Carbon Footprint Report No.3

Green Development Strategy Project

Carbon Footprint of the Inshore Creel Fishery

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CF- Carbon Footprint	**GWP-** Global Warming Potential
CPUE- Catch per unit effort	**LCA**- Life Cycle Assessment
EMFF- European Marine Fisheries Fund	**LPUE**- Landed per unit effort
GHG- Greenhouse gas	**MLS**- Minimum landing size
OFA- Orkney Fisheries Association	

1. Executive Summary

This report was conducted through funding from the EMFF to identify the seasonality of the inshore fishery in Orkney and to help support the sustainability of the fishing industry. Creel fishing in Orkney is a mixed enterprise with target species including Brown crab (*Cancer pagarus*), Velvet crab (*Necora puber*), Green crab (*Carcinus maenas*) and European Lobster (*Hommarus gammarus*). This makes management of such a diverse, dynamic and fluctuating fishery more complex than others. This report aimed to investigate the carbon footprint (CF) of the inshore creel industry. Further to this it aimed to evidence the amount of fuel use and current use and outlay of gear, labour on repair and loss of gear was to also be investigated. From these results it is hoped that pathways to change could be identified and 'greener' fishing techniques could be adopted to further enhance the sustainability of the shellfish industry.

With increasing concerns over the effect of climate change, it is important to consider the wider impacts that fishing has on the ecosystem. The inshore creel industry is a vital resource to Orkney economically and socially, therefore taking steps to identify and reduce carbon footprint could help reduce impact as well as enable fishermen to act as responsible users of the sea. The inshore creel fishery for Orkney is presumed to have a low CF given the nature of creel fishing and results from limited studies which have investigated LCA in creel fishing. Data was collected from fishermen's questionnaires, through direct figures generated from landing data to buyers and fuel purchase track history from a fuel supplier.

Results from this study found that CF values generated (3.557t CO_2e) were uncharacteristically high for the catch to landing phase of the Brown crab fishery, in comparison to other fish and meat product industries. Due to only Brown crab landings analysed for the inshore fishery, had total landings of other species been taken into account this could have offset the overall CF as a higher landing weight would have been generated for the amount of fuel consumed on fishing trips. Limitations within the model prevented this from being investigated. Fuel consumption by vessels was shown to vary due to season, travel distance, and species targeted. Gear outlay was found to be substantial however proper care and maintenance of gear was found to reduce costs and replacement. Overall for the inshore shellfish industry the greatest contributor to CF was fuel consumption. Efforts to reduce and monitor fuel consumption along with carbon offsetting such as recycling can help in developing greener pathways to change which can be adopted by fishermen to further reduce CF and increase sustainability.

Key words: Creel Fishing, Carbon Footprint, Fishing activity, Sustainability, Climate Change, Shellfish

2.1 Introduction

Fishing provides an enormous benefit to people locally and worldwide. The industry is the starting point for supply chains of local, regional and global significance (Avadi and Freon, 2013). Worldwide the seafood industry generates over 180 million jobs supporting the livelihood of 8% of the world's population (SOFIA, 2012). From this over 80 million metric tons of seafood is harvested per year which provides more than 20% of the needed animal protein to feed nearly 3 billion people (FAO, 2014). As such, environmental impacts caused by seafood production systems and overall sustainability are receiving increased attention from consumers, retailers, conservation organisations and industry itself (Ziegler *et al*, 2013). Environmental impacts have mainly addressed aspects of fishing associated with the removal of target and non-target species, changes in marine food webs, adverse effects on marine birds and mammals and impacts on marine ecosystems related to changes to benthic environments from fishing practices such as trawling (Avadi and Freon; FAO, 2003). However, the negative impacts of climate change have seldom been addressed regarding sustainability. As well as being negatively affected by climate change, fisheries themselves may be a significant contributor to global warming emissions during fishing operations, transport, processing and storage of fish (Tyedmers, 2004).

Climate change is notably already influencing fisheries and fisheries management. Changes already encountered include variation in temporal and spatial distribution of fish abundance, changes in productivity, invasion of alien species, reduction in ocean productivity and increased ocean acidity (Gaines *et al* 2018; Parker, 2012; Tyedmers, 2004). The oceans act as a sink for carbon dioxide (CO_2) as it currently absorbs one-third of the CO_2 entering the atmosphere from activities such as the burning of fossil fuels. Oceans are acting as a sink at an increased rate greater than ever before (Seafish, 2009).

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). Increased consumer awareness on the state of fish stocks has led to the development of indicators and certifications or labels, like those used by Marine Stewardship Council's 'blue tick' to highlight a sustainably managed fishery (Sandison, 2015). There is also an increasing political and scientific drive to sustainably manage all aspects of fisheries resources. The Scottish government has therefore committed to reduce the UK's greenhouse gas emissions by at least 80% by 2050 as described through their Climate change plan (Scottish Government, 2018).

2.2 Carbon Footprint and Life Cycle Assessment

A carbon footprint (CF) relates to how much greenhouse gas (GHG) is emitted by the burning of fossil fuels from the creation of a product through to the end of its life (EPLCA, 2009). Carbon footprint is expressed in its global warming potential (GWP). GWP was developed to allow comparisons of the global warming impacts of different gases and measures how much energy the emissions of 1 ton of gas will absorb over a period of 100 years (EPA, 2018). This common unit of measure allows emissions estimates of different greenhouse gases to be compared (EPLCA, 2009). Carbon footprints are therefore measured in terms of kilos or tonnes of CO_2.

The life cycle assessment (LCA) is a framework for environmental assessment of a food system based on the International Organisation for Standardisation (ISO). LCA is a method used to address concerns of environmental impact originating from the generation of products and services and ultimately how to reduce these negative impacts (Avadi and Freon, 2013). Environmental impacts resulting indirectly from fishing operations are mostly associated with energy used in extraction of fish, and of natural materials and fossil fuels used for the construction, use and maintenance of fishing units. Indirect impacts result from emissions related to fuel combustion, release of antifouling substances, cooling agents, provision and loss of fishing gear, further transportation after landing, wastewater, release of cleaning agents and refrigerant gases (Avadi and Freon, 2013).

CF is considered as a subset of LCA and is closely related to fisheries LCA due to the strong impact of fuel usage on the single impact category considered by CF: global warming (Avadi and Freon, 2013). Both LCA and CF evaluations can be made on the environmental impact related to products over their whole life cycle (cradle-to-grave), as highlighted in figure 1 where GHG's can occur at any stage of the life cycle. A 'cradle to gate' analysis can also be conducted whereby the impacts of a product are only considered for only part of the lifecycle, typically of a product at the beginning of its life through to the end of the first stage before it passes onto a different system. When this is applied to fishing, a cradle to gate analysis would consider the environmental impacts of the fish from capture to landing or processing, leaving distribution and retailers as separate stages in the assessment (BSI, 2011; Sandinson, 2015). In using a cradle to gate analysis it can be useful to in identify areas of improvements towards emissions at specific points within the fishing systems.

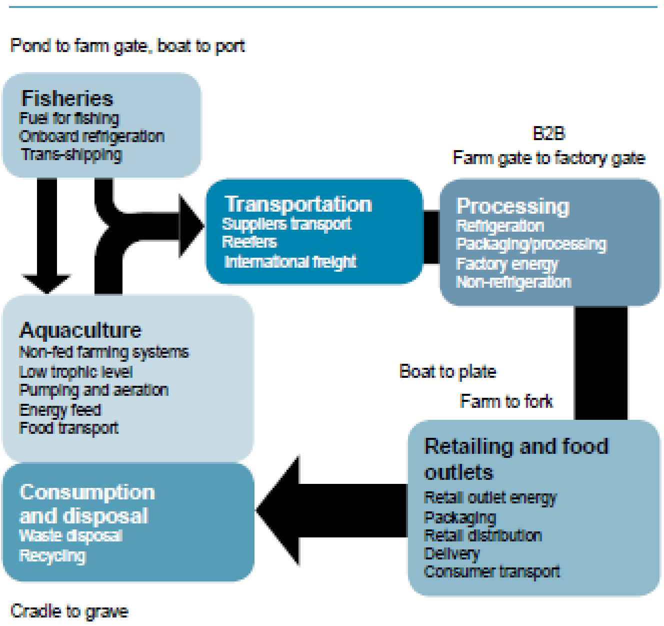


Figure 1. Adapted from SeaFish, 2014. Emissions during different stages of fisheries and aquaculture systems from cradle to grave and cradle to gate.

Emissions rates can vary at different stages within the seafood supply chain and differ between the fishing methods (Figure 2). During capture fisheries, common finds include fuel use and refrigerants which were the most important contributors to the total CF (Zielger *et al*, 2013). For fishermen of various fisheries, fuel consumption is influenced by the fishing gear and technology used, natural abundance of resource, stock status and steaming distance to fishing grounds (Avadi and Freon, 2013; Thrane, 2004; Zielger *et al*, 2013). Further influences include spatio-temporal availability of catchability (level of aggregation, depth, distance from the coast etc), management regime, skill of the vessel crew, proportion of by-catch or hull technology (Avadi and Freon, 2013; Zielger *et al*, 2013). Tyedmers 2004, suggested that during the last half of the 20th century the amount of energy consumed increased noticeably as fleets expanded and many fish stocks declined. Therefore, CF is often linked to these other impacts (Zielger *et al*, 2013).

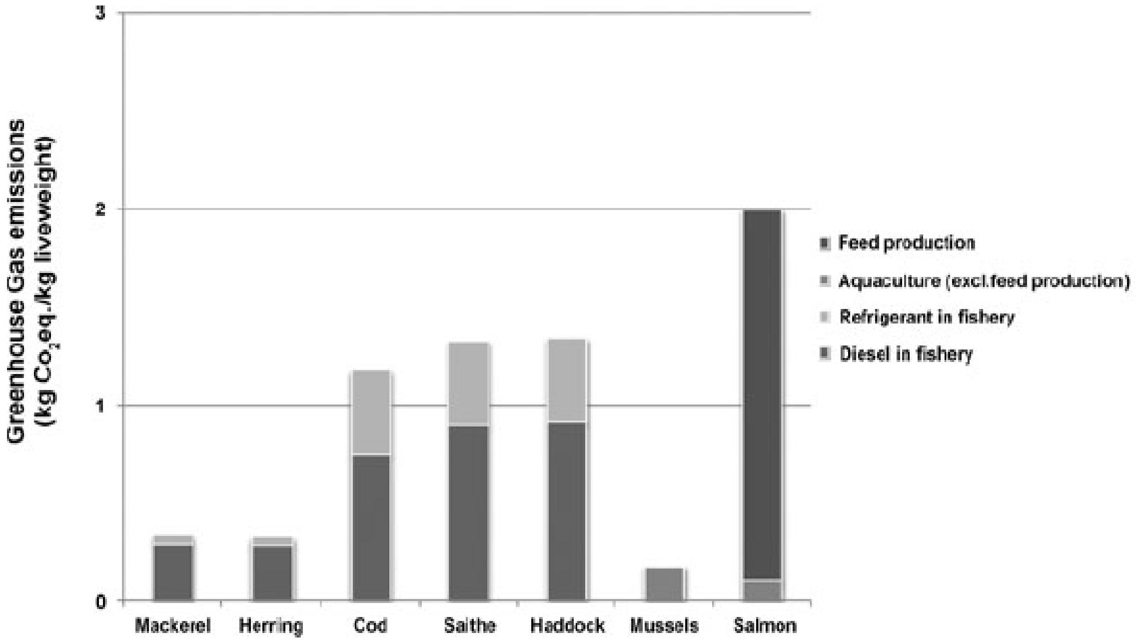


Figure 2. Adapted from Ziegler *et al*, 2013. GHG emissions for the seven types of seafood studied for the carbon footprint of Norwegian seafood products on the global seafood market up to landing stages. Attention to diesel and refrigerant use only appear in the first five fisheries.

Within the rest of the seafood supply chain, processing and packaging contribute very little to overall emissions, often under ten percent of the total. Processing and transportation are generally of low importance, the exception being airfreight (Zielger *et al*, 2013). Therefore, the distance and the mode of transport must be considered as well as the state of the product. An effect on the carbon footprint is noted when fresh products are transported over short or long distances by air or frozen products are transported over long distances (Ziegler *et al,* 2013). This is displayed in figure 3, whereby it can be seen that choosing a more a more climate friendly mode of transport by shipping rather than airfreight could reduce overall GHG production (Zielger e*t al*, 2013).

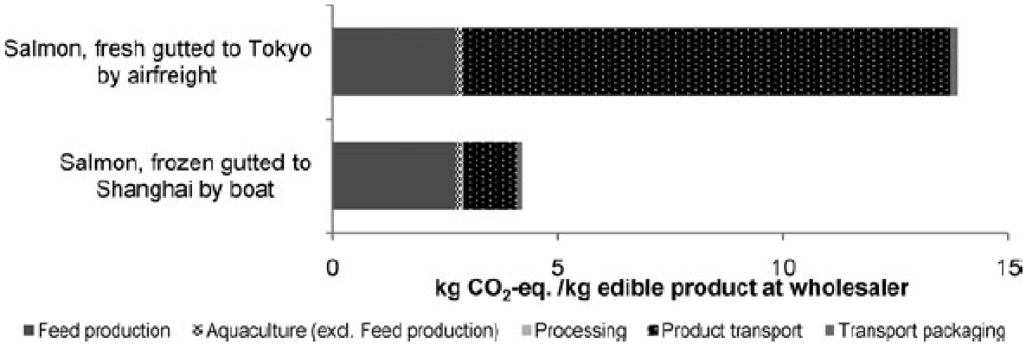


Figure 3. Adapted from Zielger *et al*, 2013. Comparison of supply chain emissions from fresh salmon taken to Tokyo by airfreight and frozen Salmon taken to Shangai on a container freighter (kilograms of GHG per kilogram edible product [kg GHG/kg edible product] at wholesaler). Designations are approximately the same transport distance from Norway.

