Emission Profile of a Keystone Fishery and Recommendations for Fuel Management - A Case Study on the Isle of Man Scallop Fishery

By

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Abstract

This study presents a review of fuel consumption and emission profiles of the Isle of Man scallop fishing fleet. The results calculated the fuel intensity per kg of live catch and per kg of meat yield landed, and the subsequent emissions this produced for two economically important scallop species targeted on the island. Data was utilised from vessel licence details, catch and satellite data and from direct solicitation with the fishermen. The results provide fuel statistics across the fleet as well as emissions data (CO_2, CH_4, N_2O and total Greenhouse gases) which result from direct fuel consumption within the fishery. Of the two fishing methods used, fuel consumption for otter trawling was found to be significantly lower than that of dredging, with a difference of 19.20 l/hr with a fuel intensity of 105.73 l/t of live weight for trawling, compared to 21.81 l/hr with a fuel intensity of 541.33 l/t of live weight for dredging. However dredging, which targets *Pecten maximus* species, was found to be of a greater economic value to the fishing industry, providing a net value of £1,720,526 over the study period, more than three times the net value from the *Aequipecten opercularis* fishery. The emissions calculated from direct fuel use were 8510g of CO_2 per kg of live catch landed for *P. maximus* and 280g CO_2 per kg of live catch landed for *A. opercularis*. Whilst the Fuel intensity values are low compared to other fisheries, the emissions produced in the *P. maximus* are much higher than other fisheries. This highlights that this is an area where management should be directed. Options for decreasing fuel consumption and emissions produced through changes in behaviour and technology were concluded from this work. Areas in which the fishery would benefit from further research were also proposed.

Acknowledgements

I would like to thank all the staff at the fisheries department at the Department of Environment, Food and Agriculture (DEFA) for all their help especially Andy Reed, Lee Murray and Colin Eastwood. I would like to thank the Scallop fisherman on the Isle of Man who participated and cooperated in providing details for my study, as well as those staff at the processing plants and at the metal company who also aided the study. I would also like to thank my supervisor Brett Day for all of his help and technical support.

Abbreviations

$CaCO_3$ - Calcium Carbonate
Cm - Centimetres
CO_2 - Carbon Dioxide
CO_2e - concentration of CO_2 that would cause the same level of radiative forcing
CH_4 - Methane
CPUE - Catch per Unit Effort
DEFRA - Department for Environment, Food and Rural Affairs
EU - European Union
EUETS - EU Emissions Trading Scheme
FAO - Food and Agriculture Organisation of the United Nations
GHG - Greenhouse Gas
GJ – Giga Joules, 10^9 Joules
Kg - Kilograms
Km - Kilometres
KWh - Kilowatt hour
l - Litres
LCA - Life Cycle Analysis
m - Meters
Manx - Common term for that which originates or resides on the Isle of Man.
Max - Maximum
Min - Minimum
N_2O - Nitrous Oxide
N/A - Non Applicable
NDPB - Non Departmental Public Body
PO - Producer Organisation
pH - Acidity of a solution
Ppm - Parts per Million
Queens/ Queenies - Queen Scallops, *Aequipecten opercularis*
R^2 - correlation coefficient
RPM - Revolutions per minute
King Scallops - *Pecten maximus*
U.S - United States of America
VMS - Vessel Monitoring System
WWF - World Wildlife Foundation
UK - United Kingdom

1. Introduction

The impact on the environment due to human activities is a growing concern, driven by government legislations and also by public perceptions. Over the past decade there has been an increase in studies surrounding method development for quantifying these impacts across a range of industries and down to the individual level. These have arisen partly due to increasing levies and legislations which oblige companies to be aware of their impact and to limit it, failure of which may entail large penalties. An example or a programme which practises such behaviour is the EU Emissions Trading Scheme (EUETS), which regulates some of the largest industries in Europe such as the energy sector. Some industries may also wish to become involved with emission identification and reduction voluntarily in order to increase long term sustainability and to raise public persona. Fisheries are currently not regulated under any emission impact legislations. However this could change in the future as it is already a sector which has been identified as one which should be integrated into emission management schemes. It is in the interest of fisheries to have an awareness of their current impact, and to practice procedures with the aim of reducing it. This potentially not only increases marketability of the products but also reduces costs, thus, increasing profits margins.

