr>
<td>Farmed Salmon</td>
<td>Norway</td>
<td>Winther et al</td>
<td>2009</td>
<td>Farmed</td>
<td>2.00</td>
</tr>
<tr>
<td>Cod</td>
<td>Norway</td>
<td>Winther et al</td>
<td>2009</td>
<td>Mixed</td>
<td>1.60</td>
</tr>
<tr>
<td>Haddock</td>
<td>Norway</td>
<td>Winther et al</td>
<td>2009</td>
<td>Mixed</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Due to the deficit of publically available UK based research, comparisons had to be made looking at general European fisheries as a whole despite the differences noted from fishery-fishery and region-region (illustrated in Table 3). Additionally while mass allocation (where allocation was required) was favoured to allow for the most accurate comparisons, an exception was made for Pelletier et al (2009) to allow for the inclusion of another UK fishery based study. However despite these concessions it was felt that the comparisons still highlight the general differences between fish species and gear types.

The results of this study suggest that, in comparison with a similar fishery (Atlantic mackerel in Galicia caught by pelagic trawl) (Irribarren, et al, 2011), the Shetland fishery has a lower CF for the initial stage of its supply chain. However, the fishing fleet in the Galician study was relatively old and outdated and refrigeration leakage contributed significantly to the end figure. Despite this, the CF of the current study is still considerably lower, even when refrigeration leakage in the Galician fishery is taken into consideration. In contrast with the Galician fleet, the Scottish pelagic trawler fleet are highly modernised vessels, most of which (5/7) were build post 2000, the remaining two having been built 1996. This almost certainly has an effect on the efficiency of the vessels, with the more modern technology presumably aiding in fuel efficiency as well as dealing with the issue of refrigeration leakage (the two main contributors to the CF). While the current study’s findings were considered low in comparison both to other fisheries and to other European Atlantic mackerel fisheries, there are other fisheries that have considerably lower footprints still. Ramos et al (2011) showed quite a variation over their study period in CF (ranging from around 0.45 t CO₂e at its highest to under 0.1 t CO₂e at its lowest), however the highest value in their findings (in line with this study’s value of 0.41 CO₂e) was caused by a single year peak, with the other years showing values closer to the lower end of their range (from 0.2 CO₂e and below). This study noted an extremely low fuel usage for the fishery for which they credited the low CF values. As with their CF values the fuel showed a great degree of fluctuation in values over the study period from approx. 16.5 litres per live tonne (lpt) to 85.8lpt (assuming a fuel density of 0.885kg per litre). The Basque study’s highest average fuel consumption of 85.8lpt is similar to the lowest average fuel consumption of 76.2lpt reported for this study. The Basque study does note that it is considerably lower than other North East
Atlantic mackerel (NEAM) fishing regions, including those within the same country (e.g. Irribarren et al, 2011 - Ramos et al concluded that the environmental impacts in general are up to 88% lower in the Basque fleet, showing the dangers of extrapolating regional figures from specific fisheries) and Norway (with the Norwegian fishery coming in at 101.7 litres per tonne). They claim this is because of the specialised fishing season in the region with the fish being caught close to port at the exclusion of any other target species.

The results of the present study are similar to those reported in Norway. The Norwegian fleet, like the Shetland fleet, consists of large, modern vessels and has been reported as having a CF lower than most (Winther et al, 2009), suggesting that, while there are examples of more fuel efficient mackerel fisheries, Shetland’s figures for fuel combustion are still considered relatively low. Furthermore, if the assertion of Ramos et al (2011) about the reasons for the low fuel impact of the Basque region are correct, it suggests that the Shetland fleet could conceivably lower its emissions further by landing its catch to the nearest port – especially during the late season when the fish are passing closer to Shetland. However, it is acknowledged that there may be economic or other practical reasons preventing this from happening. To provide a comprehensive and more detailed view of the carbon footprint of the whole mackerel fishery, additional research into the various fishing methods utilised (e.g. Scottish seine and inshore mackerel handlining) is required along with a consideration of other national fleets utilising the same stock.