2.3 Carbon footprint in the fishing industry

Since the mid 1990's increased attention towards LCA has been applied to aquaculture and fisheries research. Most of these studies have focussed on whitefish fisheries in the Northern hemisphere with less attention directed towards pelagic and shellfish fisheries (Seafish, 2014). As previously mentioned, fuel use is the greatest single source of most environmental problems among all inputs to fishing activities (Avadi and Freon, 2013). Fishing operations emit GHG's firstly as a waste product of fuel combustion and secondly through facilitating of other essentials like ice, gear and the construction and maintenance of vessels e.g the use of anti-fouling and chemical agents (Driscoll and Tyedmers, 2010). The fleet's GHG intensity (the total GHG emissions associated with a fishery per unit of catch landed) is strongly related to its fuel intensity (the fuel per unit of catch landed) (Driscoll and Tydemers, 2010).

Fuel consumption rates therefore vary greatly according to the type of fishing gear used and the fishing practice (Thrane, 2004; Tyedmers *et al*, 2005; Winther *et al*, 2009). Approximately 620 L of fuel (572kg) is used per tonne of landed fish (Tyedmers *et al*, 2005) and every tonne of fuel produces 2.25 tonnes of CO_2 (SeaFish, 2009). In studies conducted it was found that passive fishing gears such as pots, traps, long-lines and gillnets usually require on average less fuel (0.1-0.4L of fuel per Kg of catch) than active fishing gears such as bottom trawling methods (from 0.5 up to 1.5L/Kg) (Avadi and Freon, 2013; Suuronen *et al*, 2012). For the fishing method of bottom seines, fuel consumption ranks in between passive gear and bottom trawling (Runarsson, 2008). Due to the schooling behaviour of fish, active pelagic trawls and purse seining can catch large amounts of fish with one short tow or haul (Suuronen *et al,* 2012). This reduces fuel consumption for this method of fishing compared to the quantity of the catch, approximately 0.1L of fuel per kg of catch (Suuronen *et al*, 2012).

Very few studies have focussed on the carbon footprint of harvesting shellfish or the fishing method using creels. One study to conduct an LCA was Zigler and Valentisson (2008) in which they compared two fishing methods, creeling and conventional trawling, for Norway lobster (*Nephrops norvengicus*) in the Swedish west coast fisheries. The study demonstrated how LCA can be used to compare the environmental performance of different segments of a fishery. Within their study they conducted a sea floor impact assessment and a fuel use and discards assessment in the two fishing methods for the functional unit of 1kg of Norway lobster. Their results found major differences between the fishing methods with regards to environmental impact. Creeling was found to be more species selective, with fewer discards and lower fuel use and seafloor impact. Although this method of fishing did have poorer working and safety conditions and potential risk for ghost fishing.

Energy use (Figure 4) to catch 1 kg of Nephrops using trawling was found to use 325 MJ of energy in the form of diesel, while creel fishery only used 80MJ (of which 10% originated from the bait herring fishery) (Zigler and Valentisson, 2008). The fishing phase for both methods clearly shows the highest use of energy within the life cycle of cradle to grave. In the creel fishery, Norway lobster represents 97% by weight and 99% by value of the landings and 2.2 litres of diesel were used per kilogram f Nephrops landed. In the trawl fishery, Nephrops represents 27% by weight and 59% by value of the catch and 9.0 litres of diesel were used per kilogram of Norway lobster landed. The impact assessment results (Table 1) also showed the process of fishing as the dominant factor in environmental impact for both methods. Again, Nephrops caught using creels were substantially lower in impacts as diesel combustion and production were lower. Overall this study highlighted the efficiency in using creels compared to trawls and that further movement towards species selective trawls would benefit the fishery (Zigler and Valentisson, 2008).

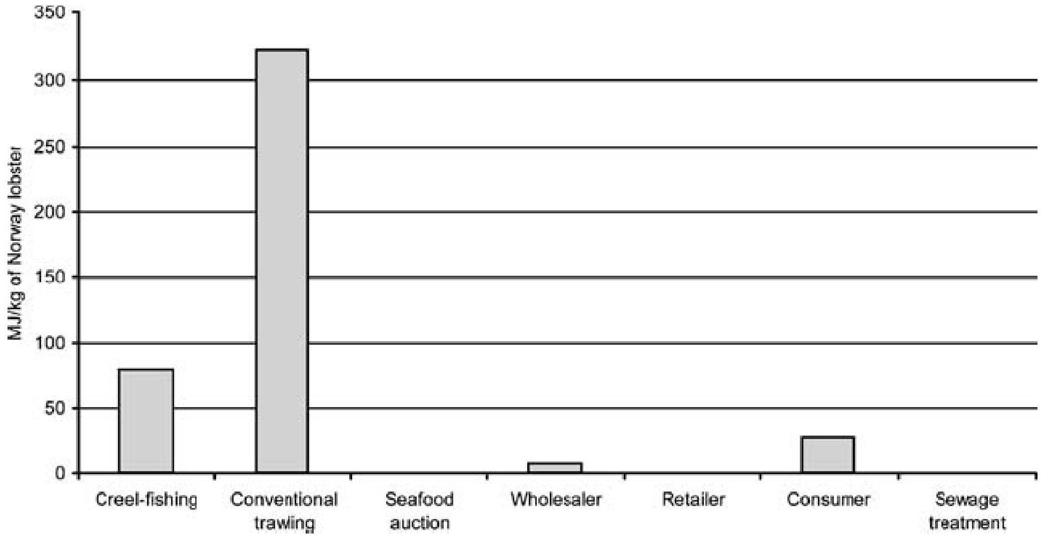
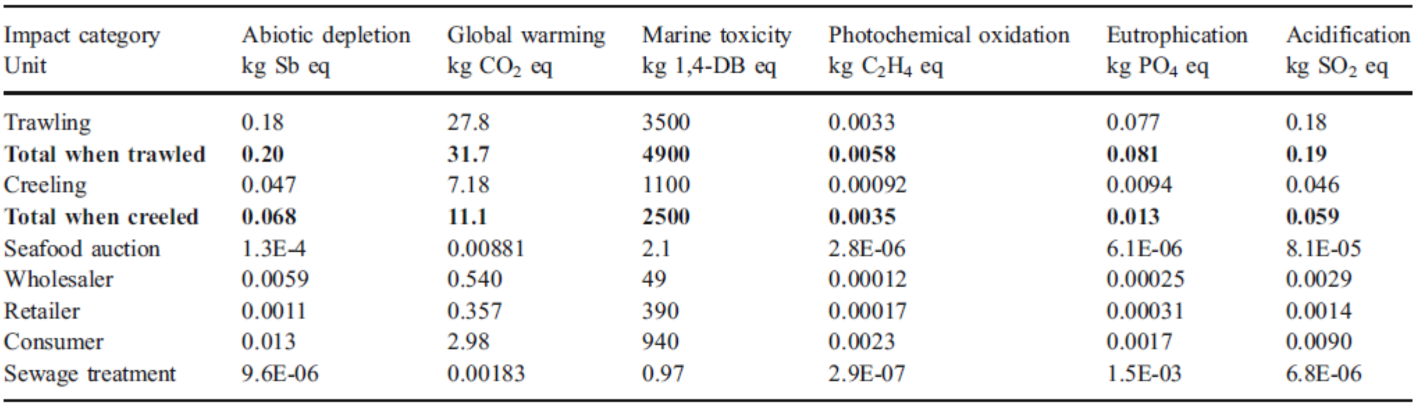


Figure 4. Adapted from Ziegler and Valentinsson, 2008. Energy use in the life cycle of a kilogram of a Norway lobster (MJ/Kg).

Table 1. Adapted from Ziegler and Valentinsson, 2008. Impact assessment results for a kilo of Norway Lobster (or 300 grams of tails) from the sea to table delivered by the two fishing methods.



Impact category Unit	Abiotic depletion kg Sb eq	Global warming kg CO$_2$ eq	Marine toxicity kg 1,4-DB eq	Photochemical oxidation kg C$_2$H$_4$ eq	Eutrophication kg PO$_4$ eq	Acidification kg SO$_2$ eq
Trawling	0.18	27.8	3500	0.0033	0.077	0.18
Total when trawled	**0.20**	**31.7**	**4900**	**0.0058**	**0.081**	**0.19**
Creeling	0.047	7.18	1100	0.00092	0.0094	0.046
Total when creeled	**0.068**	**11.1**	**2500**	**0.0035**	**0.013**	**0.059**
Seafood auction	1.3E-4	0.00881	2.1	2.8E-06	6.1E-06	8.1E-05
Wholesaler	0.0059	0.540	49	0.00012	0.00025	0.0029
Retailer	0.0011	0.357	390	0.00017	0.00031	0.0014
Consumer	0.013	2.98	940	0.0023	0.0017	0.0090
Sewage treatment	9.6E-06	0.00183	0.97	2.9E-07	1.5E-03	6.8E-06

Closer to Orkney, estimations of the carbon footprint of the Shetland fishery for Atlantic Mackerel (*scomber scombrus*) have been conducted for the pelagic trawling fishery in 2012-2014 (Sandinson, 2015). Results found from this estimated the CF of this fishery to be 0.41t CO$_2$e per tonne of fish landed. The majority of which (0.283t CO$_2$e) was due to fuel consumption while gear and maintenance contributed very little to overall CF (0.002t CO$_2$e). It was also established that in comparison to other fisheries (Table 2) the CF for pelagic trawled Atlantic Mackerel was relatively low and that fuel consumption and refrigerant leakage was the largest contributors to overall CF. It is thought the low CF is due to a highly modernised Scottish fleet which will contribute towards the efficiency of the vessels but also the use of more modern technology combining to result in relatively low fuel combustion (Sandison, 2015). In comparison to terrestrial meat production (Table. 3), the CF of the Atlantic Mackerel fishery is significantly lower than the lowest meat values (chicken and pork). It was therefore suggested that increasing the amount of sustainably caught mackerel to people’s diet (in replacement of other high emission meats) could be beneficial for the increased intake of omega three oils but also lowering the consumer’s CF (Sandison, 2015).

Table 2. Adapted from Sandison, 2015. Carbon footprint values for tonne of live fish caught or produced at farm gate expressed in tonne carbon dioxide equivalent (t CO_2e) over a 100 year period.

Meat type	**Place of study**	**Authors**	**Year of publication**	**Fishing method**	**Carbon Footprint**
Atlantic Mackerel	Shetland	This Study	2015	Pelagic trawl	0.41
Atlantic Mackerel	Galicia	Irribaren et al	2011	Pelagic trawl	0.88
Atlantic Mackerel	Galicia	Irribaren et al	2011	Purse seine	0.61
Farmed salmon	UK	Pelletier *et al*	2009	Farmed	3.27
Farmed Salmon	Norway	Winther *et al*	2009	Farmed	2.00
Cod	Norway	Winther *et al*	2009	Mixed	1.60
Haddock	Norway	Winther *et al*	2009	Mixed	1.75

Table 3. Adapted from Sandison, 2015. Carbon footprint values for UK based meat systems expressed in tonnes of carbon dioxide equivalent per tonne of live weight.

Meat type	**Place of study**	**Authors**	**Year of publication**	**Carbon Footprint**
Atlantic mackerel	Shetland	This study	2015	0.41
Beef	UK	EBLEX as per APPG on Beef and Lamb	2013	10.60-19.20
Sheep	UK	EBLEX as per APPG on Beef and Lamb	2013	11.00-13.60
Pork	England	Kool, *et al*	2009	3.50 – 4.40
Chicken	UK	Williams *et al*	2006	4.57 - 6.68

Fossil fuels are now the most dominant energy input into most of the world's fisheries. Subsequently, diesel, gasoline and kerosene, which power vessels, are now attributed to most global fisheries landings (Tyedmers *et al*, 2005). Fuel price increases, combined with future scarcity of fossil fuels and pollution have raised awareness about the efficiency use of this energy type (Cheilari *et al*, 2013). The oil price shock of 1973 and increased oil prices in 2007 and 2008 have highlighted concerns over the dependency and efficiency of energy consumption. In 2000, global fisheries burned 50 billion litres of fuel in the process of landing 80 million tonnes of marine fish and invertebrates for just an average rate of 620 Lt^{-1} (Tyedmers *et al*, 2005). As a result, fisheries accounted for 1.2 percent of the global oil consumption (Tyedmers *et al*, 2005). The variability in productivity of the world's oceans has meant that most of the energy expended is concentrated in the fishing grounds in the Northern Hemisphere, also reflecting the industrialised fishing effort in these areas. Included in these areas was the coastal waters of the north eastern and southwestern Atlantic (Tyedmers *et al*, 2005). Therefore, in terms of energy efficiency global fisheries dissipated 12.5 times the amount of fuel energy as they provided in the form of edible-protein energy (Tyedmers *et al*, 2005). This 8 percent return on energy seems low but in comparison to other food production it is high as in comparison to beef (2.5-8%), pork 7.1% and lamb 1.5 % (Pimentel, 2004).

As previously mentioned, different fishing operations use different amounts of fossil fuels and therefore have different degrees of GHG emissions. However, there are three main energy flows on board most commercial fishing vessels; a diesel engine for propulsion, a diesel generator for electrical demand and a net winch or pot/trap hauler (Thomas *et al*, 2010). Direct fuel inputs are mainly used for vessel propulsion. Secondary energy consuming activities include onboard processing, refrigeration and freezing which can contribute to a proportion of fuel burned (Thomas *et al*, 2010). Consequently, ways in which to reduce fossil fuels in fishing operations has become a major focus in fisheries technology-driven research due to increasing oil prices and need for increasing efficiency. In this way, the use of antifouling paints plays a low-cost role in the reduction of GHG's.

Antifoulants help prevent the settlement and growth on submerged areas of vessels such as hulls and propellers. Fouling on these areas can cause increased friction between them and the seawater. This in conjunction with increased weight from fouling can result in increased fuel consumption and therefore increased GHG emissions (Demirel *et al*, 2013). A layer of algal slime which is estimated at 1mm thick on a ship's hull can increase friction by 80% and a 15% loss in a ship's speed (Evans *et al*, 2000). Most antifouling applications are in the form of paints which contain toxic chemicals which form a toxic layer around the vessel in the water, preventing the attachment of fouling agents such as barnacles and weed (Demirel *et al*, 2013). Therefore, the investment of time and energy in the application of antifouling on vessels can help reduce a vessel's fuel consumption and ultimately the carbon footprint.