Past studies in the fisheries area have focused on the energy balance of fisheries i.e. the energy used to catch the product vs. the energy gained from nutritional value of the product (Watanabe & Okubo, 1989). More current studies focus more on the issue of fuel consumption and catch per unit effort (CPUE) (Tyedmers, 2001; Zeigler & Hansson, 2003; Schau et al. 2009).

Fuel is considered to be one of the greatest inputs of the total energy use in fisheries. This can be demonstrated by looking at past studies such as Watanabe & Okubo (1989), whose results show that fuel oil accounts for between 77-92% of the total energy inputs. Tyedmers (2001) also estimated that direct fuel use accounts for 75-90% of total energy use. However many of the present studies (Tyedmers, 2001; Zeigler & Hansson, 2003; Schau et al. 2009) use averages over large fleets, estimating engine size, fuel consumption and fishing time. This current study takes this analysis a step further focusing on a small fishing fleet, but which has a large economic importance to the Isle of Man. The fishing fleet is assessed in detail and all estimates are made specifically for each vessel. These results will enable more accurate understanding of the impact of the fleets fuel and emissions produced as well as identifying areas where reductions may be achieved.

1.1. Fisheries

Fisheries are one of the world's most important markets, harvesting a range of species and products from freshwater and saltwater environments. It provides a range of opportunities, including 43.5 million people with direct employment (Cochrane et al., 2009), 110 million tonnes of food annually (FAO, 2009) and 15.3 % of global animal protein (FAO, 2009). It also provides a range of recreation and tourism opportunities, and supports social and cultural heritage around the world.

1.1.1. Scallop Fisheries

A species that was previously used for bait, scallops were of little commercial significance until 1883 when large scallop beds were discovered in America (Smith 1981). This saw an opening of a new market for scallops as a commercial food. Scallops are harvested by either; dredging, a process of dragging a toothed comb over the surface of the ground to stir sessile scallops into a net; trawling, where a chain is used to initiate swimming response in motile scallops so they can be netted in the water column; or by diving, where divers hand pick scallops from the sea bed. Scallops are processed onboard or sent to processing plants where they are de-shelled to be sold as meat or prepared as half shell. These are then sold either as fresh or frozen products. The shells may also be used as decorative items or other products.

Dredging and trawling can be very destructive to the marine environment, as a consequence of this scallop fisheries are often regulated to prevent overfishing and to preserve the habitats (Jones, 1992; Turner et al, 1999). Dredging is considered the most invasive and non selective fishing method of all current legal fishing methods (Collie et al., 2000a, 2000b; Eleftheriou, 2000). However, gear is continuously being developed and is moving toward finding less intensive and more environmentally friendly methods. Dredging and trawling also are two of the most fuel intensive fishing methods, due to the weight and resistance of the fishing gear (Figure 1). Fuel intensity can be variable across different boats due to differences in engine size, vessel age, and environmental factors such as wind and tides. Figure 2 illustrates this variability across fishing methods. The results show that variation among boats and trips is much greater in fisheries using bottom trawling and much less in fisheries such as Purse Seine. This indicates that a comparison study among these vessels may highlight reasons why some boats and trips are so fuel economical and why some are so fuel intensive.