4.3 Comparison of Results with Terrestrial Meat Studies
The CF of terrestrial food systems has long been explored in both the media, with growing consumer awareness, and in scientific literature. There are difficulties in direct comparison of aquatic systems with that of terrestrial systems due to vastly different methods involved in the production of them. It can be argued that the only fair comparison would be in end of life CF or LCA studies to ensure all contributions are accounted for. Nonetheless, as with aquatic systems, terrestrial systems have typically found that the single largest contribution to most product chains is that of the initial stage (to farm gate/slaughter).
Because of regional variation, and to avoid the complication of post farm gate emissions, only studies considered the most relevant to the results of this study’s focus are shown in Table 4. The criteria for this was that it was a UK based study, ending at ‘farm gate’ or just prior to slaughter (measured in live weight), with preference given to the most recent study available. The variation shown in the table is reflective of the different farming methods investigated in the studies. It should be noted that the chosen allocation method typically used for terrestrial meat studies differs from that of the aquatic, with economic allocation or by protein/energy content preferred over general mass, as the difference in allocation methods has been shown to have an effect on the overall LCA of a product (Svanes et al, 2011). As such, caution should be used when comparing figures. However, a general theme is evident, with even the lowest values (pork and chicken) showing a figure distinctly higher than those reported for the Atlantic mackerel in this study. This conclusion is supported by additional research by Scarborough et al (2013) who noted a positive relationship between personal CF (the carbon footprint created by a specific individual in a year) and the quantity of meat eaten, with fish eaters found to have a lower CF in general than full meat eaters, very closely followed by vegetarians and then vegans. This study does not however list the typical diet of a ‘fish eater’ so it is unclear if it consists more of the higher CF value species (often the more commercial ones such as cod and prawns) or not. There is debate however as to whether the difference in personal CF is actually connected to the chosen protein source or if awareness of sustainable produce is the key factor (Risku-Norja et al, 2009).

Whether reflective of fish eaters having a lower CF diet than that of traditional meat eaters or simply the result of more informed consumer choice, it is in keeping with the findings of this study. Mackerel, as has been demonstrated in this study and many others, has a very low CF in comparison to other fish species and under current guidelines is accepted as being sustainably harvested (currently in the process of MSC assessment for recertification). Therefore an increase of mackerel in the diet (assuming it is in replacement of other high emission meats and within safe harvesting limits) could be beneficial both in increasing omega three oils in the diet but also in lowering the consumer’s personal footprint. Additionally as only around 30.6 % of people eat the government advised 2 portions of fish a week (Clonan, et al 2012), mackerel
promotion could help both achieve this goal while promoting sustainable protein choices in general and promoting fish in particular.

Table 4 Carbon footprint values for UK based meat systems expressed in tonnes of carbon dioxide equivalent per tonne of live weight.

<table>
<thead>
<tr>
<th>Meat type</th>
<th>Place of study</th>
<th>Authors</th>
<th>Year of publication</th>
<th>Carbon Footprint</th>
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<tbody>
<tr>
<td>Atlantic mackerel</td>
<td>Shetland</td>
<td>This study</td>
<td>2015</td>
<td>0.41</td>
</tr>
<tr>
<td>Beef</td>
<td>UK</td>
<td>EBLEX as per APPG on Beef and Lamb</td>
<td>2013</td>
<td>10.60-19.20</td>
</tr>
<tr>
<td>Sheep</td>
<td>UK</td>
<td>EBLEX as per APPG on Beef and Lamb</td>
<td>2013</td>
<td>11.00-13.60</td>
</tr>
<tr>
<td>Chicken</td>
<td>UK</td>
<td>Williams et al</td>
<td>2006</td>
<td>4.57 - 6.68</td>
</tr>
</tbody>
</table>

5 Conclusion

This study has found the Shetland Atlantic mackerel pelagic trawl fishery to have a comparably low CF at the point of landing in comparison both to other fisheries and terrestrial meat systems to a similar end point. This was found to be in keeping with other studies that show small pelagic species and pelagic trawl fisheries in general to have a low CF value. Though refrigerants do play a large part in the current estimation of CF for the Shetland fleet, this is caused by a minority of vessels and will no longer be the case as of 2015 and the implementation of new regulations regarding systems. Once refrigeration leakage has been omitted, fuel consumption is the single main contributor to the CF, both for the fleet as a whole
and for individual vessels. As a result, any steps to further reduce fuel consumption will have a positive effect on the fleet’s CF.

Although larger quantities of fish were landed in the later season, there was no noticeable trend in fuel intensity between the two. This is most likely due to the fleet’s preference for landing fish out-with the UK, removing any advantage of fishing close to Shetland as the fish pass during migration. Although there are undoubtedly economic reasons for this preference, if mackerel was landed locally more frequently, fuel consumption and subsequent CF would almost certainly be reduced.

Unfortunately it was concluded at an early stage that a CF for the inshore mackerel fishery of Shetland was not feasible as part of this study, but it is recommended that this be considered for future study to allow for a comparison between the two methods and a more complete figure for the Atlantic mackerel fishery of Shetland as a whole.
6 References


11. EPLCA (2009) *CARBON FOOTPRINT - what is it and how to measure it.* JRC European Commission