2.4 Fishing activity in Orkney

In 2016, the total value of all fish landed by Scottish vessels was £557 million (Scottish Sea Fisheries Statistics, 2017). The value of shellfish landings by Scottish vessels has seen an increase from 2015 to 2016 of 21 percent to £166 million and accounted for 14 percent of landings by quantity (64 thousand tonnes (Scottish Sea Fisheries Statistics, 2017). Orkney in 2016 landed 4,936 tonnes of shellfish which valued at £9,135,000. Table 4 shows the quantity and value of lobster and crab species landed into Orkney in 2016. This in turn supports a fishing fleet in Orkney waters of 131 actively registered vessels, 199 regularly employed and 93 irregularly employed fishermen (Scottish Sea Fisheries Statistics, 2017).

The inshore fishery amongst Orkney's archipelago is diverse and complex characterised by strong tidal flows. The inshore fishery is dominated by a mixed fishery fleet of 91 boats 10m and under. Orkney's mixed fishery is made up of numerous target species including Brown crab (*Cancer Pagarus*), Velvet Crab (*Necora puber*), Green Crab (*Carcinus maenas*), European Lobster (*Hommarus gammarus*), Nephrops (*Nephrops norvegicus*), Whelks (*Buccinum undatumn*), King Scallops (*Pecten maximus*) and Queen Scallops (*Aequipecten opercularis*). Scallops in Orkney are fished for using both hand diving and dredge fishing methods. The main method of shellfish capture is through baited creels. In addition there are hand lines for fin fish such as mackerel with further potential to catch other species such as Cod (*Gadus marhua*) and Haddock (*Melanogrammarus aeglefinus*). However, the main shellfish species landed in Orkney is targeted towards Lobsters, Brown Crab, Velvet and Green Crab, as seen in Table 4. of which conservation measures exist for these species in the form of various minimum landing sizes (MLS).

Table 4. Quantity and value of commercial species landed into Orkney in 2016, adapted from Scottish Sea Fisheries Statistics, 2017.

	Quantity (tonnes)	Value (£'000)
Lobster (*Homarus gammarus*)	102	1,286
Edible Crab (*Cancer pagarus*)	3,404	4,769
Green Crabs (*Carcinus maenas*)	80	58
Velvet Crab (*Necora puber*)	393	1,210
Scallops (*Pecten Maximus*)	379	1,197
Whelks (*Buccinum undatumn*)	452	410

Further fishing around Orkney waters also includes fishing for whitefish with three Orkney registered whitefish fishing vessels. However, Orkney has no designated landing port or fish market, therefore landings operate at other local registered ports such as Shetland, Scrabster, Fraserburgh, Peterhead, Aberdeen or ports on the West Coast of Scotland. The quantity and value of demersal and pelagic fish landed into Orkney can be seen in table 5. Mackerel quantities can be seen to increase in this table from 2014. This was due to the Scottish government launching a trial to expand the fisheries in the inshore waters through allocating 10 meter and under vessels in the non-sector access to 1,000 tonnes of North Sea Mackerel (Marine Scotland, 2017).

Table 5. Adapted from Scottish Sea Fisheries Statistics, 2017. Quantity and value of total demersal and pelagic fish landed into Scotland from 2012 to 2016.

	Quantity (tonnes)					Value (£'000)				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Total demersal	40	33	19	24	6	52	38	61	38	19
Total pelagic (Mackerel)	13	7	41	37	36	20	4	25	17	22

Processing of shellfish in Orkney is conducted through the Orkney Fishermen's Society in Stromness. It was established in 1953 and is one of the foremost processors of Brown crab in the UK. This co-operative handles the largest share of Orkney's Lobster, Velvet and Brown crab catches from ports of Stromness, Tingwall and Kirkwall, along with the islands of Westray, Sanday, Stronsay, Rousay and Hoy. Westray also has its own processor (Westray Processors Ltd) which was established over 40 years ago to handle the production of fresh and frozen crabmeat from the local fishing fleet.

2.5 Aims of Report

With increasing concerns over the effects of climate change, it is important to consider the wider impacts that fishing has on the ecosystem. The inshore creel industry is a vital resource to Orkney economically and socially, therefore taking steps to identify and reduce carbon footprint could help reduce impacts as well as to act as responsible users of the sea. The inshore creel fishery of Orkney is presumed to have a low CF given the nature of creel fishing and limited studies which have investigated LCA in creeling.

The aims of this project are as follows;

- To investigate the CF of the inshore creeling fishery within Orkney from cradle (point of fishing) to gate (landing of shellfish).
- Identify fuel use of inshore creel fishing fleet.

- Evidence of current use of gear, outlay on gear, labour on repairs and loss of gear, replacement costs of gear.
- Area covered by fuel consumption
- Identify pathways in which to reduce CF

In future assessments a full LCA should be considered to address all aspects of the fishery (cradle to grave) as improvements could be made where one sector may affect another. At this time a carbon footprint profile is the first step in the analysis of this fishery, further assessment would also address all harvested inshore shellfish.

3. Methodology

For this study the CF of the inshore creel fishing industry will focus on the capture-landing phase of Brown crabs (*Cancer pagarus*) and Velvet crabs (*Necora puber*). The CF will address the cradle to gate sector of the shellfish lifecycle, defined as the point of landing. This will not include construction phase of the vessel as it has been found in previous studies that its overall contribution to environmental impacts is negligible (Ziegler *et al*, 2003).

A questionnaire was sent out to all members of Orkney Fisheries Association that currently use creel fishing methods in Orkney. Table 6 summarises the fishing inputs and outputs asked for in the questionnaire in which fishers were asked to approximate for and identify any difference between fishing in summer and winter months. A total of 9 vessels provided enough statistically robust data to allow for analysis which also covered a range of vessel sizes and diversity of fishing areas covered within Orkney.

Table 6. Data collected during questionnaires on vessels average fishing inputs and outputs.

Fishing Inputs	**Fishing Outputs**
Gear Consumables: • Creels- number, age, life expectancy, maintenance, use of anodes. • Nets • Lines/hooks • Rope – type and quantity.	Catch • Landed catch • Landed bycatch
Cooling materials: • Refrigeration	Emission • Fuel emissions
Engine • Size • Age of Engine • Make/Model • Service hours	

Fuel use • Type • Capacity of tanks • Steaming speed • No. of fishing days per year • Quantity used per day • Max. travel distance from port • Average fishing hours • No. of creels hauled per day • Average sort time per rope	
Materials used for maintenance • Lubricating oil • Anti-fouling agents • Cleaning agents	
Vessel information • Name and PLN • Length • Year was built • No. of active fishing years	

Data analysis of GHG emissions was conducted using the SeaFish GHG Emissions profiling tool online in partnership with Dalhousie University [http://profiler.fantata.com/index.php]. The tool used is to provide insight into the carbon implications of seafood provision and give a better understanding of the major contributors to the carbon footprint of seafood products. Insight is also given into the influences of different aspects of the seafood production chain and their effect on final GHG emissions. The tool follows the BSI PAS2050-2 standard for assessing GHG emissions in seafood and other aquatic food products. The profiling tool addresses major potential drivers of emissions including direct fuel inputs to fishing, form and scale of transport used and the amount of time seafood products are held in cold storage. Further to these are emissions associated from bait acquisition, storage, refrigerants, electricity use and packaging.

For this study GHG emissions for Orkney inshore Brown crab fishing using creels was conducted using the described profiling tool. The starting point of the process was the catch phase and the end point of the chain was when the product was landed. Yield of fish landed to fish caught was estimated at 100%. While yield of final processed fish (weight of fish product) to fish into processing (landed weight) was indicated at 30%. The fraction of co-products was 70% obtained from fish into processing. Energy consumption in the fishery was identified as energy used within fishing methods to catch shellfish and crabs by traps. According to SeaFish information this fishing method is likely to have direct fuel inputs of between 100 and 1200 litres to each landed one tonne of live weight. The value of 700 litres fuel per live tonne was used to represent the fishery based on their evidence. No onboard refrigeration systems were noted on any of these vessels, therefore no refrigerant emissions were present in this fishery. Bait consumption was recorded as fish sourced from pelagic fisheries. According to SeaFish information, typical GHG emissions for this bait are estimated to be 0.98kg CO_2 equivalents per tonne of bait produced and delivered. An estimated 36kg of bait is used per tonne of caught live weight. No packaging was use on board the fishing vessels, this was added once products were landed after processing. Materials to maintain fishing operations was estimated as 110kg of plastic used in fishing gear that were replaced annually. An estimation of 330kg of metal (steel, lead etc) was used to replace fishing gear annually and 10kg of lubricants and non-fuel oil used on the fishing vessel annually. Information associated with other stages of process such as transport, packaging and ingredients added were not considered as this was post landing.

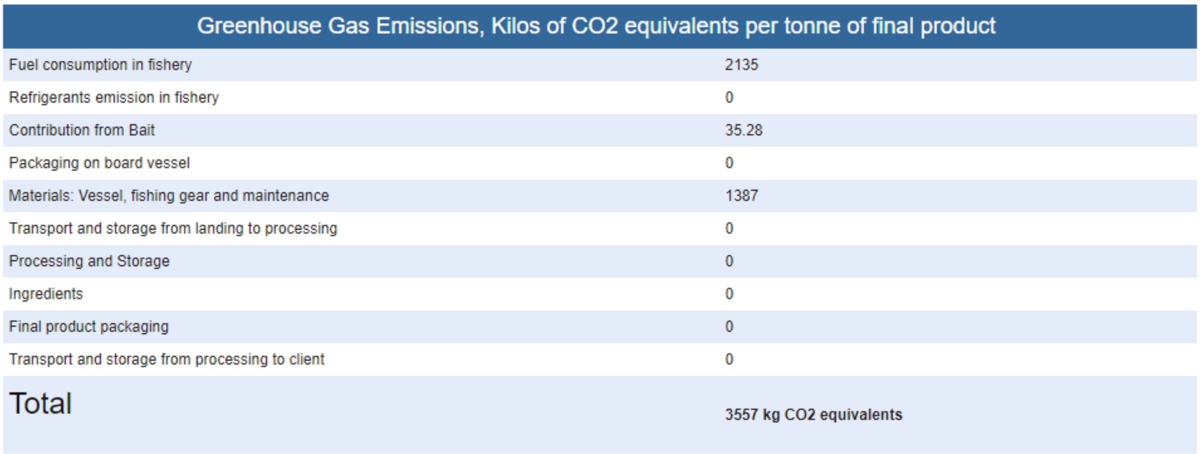
To calculate the end figure of CF, landings per year for four selected inshore creel vessels were calculated from landing data obtained from quantities landed at Orkney Fishermen's Society Ltd. Further fuel data was obtained through direct use (litres) and fuel purchase by members of Orkney Marine Oil Co. and results are reported within the case study section of results which covers 2016 to 2018. A case study of Orkney fuel use was conducted from data collected from the carbon footprint and OFS landing information. Statistically robust data was used on four Orkney vessels of varying sizes which targeted a range of shellfish species including Lobster, Brown, Velvet and Green crabs.

Statistical analysis was conducted using Minitab (version 18). Tables and graphs were constructed using Microsoft Excel 2015. Pearson Correlation Coefficient was conducted and significance of data was accepted when P values were below 0.05.

4. Results

4.1 Carbon Footprint

An overall estimated carbon footprint for the inshore was derived for Brown crab caught through creels in the catch to landing phase and was calculated by combining catch and fuel data for four Orkney vessels in the year 2017. The estimated carbon footprint for this fleet for 2017 was 3.557t CO_2e. The breakdown of this carbon footprint is seen in figure 5. The contribution of fuel to the overall footprint is most notable within the fishery along with materials and gear needed for fishing. Contribution from bait is relatively low for the overall contributions.



Greenhouse Gas Emissions, Kilos of CO2 equivalents per tonne of final product	
Fuel consumption in fishery	2135
Refrigerants emission in fishery	0
Contribution from Bait	35.28
Packaging on board vessel	0
Materials: Vessel, fishing gear and maintenance	1387
Transport and storage from landing to processing	0
Processing and Storage	0
Ingredients	0
Final product packaging	0
Transport and storage from processing to client	0
Total	**3557 kg CO2 equivalents**

Figure 5. Estimate average footprint for the inshore brown crabs caught by creel vessels in 2017.

4.2 Fishing area distribution and vessel size

The fishing effort amongst Orkney is not equally distributed throughout its geographical location. Figure 6a and b show that the most heavily fished areas are in sectors 4 and 5 supporting over 42 fishermen in these areas collectively throughout a typical fishing year. Areas 9 and 10 were found to have the least number of fishermen when asked at interview which areas the fisher uses. These results give a good indication the spread of fishing effort across Orkney but does not consider hobby fishermen and those full-time fishermen not included within the interviews.

The distribution of fishermen across Orkney is related to their home ports, associated steaming time to fishing grounds, size of vessel and species targeted. From table 7 the highest concentration of fishermen is associated with the port of Kirkwall (9), followed by Westray (8) and Stromness (7). Shapinsay and Burray are the ports which are least used by fishermen, from amongst those interviewed. Within Orkney most vessels fall within the under 10-meter category (29 fishers), while 11 fishers were reported to fish with boats over 10 meters (figure 7). The advantages in having a larger boat is that because they are generally larger in size, they can withstand more elements of poorer fishing weather associated with fishing grounds further offshore.