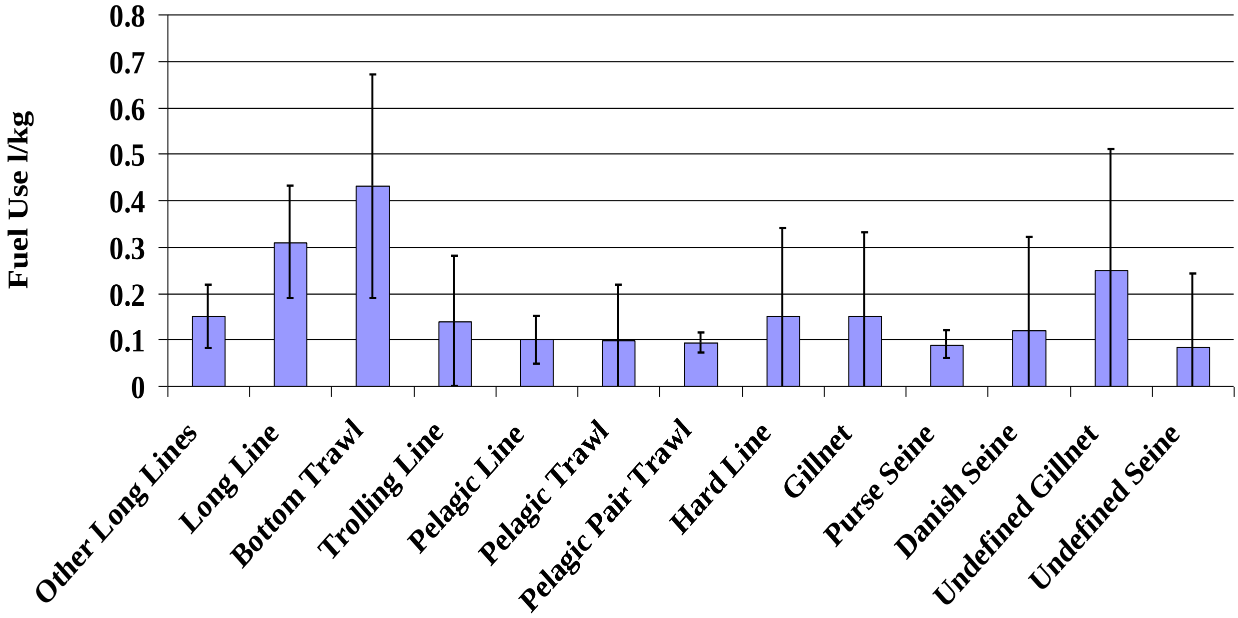


Figure 1. Fuel Factors of different fishing methods. Graph prepared using data from Winther et al. (2009). Fuel Factor measured in litres of fuel per kg of catch. Error bars show ± 1 Standard Deviation.

Although dredging and trawling are more fuel intensive methods of capture fishing, the fuel intensity, when compared to catches of specific commercial species, is often less. This may be due to overexploitation in some fisheries resulting in longer searching or travelling times. Tyedmers (2001) conducted a study which compared energy input vs. tonnes of catch output. He found that fisheries which use long-lining for large pelagic species, and other fisheries targeting invertebrates and ground-fish, were much more fuel intensive that a scallop dredging fishery (Figure 2). This is because fishing activities such as long lining for tuna often involve long journeys to fishing grounds, long periods at sea, and large volumes of bycatch, all of which increase the energy input per unit of catch (Hospido & Tyedmers, 2005)