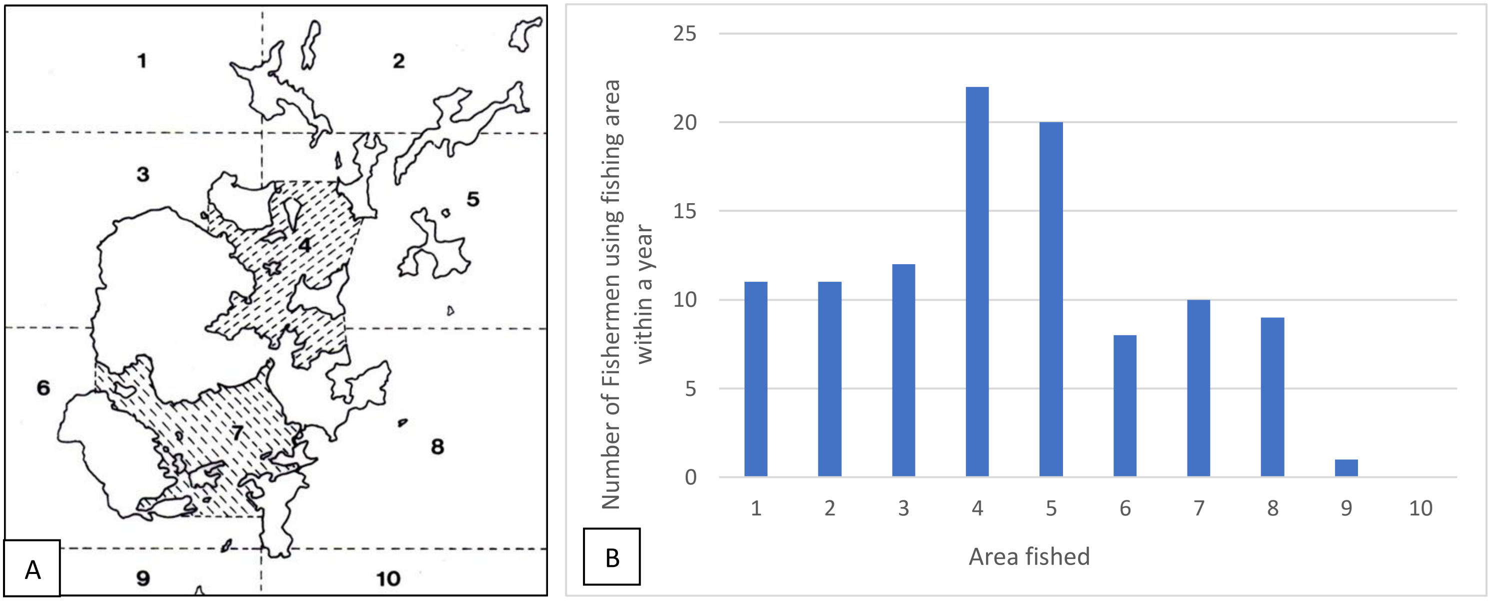


Figure 6a). Map of Orkney separated into fishing area sections. B) Histogram showing fishing effort as the number of fishermen using fishing areas within a standard fishing year.

Table 7. Number of fishermen in relation to their home port interviewed during questionnaires.

Port	Number of Fishermen
Stromness	7
Kirkwall	9
Tingwall	5
Hoy	2
Westray	8
Stronsay	5
Other- Burray, Rousay, Shapinsay	4

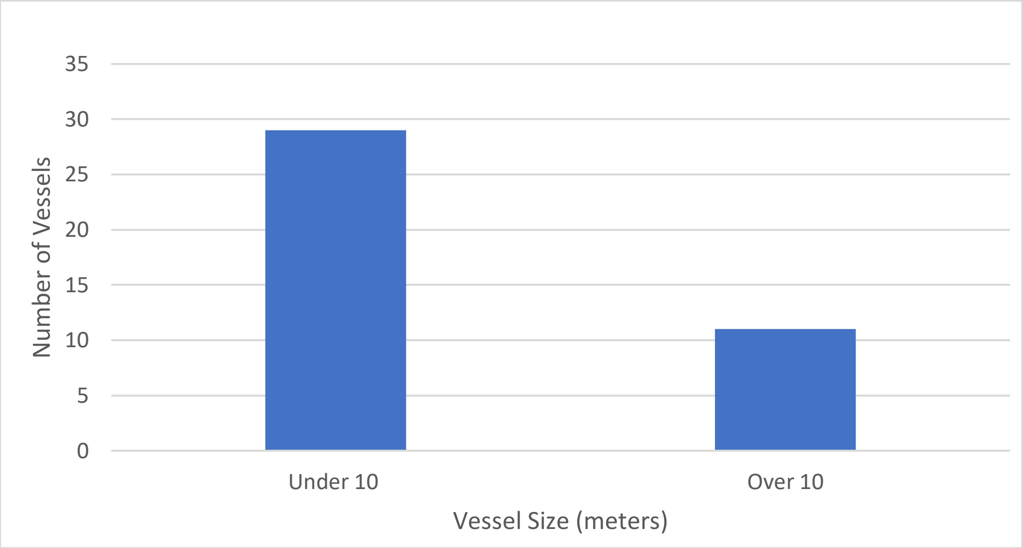


Figure 7. Vessel size fished by fulltime fishermen within Orkney, separated into under 10 and over 10 meters.

4.3 Gear Outlay

Fishing gear commonly used by inshore fishers in Orkney in the targeting of multi-species of Brown crabs, Lobsters, Velvets and Green crabs, were standard D-shaped 8mm soft eye creels. Usually they were 24 or 30mm in length, 16mm height and 14mm width and covered with 3.5mm black braid netting of 60/70mm mesh size with soft nylon eyes. Prawn creels were most commonly used for prawn capture but also for the targeting of Velvet crabs. Prawn creels have a hard eye opening and are covered in 33mm polyethylene nylon mesh. On an average creel which is 24(l)x 16(h)x14(w)mm, an estimate of 1.5m^2 mesh is required to cover the creel excluding the bottom which is fitted with bars or plastic covering. On a rope of 30 creels this would equate to roughly 60m of netting.

Current outlay of gear can be seen in table 8. Prices for D-shaped creels average between £60 to £100 per creel. Therefore, at the lowest price, a line of rope with 30 creels would cost on average £1800 for creels alone. There is no direct correlation between boat size and the number of creels fished. Additional gear and expense also included the use of plastic propcorn barrels referred to as ‘bongos’, wooden boxes for the keeping of shellfish, plastic fish boxes, keep-net bags and Buckie pots. Further additional gear for finfish fishing reported on boats also included mechanical jiggers, lines and nets.

No relationship between size of vessel and number of creels was found. Instead, vessels deck space is the limiting factor to the number of creels on a rope. Therefore, smaller boats could fish the same number of creels as larger boats, providing it was time and cost efficient. Table 8 shows that creels are the most expensive cost in fishing outlay, followed by rope. In this assessment the cheapest costings were used but there are more expensive options available. In reducing outlay costs, fishermen widely reported making elements of outlay such as keep nets, wooden boxes and locally sourcing bongos. However, it can be noted that increased costings are associated with diversification into other fishing enterprises, as seen in some three vessels purchasing Buckie pots. On average, a vessel’s gear outlay will cost £55,800.

Table 8. Outlay of gear currently employed amongst Orkney creel fishermen of varying vessel size as reported in carbon footprint questionnaire.

Vessel Length (meters)	11.1	9	9.8	8	8.9	6.9	10.4	8	5.4	Average
number of creels	800	150	750	650	390	450	250	800	100	482
Total cost of creels (£60)	48000	9000	45000	39000	23400	27000	15000	48000	6000	28933
Amounf of coils of twine used	6	3	3	20	2	1	40	5	3	9
Total cost of twine (Nylon £9)	54	27	27	180	18	9	360	45	27	83
No. of 220m rope used	190	18	125	91	56	45	49	82	91	83
Total cost of rope (Polysteel leaded rope 8mm £74.99)	14250	1364	9375	6818	4193	3409	3651	6136	6818	6224
Bongos	80	40	30	25	18	40	7	30	5	31
Total cost (£10)	800	400	300	250	180	400	70	300	50	306
Wooden Boxes	70	30	50			30	25			41
Total cost (£40)	2800	1200	2000			1200	1000			1640
Plastic fish boxes		40	30	50	50	30	4	60	20	35.5
Total cost (£22)		880	660	1100	1100	660	88	1320	440	781
Keep bags	10	30		10	20	10	15		10	15
Total cost (£10)	10	300		100	200	100	150		100	137
Buckie pots				400			100	600		367
Total cost (£33)				13200			3300	19800		12100
Anodes	800	150	750	650	0	450	0	800	0	400
Total cost (£13.99)	11192	2099	10493	9094	0	6296	0	11192	0	5596
Total cost per boat (£)	65914	13171	57362	60648	29091	32778	23619	75601	13435	55800

Figure 8 highlights the number of creels currently employed per fisherman within the inshore fishery. Ten fishermen interviewed reported their current fleet of creel numbers to be between 300 and 500 and this was the range most common used per boat. Eight fishermen also reported having a fleet of 900 to 1000 and 100 to 300. Using these numbers, it is therefore estimated that the total amount of creels used within Orkney is 26,200. Consequently, the total number is 26 creels per km^2 of Orkney mainland (990 km^2). However, it is likely that this is an underestimate due to the presence of hobby fishermen, fishermen not included within this survey and creels currently stored onshore. Table 9 highlights the fishers' responses to gear numbers, treatment and use of anodes in commercial creels. The lifetime of a creel is reported to be anything from three years or more with one fisherman stating that 'there is no limit to creel lifetime as it is dependent on how well they are looked after'. The lifetime of a creel was also dependent on the fishing areas in which they were placed and moved in preparation for poor weather. Lines of creels are also vulnerable to other fishing methods as entanglements where loss of creels were reported to have occurred.

Labour on repair of creels is usually conducted at sea on an 'as needed' basis and generally consists of net mending. But creels are usually brought ashore once a year for cleaning and additional repair work (Table 9). Popular cleaning preferences included the use of sodium hypochlorite and just letting them dry out naturally. Cleaning of creels not only helps prolong the lifetime of creels by allowing time for mending, but cleaner creels were reported to fish better. The lifetime of creels was also extended by the addition of an anode which helps prevent corrosion of metal frames. The majority of fishermen use anodes on their creels and they allocated one per creel on all their creels.

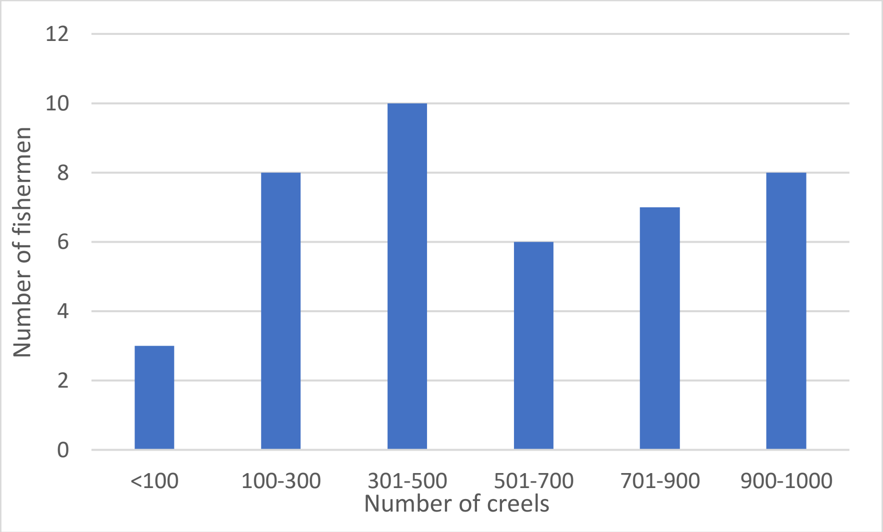


Figure 8. Number of creels currently employed per fisherman within the fishing industry within Orkney's inshore fisheries as reported amongst fishermen's ecological knowledge questionnaire.

Table 9. Fishers responses to gear number, treatment and use of anodes in commercial creels**.**

Fisherman	1	2	3	4	5	6	7	8	9
No. of creels	800	150	750	650	390	450	250	800	100
Average no. lost this year	200	150	10	20-30	3	3	3	50	10
Lifetime expectancy of creels (years)	10 -12	8+	8-10	No limit	6	15	n/a	11-12	3-4
How often creels brought onshore	As necessary	Once a year	1-2 years	Once a year	Once a year	Once a year	Once a year	Once a year	Once a year
Cleaning agents used	Sodium Hypochlorite	Pressure washer with water	Let them dry out	Bleach	Sodium Hypochlorite	Dry out	Sodium Hypochlorite	Dry out	Sodium Hypochlorite
Anodes used?	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Number of anodes used?	Most but not all creels	One per creel	One per creel	One per creel	0	One per creel	0	600	0

4.4 Antifoul

Antifouling was reported to be conducted on vessels within Orkney once every year, as seen in Table 10. Only 1 boat was reported not to use any antifoulant, mainly because the boat was taken out of the water on a trailer each day. Fisher's comments inferred that antifouling was conducted at the same period as 'refit time', usually when other maintenance was being conducted on the vessels. At this time the boat was usually taken out of the water for one to two weeks, normally during periods of bad weather, unsuitable tides and when fishing was generally functioning under less optimum conditions. Antifoul paints were the popular application of choice along with the brand 'International Trilux 33'. The volume of use varied between vessels and vessel sizes, showing no relationship between the two but rather personal preference.

Table 10. Fisher’s response in carbon footprint questionnaire to the quantity, type and frequency of antifouling agents used on their vessels. International refers to the brand name ‘International Trilux 33’ paint and S force is the brand name ‘Joutun SeaForce’ paint.

Fisherman	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
How often vessel antifouled	Yearly	Yearly	Yearly	Yearly	Yearly	Never	Once every two years	Yearly	Yearly
Type of Antifouled	n/a	International	Inter.	Inter	S force	None	Inter.	Inter.	Inter.
Volume of antifoul (litres)	8	10	10	5	5	None	10	10	2

4.5 Fuel use

From the carbon footprint questionnaires distributed to fishermen, fuel use (litres per day) can be seen in figure 9. This figure shows on average 8.4 litres used more per day in summer than winter. A significant positive relationship ($P<0.05$, $R= 0.68$) between vessel size and quantity of fuel used in winter months. The overall relationship between fuel use in summer months and quantity of fuel used were found not to be significant ($P>0.05$). Therefore, larger vessels in winter were found to use more fuel.