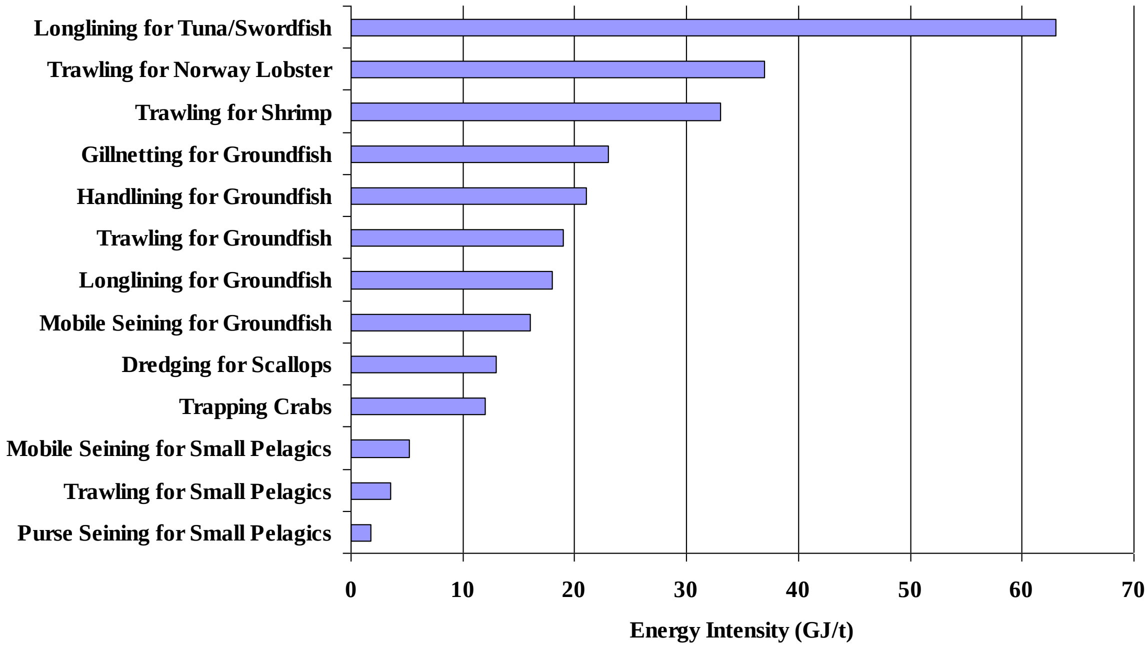


Figure 2. Fuel Intensity of different fisheries measured in GJ of energy per tonne of catch landed. Results adapted from Tyedmers (2001).

1.2. Climate Change

Climate change has been a topic of much debate over recent years, and there are grave concerns about the impact we as humans may be having upon it. Since instrumental records began, a strong correlation has been found linking changes in our earth's climate with increasing human activity (Trenberth et al, 2007). It has been the task of many scientists to investigate whether these climate changes are attributable to human activity, and it is now believed that it is extremely likely that human activities have exerted a substantial net warming influence on the earth's climate since 1750 (Solomon et al., 2007). One of the major impacts human activity has had on the earth is increasing concentrations of atmospheric greenhouse gas (GHG) concentrations. These GHG's are predicted to have vast and possibly severe impacts on the earth (Parry et al., 2007).

1.2.1. The Contribution to Climate Change by Fisheries

Fisheries have heavy environmental costs, depleting fish stocks, damaging sea beds and contributing directly to global emissions. It has been estimated that fisheries account for approximately 1.2% of global oil consumption and directly emit over 130 million tonnes of CO_2 in to the atmosphere (Tyedmers et al., 2005). Fossil fuels have been used in the fishing industry since the late 1800's when they took over from traditional animate (muscle powered) and wind powered fishing. Fishing vessels have progressed similarly to automotives originally being powered by steam with a move toward internal combustion engines after their invention (Tyedmers, 2004).

Direct fossil fuel use in fisheries accounts for 75-90% of all energy inputs (Tyedmers, 2001). The remaining inputs come from energy use in construction and maintenance of vessels and gear, and the processing in to final products. Seafood products are some of the most travelled products in the world (Anderson, 2003) exceeding trade in meat, tea, coca and wine, with significant emission implications.

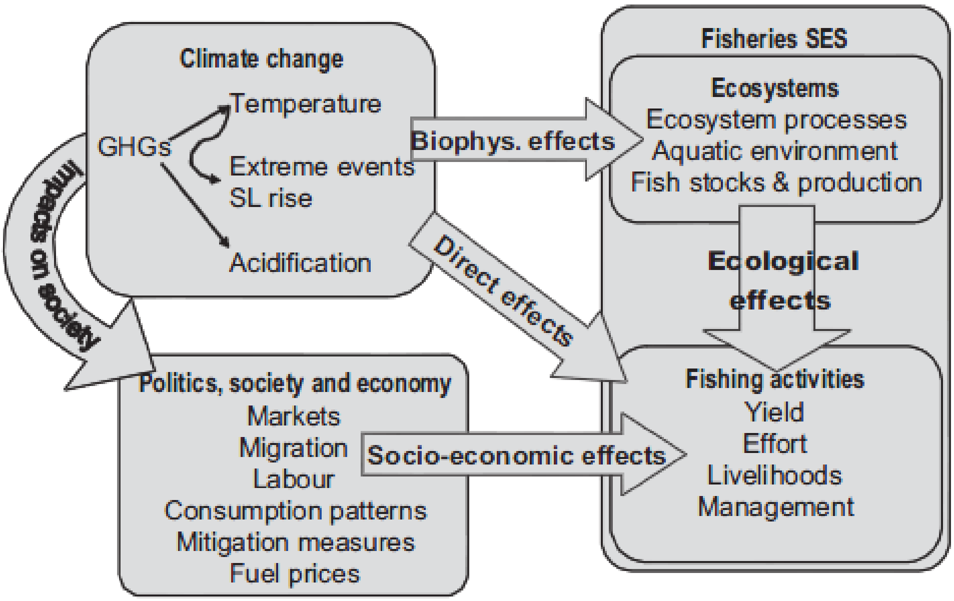
Red diesel is the fuel used by the majority of fishing vessels (Abernethy et al., 2010). Red diesel is distinguished by its red colour, a chemical dye to prevent illegal use in road vehicles. Chemical differences between this type of diesel and roadside (or white) diesel lay in the sulphur content and the combustion quality (cetane rating). Red diesel contains more sulphur than automobile diesel up to 0.2% compared to white diesel which has a low content of 0.005% (Caslake & Garrett, 2009). Red diesel is also slightly harder to burn as a small percentage is dye and so it is not pure.

A process which systematically describes and quantifies environmental impacts is Life cycle analysis (LCA); this has been increasingly applied to food production systems (Mattsson & Sonesson, 2003). LCA has been conducted on a number of different fisheries (For review see, Pelletier et al., 2007). These have highlighted many of the major environmental and socio-economic impacts of fisheries, and indicate that the impacts of fuel consumption in the fishery dominate the overall environmental impacts. Due to this disproportionate share of impacts, fuel use should be assessed individually from other impacts. The quantification of fuel use alone may provide a valuable indicator of environmental performance (Papatryphon et al., 2004). Fuel use may also act as an indicator of exploitation levels. This is due to the indication that overexploited stocks require greater fuel in order to fish the same value of fish (Tyedmers, 2001; 2004; Schau et al., 2009). Therefore greater fuel intensity may indicate an over-exploited stock.

A comprehensive LCA was conducted by Thrane et al. (2009). This systematically identified all impacts arising from Fisheries in Denmark. The process incorporated; fishing vessel and gear production, stock impacts, impacts on other species, impacts on the marine ecosystem, GHG's, processing and Consumer impacts. A study which assessed each of these impacts on a stage by stage basis would provide a comprehensive study of the environmental impacts of a fishery and would be very useful especially on a fishery which contributes such a high percentage to the economy such as scallops on the Isle of Man. However due to time constraints this type of comprehensive LCA methodology will not be conducted here.

1.2.2. Impacts of Climate Change on Fisheries

Fisheries do not just contribute toward climate change but may also be heavily impacted by the consequences of climate change. Fisheries have long been influenced by changes in the climate such as upwellings and hurricanes (McGowan et al., 1998). However future climate predictions forecast that as well as increases temperatures, there is a risk of increasing occurrence of extreme events, both of which will have severe implications for fisheries in the future (Bindoff et al., 2007). Figure 3 summarises some of the effects on fisheries and fishery communities that are likely to occur due to climatic change in the future, highlighting the variety of impacts that can result from these changes. A more detailed description of these can be found in Allison et al. (2005). These impacts highlight the importance of fisheries tackling their own contribution to climate change in order to help provide a sustainable future.



Ecological impacts (covered in paper 1)	Direct impacts	Socio-economic impacts
Change in yield Change in species distribution Increased variability of catches Changes in seasonality of production	Damaged infrastructure Damaged gears Increased danger at sea Loss/gain of navigation routes Flooding of fishing communities	Influx of migrant fishers Increasing fuel costs Reduced health due to disease Relative profitability of other sectors Resources available for management Reduced security Funds for adaptation

Figure 3. Ecological, direct and socio economic impacts of climate change on fisheries. Taken from Daw et al. (2009)

1.2.3. Emission Profiling

Very few studies focus specifically on emission reduction or the contribution from fisheries in regards to climate change. Some studies have attempted to estimate the total past emissions of the global shipping industry including fisheries (Eyring et al, 2005; Endresen et al, 2005). Other studies have estimated the carbon footprint of fishing activities. A study carried out by the World Wildlife Foundation (WWF) attempted to profile the carbon impacts of tuna fisheries (Tan & Culaba, 2009). The study used life cycle analysis based on input-output models which are inspired by

Leontief methodologies. Using estimations of fishing time and averages of catch, fuel consumption per kg was calculated, which was then transcribed in to CO_2 equivalent.

Tydemers (2001) conducted a study in the North Atlantic fisheries. Direct fuel estimates were made using a solicited value of fuel consumption, vessel horsepower and the time spent at sea. This gave a result for fuel consumption vs. effort; this was further transcribed in to fuel intensity giving values for litres of fuel per tonne of catch over a range of fishing methods which can be used as a comparison against other fisheries.