Figure 10 shows the maximum travel distance (miles) per day between summer and winter months for different vessel sizes (meters). For vessels on average 6.6 more miles were covered in summer than in winter. A vessel’s average maximum range covered in summer was 16 miles while in winter this was reduced to 10 miles from home port. Again, a positive significant relationship ($p <0.05$, $R= 0.8$) was observed between vessel size and miles travelled in winter. No significant relationship was recorded between vessel size and maximum travel distance per day in summer. Therefore, larger vessels in winter months travelled further. The maximum travel distance reported by vessels per day was 30 miles from home ports. In winter, only 10 miles from hope port was reported as the maximum travel distance.

The average number of fishing hours per day by Orkney vessels was 10 hours in summer and 8 hours in winter (Figure 11). There was found to be no relationship between vessel size and the number of hours fished during summer. However, in winter a significant relationship ($p<0.05$, $R= 0.82$) was found between vessel size and number of fishing hours per day.

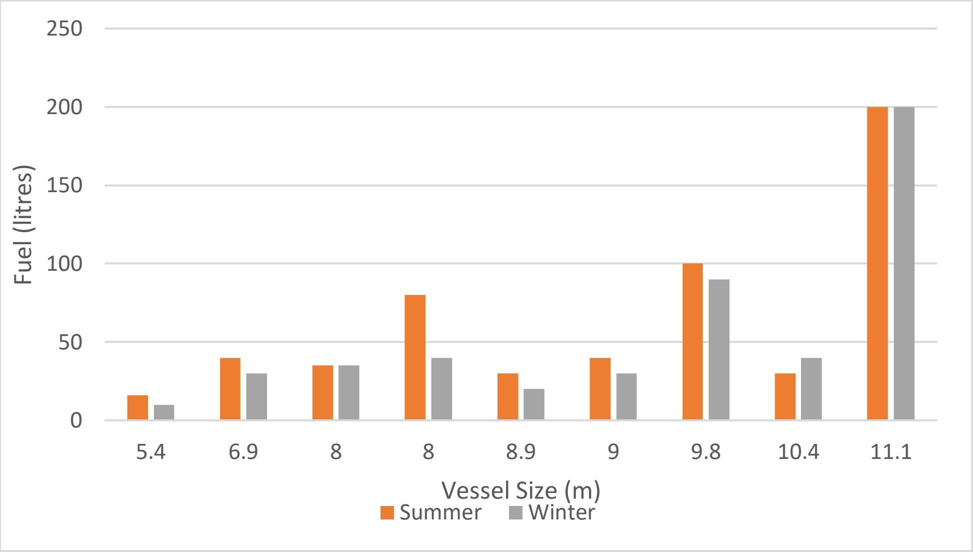


Figure 9. Quantity of fuel (litres) used per day between summer and winter months in difference vessel size (m).

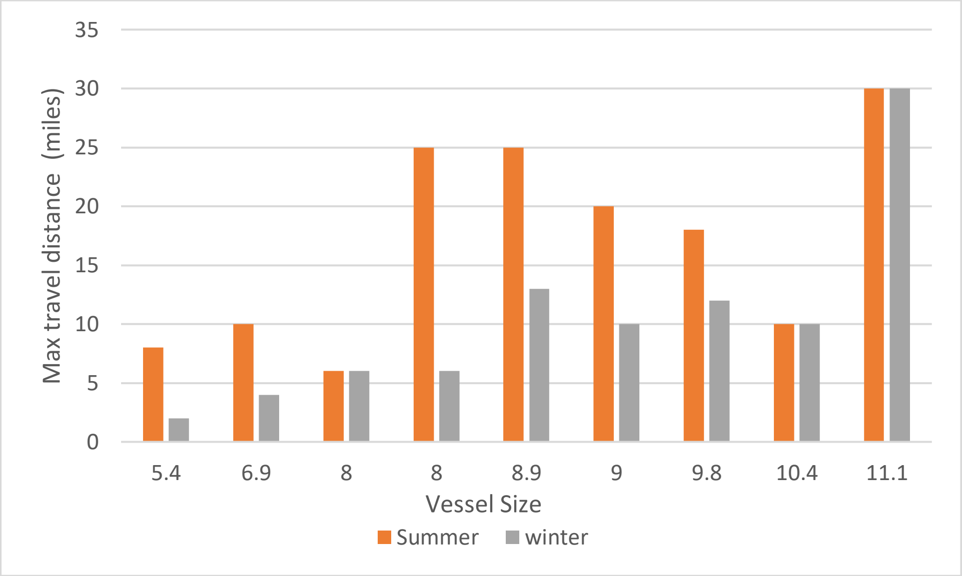


Figure 10. Maximum travel distance(miles) per day between summer and winter months in different vessel size (m).

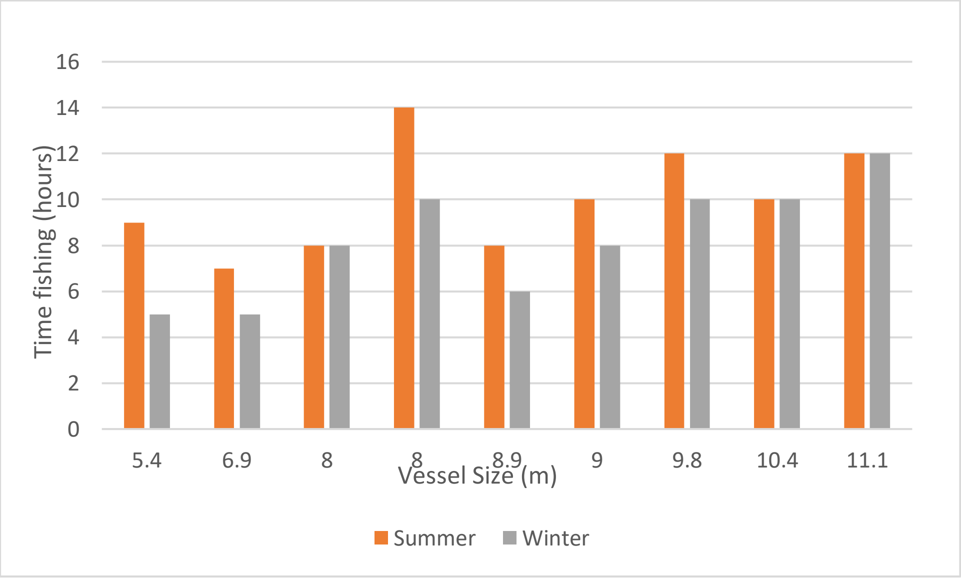
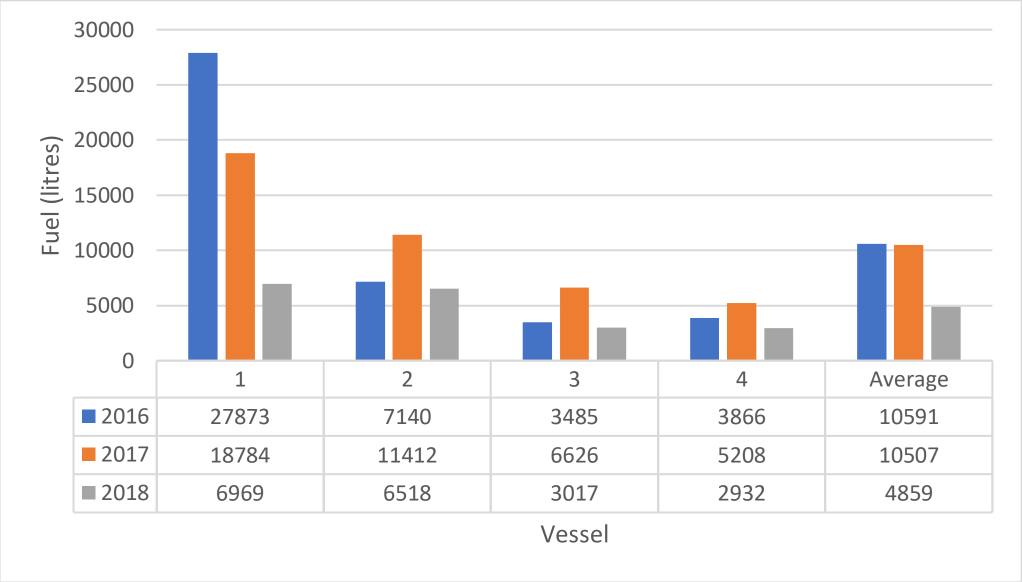


Figure 11. Number of fishing hours per day between summer and winter of different vessel sizes.

4.6 Case study of fuel use

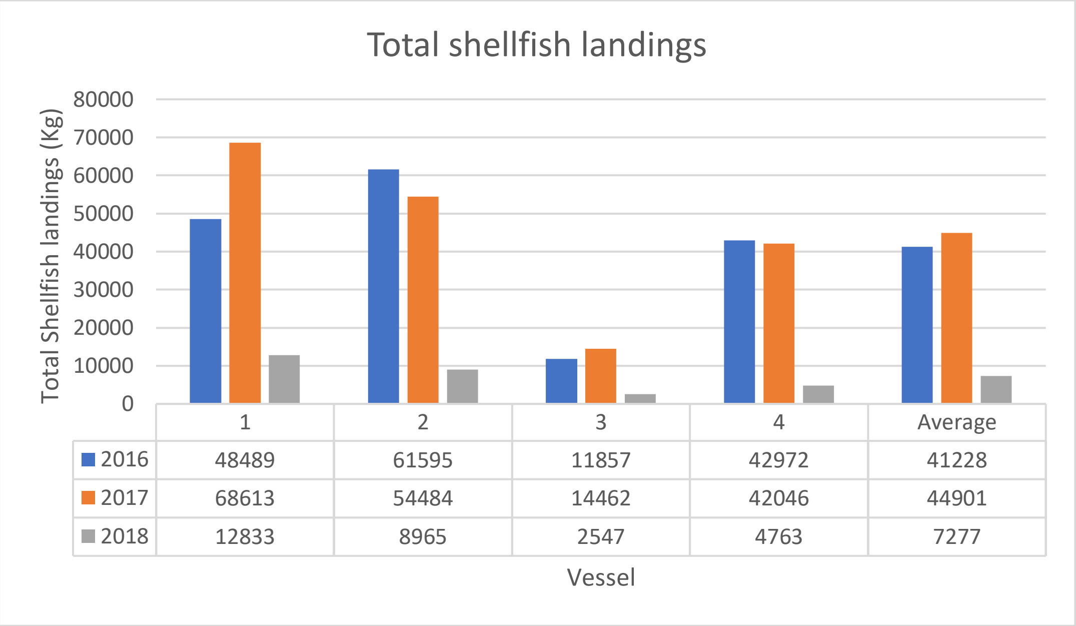
This section explores the individual components of fuel use amongst four sample inshore creel vessels within Orkney that fish for Lobsters, Brown crab, Velvet and Green crabs. Vessels 1 and 3 are over 10 meters while vessels 2 and 4 analysed are under 10 meters. In 2016 data analysis was compiled from February to December, 2017 comprised the whole year and analysis of 2018 was conducted from January to May across all vessels. The overall fuel consumption attributed to creel fishing for shellfish within Orkney is shown in Figure 12. Vessel 1 shows the highest fuel consumption in all years and Vessel 4 shows the lowest fuel consumption across all years except in2016. In 2016 the lowest fuel consumption was obtained by vessel 3. While the average fuel consumption within 2016 and 2017 are similar between these vessels, they do not show an overall increase. The 2018 figures are significantly lower due to the availability of data as its fuel consumption was only accounted for the month up until April.



	1	2	3	4	Average
■ 2016	27873	7140	3485	3866	10591
■ 2017	18784	11412	6626	5208	10507
■ 2018	6969	6518	3017	2932	4859

Figure 12. Fuel (litres) allocated to the inshore shellfish creel fishing between 2016 and 2018.

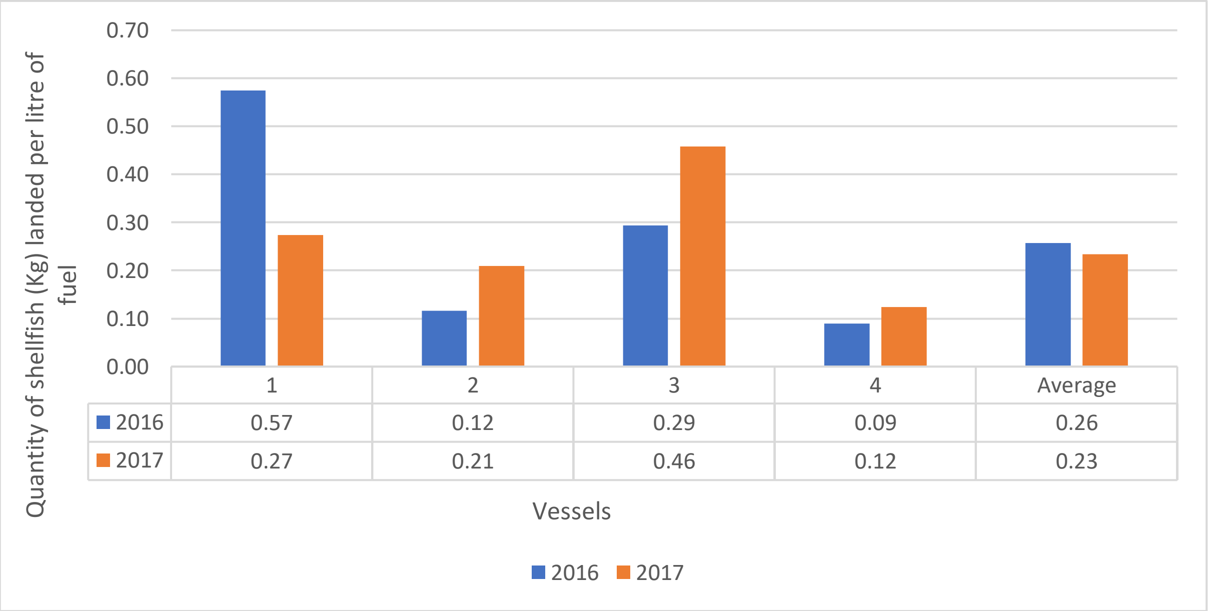
Figure 13. shows the total weight of shellfish landed per vessel per year between 2016 and 2018. Vessel 1 shows significant increase in shellfish landings between 2016 and 2018. Vessel 3 also shows a slight increase in the quantity of shellfish landed between 2016 and 2017. For vessels 2 and 4, which are both vessels under 10 meters a decline in shellfish landings between 2016 and 2017 is shown. Overall averages reflect a small increase in shellfish landings for these vessels between 2016 and 2017. For the beginning of 2018 vessels 1 and 2 show higher landing weights compared to vessels 3 and 4. Appendices Figure 1 highlights the variability in quantity of species landed (Kg) between vessels and yearly variations. The largest landing quantities (Kg) was Brown crab by all vessels at a total of 10,3919kg (2016), 13,2817kg (2017) and 20786kg (2018). The next largest quantities were Velvet crabs, Lobster and Green crabs. There was not a significant difference in the shellfish landings (kg) between individual species in years 2016-2017. However, two vessels were seen to reduce the targeting of Green crabs after 2016.



	1	2	3	4	Average
2016	48489	61595	11857	42972	41228
2017	68613	54484	14462	42046	44901
2018	12833	8965	2547	4763	7277

Figure 13. Total annual landings for shellfish species (Lobster, Brown crabs, Velvet crabs and green crabs) for the inshore creel fleet between 2016 and 2018 by vessel.

The weight of shellfish landed per kg and per litre of fuel used is reflected in Figure 14. Fluctuations are seen between vessels and between years with no distinct trend between 2016 and 2017, as seen within the averages. The average kilogram of shellfish landed per litre of fuel consumed decreased slightly from 2016 (0.26kg/l) to 2017 (0.23kg/l). Vessel 1 is the only vessel to show a significant decrease in kilograms of shellfish landed per litre of fuel used between 2016 and 2017. All the other vessels show an increasing trend in shellfish landed per litre of fuel consumed. However, vessel 3 shows it landed more shellfish (Kg) per litre of fuel used between 2016 and 2017, increasing from 0.29kg/l to 0.46kg/l.



	1	2	3	4	Average
2016	0.57	0.12	0.29	0.09	0.26
2017	0.27	0.21	0.46	0.12	0.23

Figure 14. Quantity of shellfish landed (Kg) per litre of fuel for four vessels between 2016 and 2017. Data for 2018 was excluded from this due to less data available.

4.7 Seasonal variance

Seasonal variance in the quantity of species landed from 2016 to 2018 is represented in figure 15. An increase in lobster landings quantity can be seen from August (1606 kg, 2017) to October (1212 kg, 2017) in 2016 and 2017. The highest landing quantity for Brown crabs can be seen to increase in August and lasts to December. The maximum landings were seen in August in both 2016 (16,830kg) and 2017 (15,972 kg). For Velvets, an increase in landings is observed between September to December. The highest landings being achieved in December 2016 (11,262kg) and 2017 (6079kg). There was a slight decrease in the average landings between 2016 and 2017, from 3944kg to 3019kg. Green crabs landings increased at the start of the year from February to March (2752 kg). A decrease from 2016 in the quantity of Green crab landed because of two vessels no longer fishing for them.

Appendix figure 2 shows the seasonal variation of total fuel use per month for the four vessels analysed from 2016 to 2018. This shows fuel use to be variable throughout the months and years. Figure 16. highlights the total kilograms of shellfish landed for the four vessels and totals per litres of fuel consumed from 2016 to 2017. Results found an increase in the best return for quantity of shellfish landed per litre of fuel consumed occurred in December 2017 (0.08 kg/l). Between August (0.02, 0.03 kg/l) and December (0.025, 0.08 kg/l) in both 2016 and 2017, litres of fuel per kg of shellfish landed is the highest in these months compared to the rest of the year. July (0.006 kg/l) and January 2017 (0.007 kg/l) were the lowest months for the litres of fuel consumed per kilogram of shellfish landed in the four boats analysed.

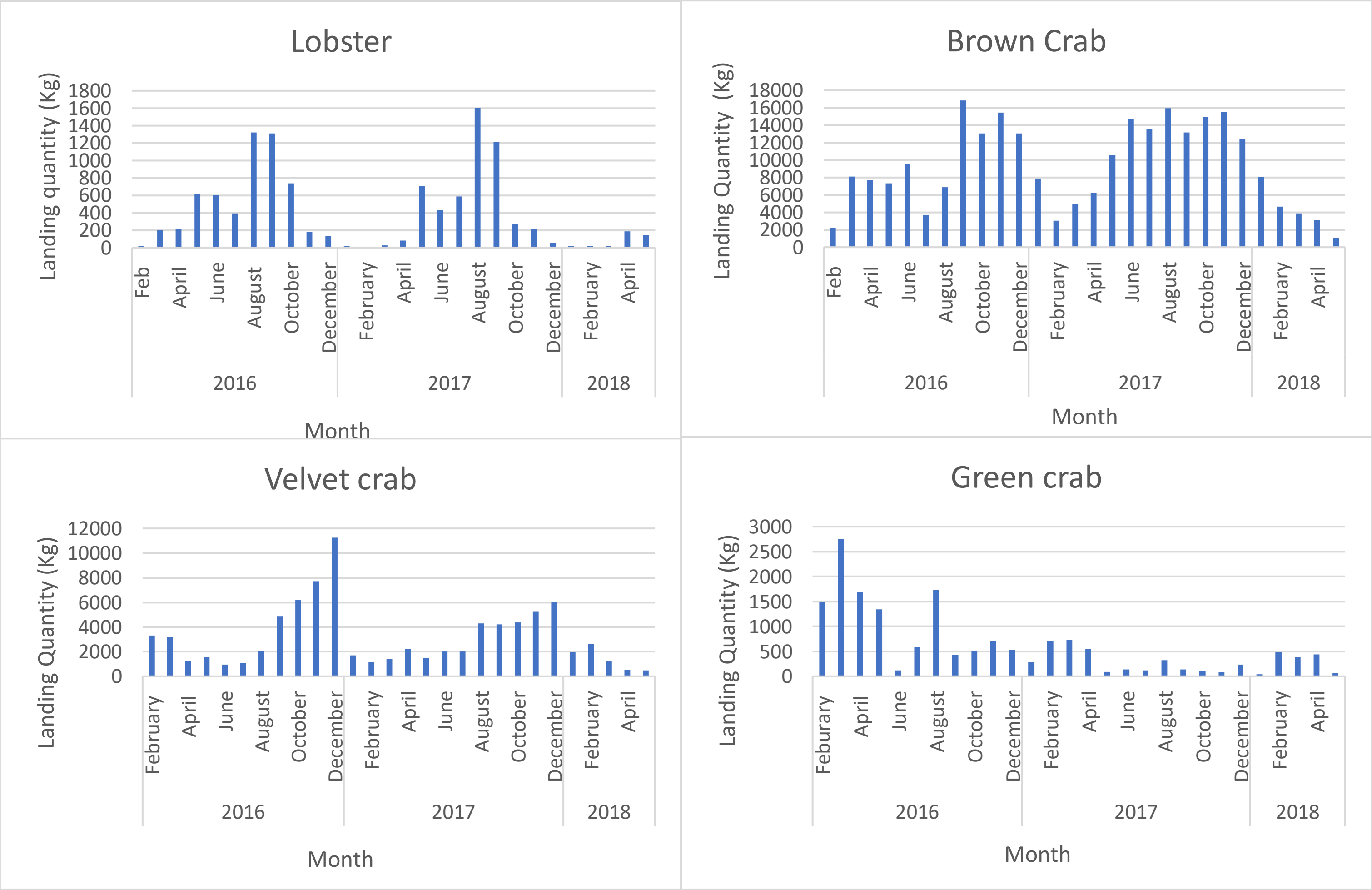


Figure 15. Total quantity of species landed (kg) of Lobster, Brown crab, Velvet Crab and Green Crab from all four inshore vessels between 2016 and 2018.

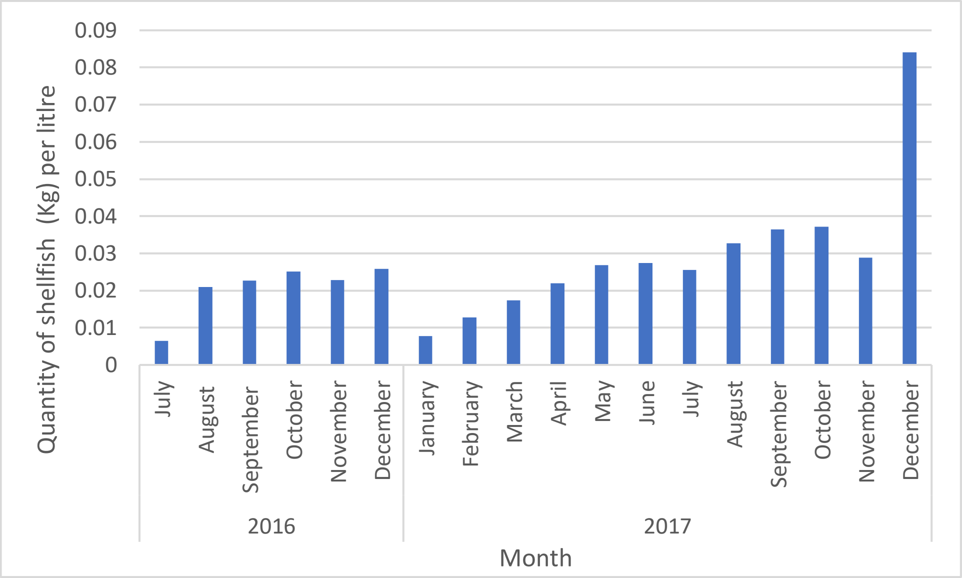


Figure 16. Kilograms of total shellfish landed for the four vessels total per litres of fuel consumed from 2016 to 2017.

5. Discussion

The inshore fishing sector within Orkney is predominately dominated by under 10 metre creel vessels. The distance covered by this inshore fleet can vary up to 30 miles offshore for the over 10 vessels, however the smaller inshore boats can cover the same amount of coastline per day. The busiest fishing areas covered within Orkney as reported by vessels fishing was found to be in areas four and five on the map. This area also contained the busiest port, Kirkwall. The area encompasses fishing areas inside the North isles. The geographical location of the isles makes fishing in area 4 and 5 relatively sheltered from poor weather which predominates in the form of westerlies. Strong tidal movements within this area also makes for good water movement which could aid in providing the area with nutrient transport, recruitment, oxygen, thereby making it profitable.

The results from this study show that most emissions in the CF for the inshore fleet is caused by fuel consumption and gear maintenance, as found in other studies (Parker 2012; Sandison, 2015). Surprisingly, bait consumption was particularly low. However, in comparison to other fisheries, refrigeration provided no contribution to the overall CF as refrigeration is not present onboard vessels. Despite these findings, the overall CF value was exceptionally high in comparison to other industries and was not as expected. The overall CF value for Brown crabs caught using creels (3.557t CO_2e), for a small proportion of the chain process (catch to landing), was as high or higher than the total CF value for tonne equivalent of live weight in pork (3.5-4.40), chicken (4.57-6.68) and farmed salmon in the UK (3.27) and Norwegian (2.0) industries, as seen in table 2 and 3. In other industries such as pelagic fisheries, trawlers usually have a high fuel expenditure but also land high volumes of fish, therefore the fuel to catch ratio is low and in turn also their carbon footprint (Sandison, 2015). The CF generated may be high due to the full catch of species within the creel not being included within the analysis.

Had other species such as Lobster, Velvet and Green crabs been included within the figures submitted of total commercial weight landed this may offset some of the fuel consumption used to catch these species using creels. Further investigation into the landed commercial shellfish from creel fishing throughout the whole chain analysis (cradle to grave) following processing, may also further lower total CF values.

Despite the quantity of shellfish landed per litre of fuel consumed (Figure 14) not being particularly high and therefore reflective of their catches, it would indicate that the CF of the inshore Brown fishery to Orkney should be modest if not low. Overall, fuel consumption was the main source of carbon consumption during fishing trips. Technical errors within the calculations using amalgamation of vessel landing and fuel data could exist causing particularly high values in CF which could be represented as an error. Unfortunately due to technical errors within the SeaFish model, further simulations of the data could not be run again prior to the completion of this study. It is further recommended that once errors within the software are fixed, further analysis should be carried out for this industry to obtain a CF which is more reflective of catch-landing phase of the process to gain an accurate representation.

Further results again from fishermen's carbon footprint questionnaires showed that on average 8.4 litres more fuel was consumed in summer than winter. A positive relationship was found between vessel size and fuel consumption within winter. This positive relationship is most likely a reflection on the ability of larger vessels to fish in poorer weather as well as reaching grounds further from home ports. This was also reflected in a positive relationship between the vessel size and the distance travelled in winter. Whereas in summer, there was no relationship found between vessel size and distance travelled. However, summer time saw an average increase in travel of 6.6 miles compared to winter. In summer the average distance travelled from home port by fishermen was 16 miles and in winter it was reduced to 10 miles. Better weather and longer daylight hours meant that fishermen can set off earlier to reach further away fishing grounds, ultimately spending more time at sea. From the results fishing hours were seen to decrease from 10 hours in summer to 8 hours on average in winter.

Gear outlay of the inshore fishery for shellfish is mainly of creels or pots. Creels can be used on single lines but are commonly fished using lines comprising of 15-40 creels. On average, individual fishers used 450 creels within their personal fleet. No relationship was found between vessel size and number of creels used to fish with. It is thought that deck space is a limiting factor to the number of creels worked along with how many can be hauled per day. From the questionnaire responses it is estimated that 26,000 creels are in active use within Orkney waters. On average this makes 26 creels per km^2 around the Orkney mainland coastline. However, it is likely that this figure is underestimated and is expected to be higher as not every fisher within Orkney was interviewed and this report did not include hobby fishermen. Gear outlay for vessels on average costs £58,000 per vessel using the lowest priced available equipment from Sea Gear Supplies. Creels on average can cost upwards from £60 per creel. Despite this, fishers reported that the lifetime a creel could fish effectively for, was on average 8-10 years providing gear was maintained regularly. Maintenance of creels is usually carried out at sea as required. Longevity of the creel is extended through regular cleaning with most fishermen using Sodium Hypochlorite. Anodes were widely reported to be used in all creels to prevent rusting. Recycling of old nets was reported in order to replace mesh on creels as a method of recycling nets and reducing costs.

Antifouling of vessels was regularly conducted by most fishermen once per year as they recognised the need for this to improve fuel efficiency. Increasing fuel efficiency is an essential step in helping to reduce carbon footprint as decreased fuel consumption ultimately leads to lower emissions of greenhouse gases (Evans *et al*, 2000). Biofouling of vessels can also on occasion cause damage to the structure of the vessels so prevention of further financial investment is also a driving factor in the use of antifouling. However, with the increased use of antifouling coatings there is a growing concern over their effects on the marine environment. Since the banning of tributylin (TBT) in the 1980s the majority of antifoulants have been copper based, using cuprous oxide which is toxic to marine life (Boxall *et al*, 1998). Leaching of copper from the antifouling paints raises concerns of bio-accumulation in areas and the indirect impacts produced further up the food chain (Callow and Callow, 2002). While it is recommended that antifouling is necessary in the ultimate reduction of carbon footprint, there is also environmental risks which could offset these positive changes. Recommended best practice to prevent environmental impact includes the correct disposal of paints and varnishes along with their tools for application (The green blue, 2008). This prevents anti-fouling from unnecessarily entering the water, also better is the use of a tarpaulin to collect flakes and drips during the scraping or painting process. Other best practices include using the correct amount of antifouling and the prevention of spillages along with collecting resides after wash-down (The green blue, 2008).

Increased fuel prices in recent times have also forced fishermen to reconsider their operational practices. Fuel use within the fleet was found to have increased in consumption in 2017 for individual boats investigated. However, on average across the four vessels investigated there was no significant change from 2016 (10591 litres) to 2017 (10507 litres) in the volume of fuel consumed. This coincides with average shellfish landings from 2016 (41,228 kg) to 2017 (44901 kg) whereby on average there was no significant change. However, fuel use for creel vessels varies throughout the year along with the seasonal targeting of shellfish species and weather conditions. The amount of fuel consumed (litres) was seen to increase in the months between August and December. It is likely that increased fuel consumption is associated with increased fishing effort to meet Christmas markets in which demand is increased for shellfish species.

On average there was no significant difference in the quantity of shellfish (kg) landed from 2016 to 2017 per litre of fuel consumed. In 2016, 0.26 kg/l was found while 2017 saw a slight decrease to 0.23 kg/l. For 3 individual vessels, their quantity of shellfish landed per litre of fuel consumed increased slightly. One vessel saw a significant decrease in quantity of shellfish per litre of fuel consumed. From interview results this could be due to longer refit times, vessel out of water along with changing the species targeted from Brown crab to Velvets or seasonal variation in the quantity of shellfish landed per litre of fuel consumed. August (0.03kg/l) and December (0.08 kg/l) in 2017 were the two months which showed the best returns of efficiency. It is most likely that this was due to the increased targeting of commercial species due to market-driven pressure and the seasonality of species. During these months the ability to land better quality and increased quantity of shellfish may be related to better shell quality of crab and their seasonal movements, therefore availability.

Thrane (2004) also indicated that apart from fishing gear and vessels' size, the target species are also a determinant on the fuel consumed. From Thrane's results, it was found that 27GT trawls have a ratio of litres of fuel per kg of fish of 0.33 kg/l and 110GT trawlers of 0.38 kg/l. While Danish seine of 71GT have an average ratio of 0.42 kg/l and bottom trawling for Norway lobster have a ratio approximately three to four times higher than bottom trawl targeting flat fish. For Orkney's inshore creel fishery they show very small ratios of litres of fuel per kg of shellfish. The fuel efficiency of the fishing industry is one of the environmental pressure indicators proposed by the European Commission to measure the effects of fisheries on the marine environment. Therefore, good energy performance is critical in achieving sustainable fisheries and reduced carbon footprint. Increases in fuel prices, variation in stock availability and in turn operational costs can provide the opportunity for fishers to rationalize fuel consumption. With fuel price increases in the future probable, actions taken now to increase efficiency in fishing and to prepare for these changes will ensure economically, socially and environmentally sustainable use of fisheries resources (Cheilari *et al*, 2013).

Pathways to change

Creel fishing has many advantages in comparison to other fishing techniques including its relatively low energy use, operation inshore on rough bottom, selectivity for species and sizes, minimal habitat impact and potential for good quality live catches (Suuronen *et al*, 2012). The disadvantages of creel pot fishing exist in the potential for ghost fishing from lost creels which contributes to marine litter which takes a long time to degrade (Suuronen *et al*, 2012).

With fishers taking a proactive approach to reduce their carbon emissions as responsible users of the sea, this can provide economic incentives as it can pay to reduce waste but also incentivise sustainability in order to continue to ensure fishing into the future (SeaFish, 2009). Skippers can take a proactive approach in actively trying to reduce their fuel consumption (per tonne of fish/shellfish landed). These changes can be both operational and strategic and while some may require little or no cost to the vessel, other changes may require significant investment (Curtis *et al*, 2006). Suggestions for operational and strategic changes are highlighted in Table 11.

Engine maintenance and upkeep can play a crucial role in the reducing of overall fuel consumption and contribute to reducing a fleet's carbon footprint by utilizing innovative solutions such as re-manufactured parts, fluid analysis and remote monitoring of engine performance. This in turn could generate savings and help reduce maintenance costs and improve efficiency. Savings can be made in using a fluid analysis service which generates data that can help analyse, interpret and evaluate data gathered from engine oil, fuel, coolant and diesel exhaust fluid samples. This in turn can lead to early diagnosis of potential problems and thus enables repair before breakdown. Skippers can then use the information generated to improve up-time and reduce equipment whole-life costs. They can further employ remote monitoring to improve efficiency and engine performance. Using wireless technology, engine monitoring can highlight potential issues before damage occurs. Certain engines, such as Cat marine, can generate information on total fuel used, average fuel burn rate, oil pressure, engine load, temperature and speed. Accessing this data can help inform fishermen on engine performance and make changes when necessary in reducing costs and increasing performance.

Developments are being made within the sector of biodegradable fishing gear to reduce the amount and distribution of lost and abandoned fishing gear. Fishing gear over the years has transitioned into the use of heavier carbon-compound products including synthetic, more durable and buoyant fishing materials (Gilman, 2016). In turn, this means that if lost, gear has the potential to continue fish and exist within the marine environment for many years, and is known as 'ghost fishing'. Progress is being made with the development of new synthetic materials for monofilament twine for gillnets. Kim *et al*, 2016 has studied its breaking strength, degrading time and fishing efficiency relative to commonly used nylon twine. Their report found that the biodegradable twine degraded after 2 years within sea water in comparison to nylon gillnets which can take decades (Kim *et al,* 2016). If this biodegradable method was applied to the nylon mesh and was adopted for use within creel pots, it could be a significant step forwards in pathways to change to help reduce carbon and synthetic compounds entering the marine environment. Further to this, this adoption of using biodegradable twine in mending or securing of escape panels as well as recycling of tyres for rubber base protection on the bottom of creels, are all better practices which could be adopted.

However, there are concerns that the use of biodegradable fishing gear which may be weaker would increase the frequency that gear components needed repair and replacement and increase gear loss (Kim *et al*, 2016). The use of recycled tyres and other synthetic compounds in fishing gear components may leach toxic chemicals or degrade into microplastics into the marine environment, causing accumulation within the marine food web (Gilman, *et al*, 2016). Preventative measures to reduce gear loss can be adopted to reduce replacement costs and marine impact. Measures could include the management of fisheries areas by separating passive and mobile gear types, adequate marking of gear to identify ownership and increased passive gear visibility.

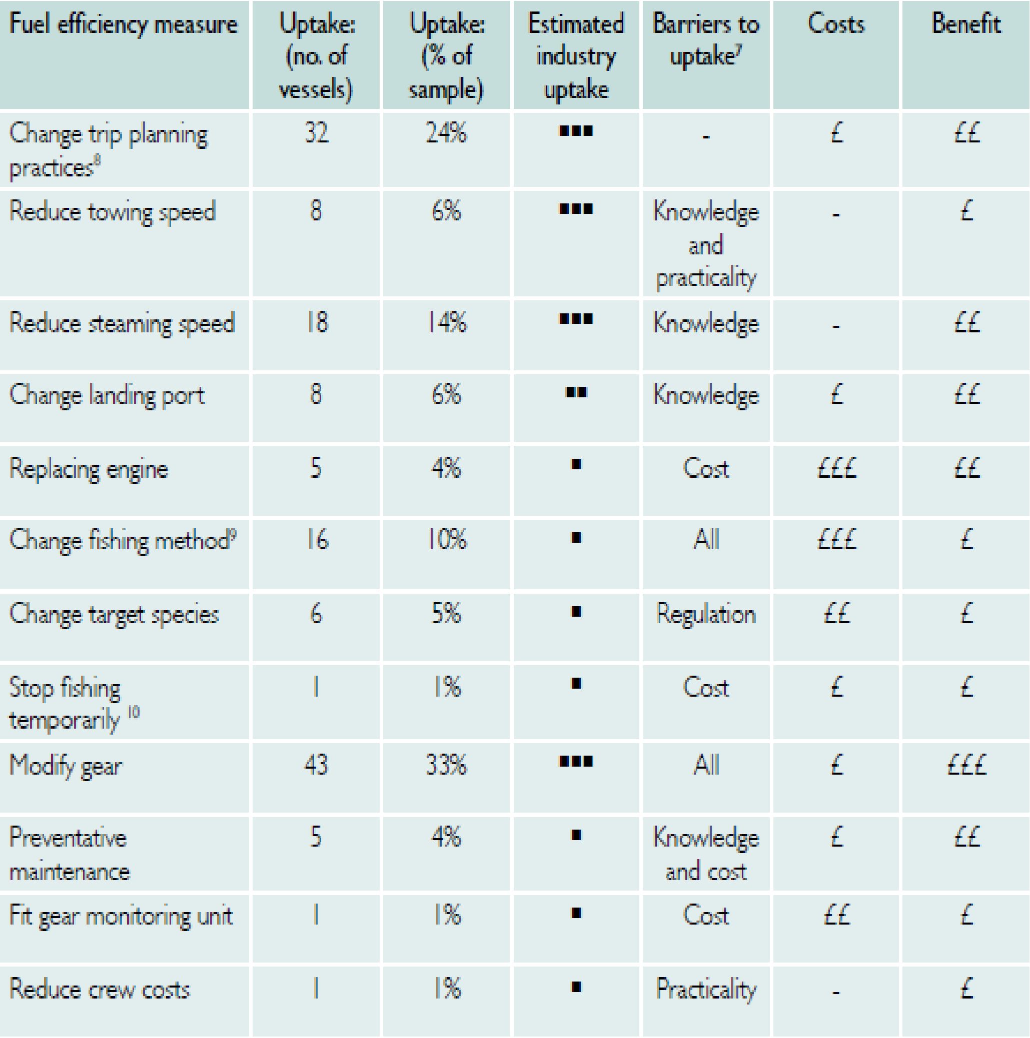
Table 11. Operational and strategic changes fishers can employ in order to reduce fuel consumption and overall carbon footprint. Adapted from Curtis *et* al, 2006 and Sea Fish, 2009.

Operational Changes	Strategic Changes
Reducing steaming speeds to improve fuel efficiency	Using fishing grounds closer to home ports
Replacing engine with a more fuel-efficient engine	Seasonal targeting of species to allow for increased quantity high quality shellfish for fuel consumption.
Remove excess weight to lighten up the vessel and contribute to reduced fuel consumption	Install electric fuel meter to help monitor fuel consumption and establish optimum steaming speed
Maintain hull and engine to reduce drag and improve engine performance	Reducing days at sea in bad weather
Modifying gear/ vessel to allow for more efficient hauling times.	Temporarily stopping fishing when profit returns are not generated
Use of alternative fuels such as low sulphur, biofuels. The oxides from BioDiesel are at least 80% lower than sulphur fossil diesel.	

In adopting these changes to change fuel efficiency there are benefits, costs and barriers to vessels. However, in adopting technical improvements and behavioural changes, fisheries can decrease their damage to marine environments, reduce emissions and fuel costs without impacts on efficiency. Table 12 summarises the uptake, barriers, costs and benefits of various fuel efficiency measures taken by vessels in a survey sample conducted by Sea Fish. Barriers to change exist in the lack of familiarity with cost-effective and practical alternatives. For the creel industry technological advances are not necessarily available in comparison to other gear types (Suuronen *et al*, 2012). Further barriers exist with the incompatibility of vessels to adapt to alternative gears to allow for change. In order to invest in new gears this would bring high investment costs along with lack of capital or restricted access to capital (Suuronen *et al*, 2012). Not only this but barriers exist towards change as using unfamiliar fishing techniques could mean additional work, risk of losing marketable catch and safety concerns at sea from using unfamiliar gears or strategies (Suuronen *et al*, 2012).

Further barriers to change may exist through fisheries management decisions and impacts on fleet fuel consumption and GHG emissions (Driscoll and Tydemers, 2010). Fisheries management decisions such as quotas which restrict fishing areas, closure of fishing areas at certain times of year, acquisition of fishing licences and associated engine sizes may contribute to affecting fuel-use patterns. Strict regulatory regimes can therefore restrict flexibility in adopting innovative and new technologies (Suuronen *et al*, 2012). Ultimately in switching to new gears and practices fishers are mostly concerned with economic benefits associated of these and an effective fishing gear or practice which increases work load and reduces earnings will not be adopted (Suuronen *et al*, 2012).

Table 12. Adapted from Curtis *et al*, 2006. Summary of uptake, barriers, costs and benefits of various fuel efficiency measures taken by vessels. Estimated uptake, costs and benefits are illustrated in approximate categories of low (£ and ▪), medium (££ and ▪▪) and high (£££ and ▪▪▪) based on data collected from their fleet survey.



Fuel efficiency measure	Uptake: (no. of vessels)	Uptake: (% of sample)	Estimated industry uptake	Barriers to uptake[7]	Costs	Benefit
Change trip planning practices[8]	32	24%	▪▪▪	-	£	££
Reduce towing speed	8	6%	▪▪▪	Knowledge and practicality	-	£
Reduce steaming speed	18	14%	▪▪▪	Knowledge	-	££
Change landing port	8	6%	▪▪	Knowledge	£	££
Replacing engine	5	4%	▪	Cost	£££	££
Change fishing method[9]	16	10%	▪	All	£££	£
Change target species	6	5%	▪	Regulation	££	£
Stop fishing temporarily [10]	1	1%	▪	Cost	£	£
Modify gear	43	33%	▪▪▪	All	£	£££
Preventative maintenance	5	4%	▪	Knowledge and cost	£	££
Fit gear monitoring unit	1	1%	▪	Cost	££	£
Reduce crew costs	1	1%	▪	Practicality	-	£

Recycling

In addition to the operational and strategic changes fishermen can make to their vessels and fishing practices to offset carbon emissions, further efforts can be concentrated towards recycling and reducing environmental impact. Increasing levels of marine litter are becoming an increasing concern. It is estimated that 640,000 metric tons of fishing gear are lost or discarded in every ocean annually. In response to this there are innovative and sustainable products created from marine plastic waste along with the ability for remote communities to develop sustainable and green business opportunities.

Currently lack of options exist for the disposal of fishing gear. Traditional disposal is associated with burying or incineration of nets. Lack of disposal opportunities and costs associated means that fishing gear often ends up back in the marine environment. An improvement which could be made in the pathways to change which would enable recycling of gear to more effect is to improve harbour reception facilities and the pre-processing of nets for recycling schemes.

‘Healthy Sea’ is an organisation which seeks to remove waste, fishing nets and other marine litter for the purpose of recycling these into textile products. However, their collection of marine litter is only currently associated with the recovery of nets through diving in association with ‘Ghost Fishing UK’. Fishing for Litter, established in 2004, is currently an ongoing project which was designed to reduce the amount of marine litter by providing participating vessels with hardwearing bags to collect marine litter caught during normal fishing activities. The filled bags are then deposited at participating harbours where they are moved to a dedicated skip for disposal and the project covers all waste costs. There are 18 Scottish harbours participating and Orkney could participate in reducing the effects of marine litter within the environment.

Fishing recycling is still very much in its infancy. Currently only two companies, Italian company Aquafil and Danish company Plastix have the resources and technology to recycle on a large scale. Aquafil currently cover the shipping costs and pay a small sum of money for nets. Aquafil only recycle the material for nylon6, where fishing gear such as trawl nets and crab pots cannot be recycled yet. However, Plastix has the technology not only to convert nylon6 but also the ability to accept trawl nets and crab pots. Here they take the gear, shred, clean and separate it and then extrude it into material that is sold for plastic product manufacture. Another company, Vecoplan AG, also has shredders and the ability to clean material which allows the processing of nets that are contaminated with chemicals and metals. UK based company Fishy Filaments is also currently producing high quality 3D filament made from nylon fishing nets and future developments include seeking to use mixed polypropylene/ polyethylene netting. There is future potential within recycling for the development of a circular economy solution to waste.

Innovative and original solutions have emerged from the collection and reprocessing of discarded fishing gear and present several business opportunities resulting in the creation of accessories, clothing, footwear, homeware and recreational products (Charter *et al*, 2017). Currently in Orkney old fishing rope discarded on the shores or donated by local fishermen is turned into mats, doorstops and other items and is commercially sold by local business ‘Afrayedknot’.

Pathways to change to reduce the carbon footprint further is mainly associated with fuel consumption. Fishermen can adopt better practices which increases their fuel efficiency through strategic or operational changes to fishing patterns and vessels. In maintaining gear quality use of anodes can reduce the effects of ghost fishing and outlay on replacements. Further opportunities to change are associated with increased recycling efforts. This includes better harbour facilities to recycle rope and developing partnerships with industry partners which can facilitate the recycling process.

6. Conclusion

In conclusion, climate change is notably already influencing fisheries and fisheries management and increased attention is being directed towards reducing industry's overall CF. The CF of the inshore Brown crab industry was found to be unusually high and possibly unrepresentative of the industry. Efforts to reduce and monitor fuel consumption along with carbon offsetting such as recycling can help in developing greener pathways to change which can be adopted by fishermen to further reduce CF and increase sustainability.

Future developments and pathways to change should focus on;

- Whole chain analysis of Brown crab from catch to grave. Further analysis should also include other commercial shellfish species.
- Increase opportunities for fishermen to recycle more readily through improved infrastructure and incentives.
- Continued gear, vessel and engine maintenance to reduce fuel consumption and the replacement of gear.
- Reduction of overall fuel consumption through strategic and operational changes.

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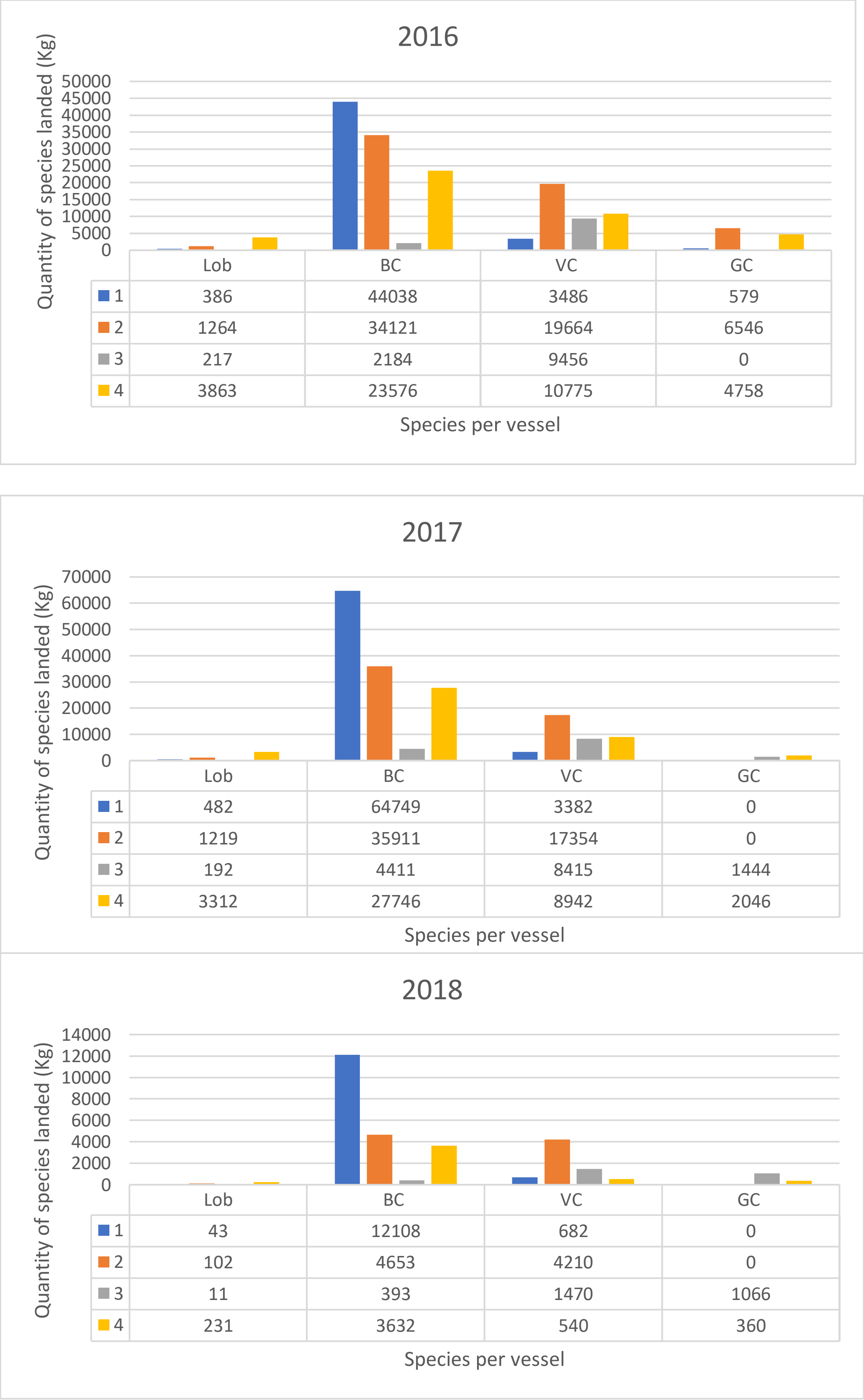
Appendices



2016

	Lob	BC	VC	GC
🟦 1	386	44038	3486	579
🟧 2	1264	34121	19664	6546
◼ 3	217	2184	9456	0
🟨 4	3863	23576	10775	4758

2017

	Lob	BC	VC	GC
🟦 1	482	64749	3382	0
🟧 2	1219	35911	17354	0
◼ 3	192	4411	8415	1444
🟨 4	3312	27746	8942	2046

2018

	Lob	BC	VC	GC
🟦 1	43	12108	682	0
🟧 2	102	4653	4210	0
◼ 3	11	393	1470	1066
🟨 4	231	3632	540	360

Figure 1. Quantity (Kg) of shellfish species landed (Lobster, Brown crab, Velvet crab and Green crab) between 2016-2018 on four inshore Orkney creel vessels.

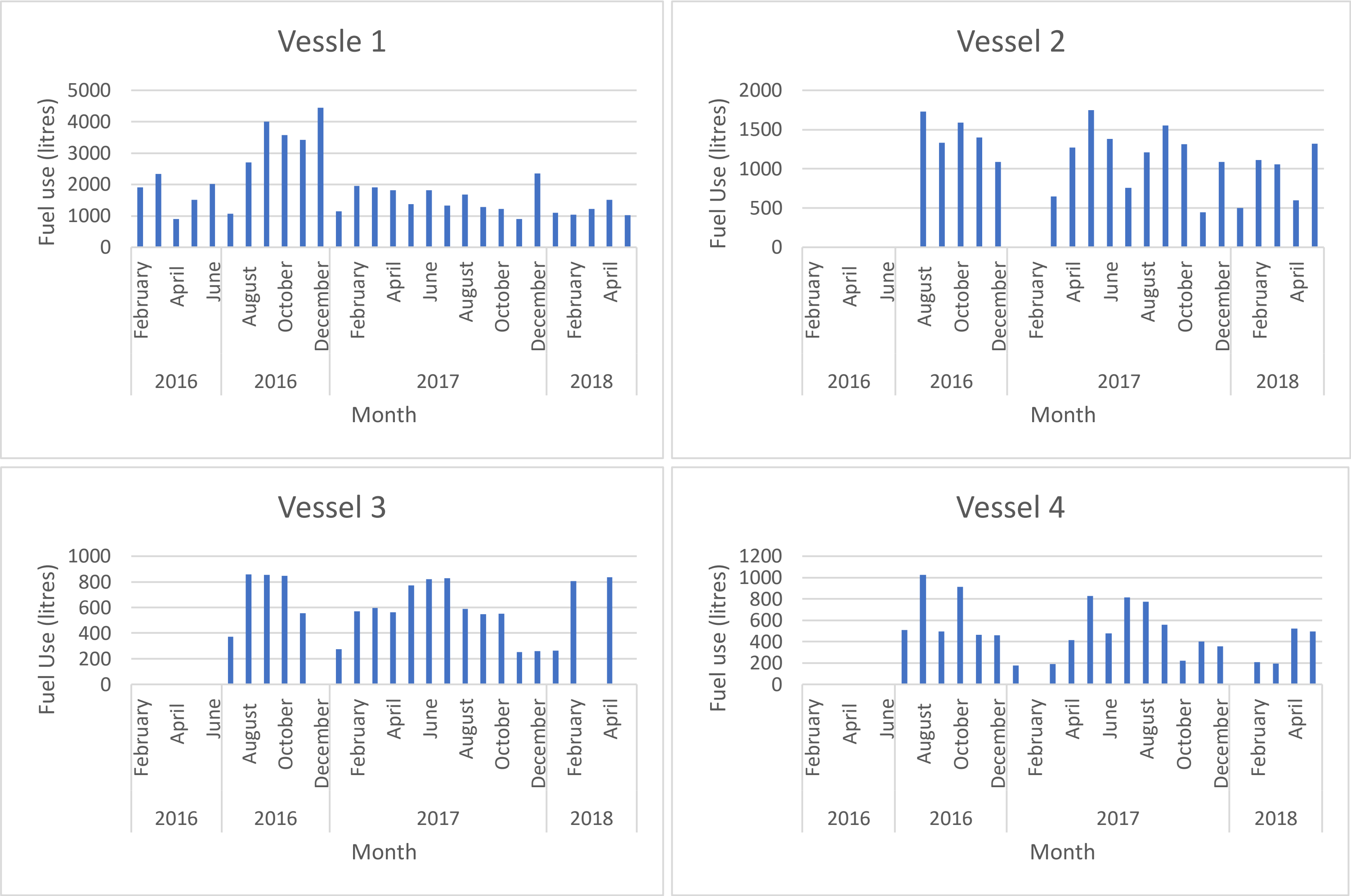


Figure 2. Monthly fuel consumption (litres) among four inshore creel vessels from 2016 to 2018.