A study by Zeigler & Hansson (2003), profiled the emission data resulting from direct fuel use in the Swedish cod industry. This data was then combined with future scenarios in the fishery, to estimate what differences could be made and what impact this would have on the fishery. The results estimated emissions per kg of catch and presented a range of proposals for fuel reduction within the fishery.

1.2.4. Emission Reduction

One of the major ways fisheries can decrease their climatic impact is via emission reduction strategies. These can often be very low cost and even cost saving providing incentives for behaviours to be continued. A study carried out by Seafish, a Non Departmental Public Body (NDPB) sponsored by UK government fisheries departments, investigated fuel efficiency in the UK fishing fleet and proposed where reductions can occur (Curtis et al., 2006). Many of these reductions proposed incurred no additional costs such as reducing towing and steaming speeds but could provide up to 50% fuel reductions at 70% of the maximum speed. However it is difficult to place a value on what towing RPM or speed should be used as the fuel efficiency will be heavily impacted by tides, wind and waves. This means that what may be optimal in one direction, may not be optimal in another. But if the reductions are performed right, fishing vessels are estimated to make substantial fuel savings, e.g. a reduction in steaming speed saving 28 litres a day over 220 fishing days a year and over 35 fishing vessels, equals a financial gain in the region of £70,000. Other fuel saving practices included changing trip planning practices, changing landing port and replacing the engine, some of which may incur much heavier costs. In order to assess the best saving to be made, vessels must be assessed on an individual basis.

The energy efficiency of fisheries is, highly influenced by management and regulatory strategies set out by fisheries management divisions (Standal, 2005; Driscoll & Tyedmers, 2010). Regulations such as quota limitations, spatial, temporal, technological limitations, and landing restrictions, all impose changes in fishing behaviour which may directly influence fuel efficiency. As fisheries, lay outside of any emissions reduction proposals, it currently lies upon the actions of local authorities, regulators, and fisherman to tackle fisheries current environmental impacts, including emissions, to ensure long term sustainability. Adoption of emission reduction schemes can potentially provide economic incentives, such as decreasing costs due to lower fuel use and increasing sales due to market demand for sustainable products.

Individual fisheries need to be assessed independently in order to achieve the most efficient and appropriate strategies. These strategies must tackle; the anticipation of fish population changes; identifying those areas most at risk and those which are most resilient; assessing and quantifying current contributions to climate change and adopting appropriate measures to reduce these; adopting integrated management plans which look at reducing impact as well as preserving stock and promoting sustainability; planning for social and economic consequences of climate change and planning appropriate adaptation and mitigation measures. In order to achieve these, research must be carried out into the ecology of the fishery, climate change predictions and impacts on the fishery, as well as research in to the adaptive capacity of the fishing and local communities. It is advisable that precautionary approaches should be adopted, and although these may initially infer increased costs or decreased profits due to gear changes or catch restrictions, in the long term it is likely to provide prolonged sustainability of the fishery and greater economic certainty for the community. Reductions in fishing pressures and expansion in to new species and markets may reduce strains on individual species while minimising economic losses. Expansion of industries that communities rely on, and the provision of new job training for existing fishermen, can help to decrease reliance on fisheries and provide greater economic expansion opportunities increasing the resilience of communities particularly in small isolated fishing dependent areas (Glyfason, 2004).

2. Case Study – The Isle of Man Fishery

The Isle of Man is a self-governing dependent territory of the Crown. It is situated in the west of Europe in the Irish Sea, between the islands of Great Britain and Ireland. The island is not part of the United Kingdom, but its foreign relations, defence, and ultimate good governance are the responsibility of the Government of the UK. The island's own parliament and government are responsible for all domestic matters. The island is also not part of the European Union (EU) but allows free movement of goods between itself and the EU as set out in Protocol 3 to the Act of Accession annexed to the Treaty of Accession 1972.

The island is 52 km long and 22 km wide at its widest point. It has an area of around 572 square km. The fishery is contained within a 12 nautical mile radius around the island, giving a total fishing area of 3967.4 km^2.

The fishing fleet on the Isle of Man currently exploits five main fisheries; king scallops *Pecten maximus*, queen scallops *Aequipecten opercularis*, common lobster *Homarus gammarus*, brown crab *Cancer pagurus* and whelks *Buccinum undatum*. Some bony and cartilaginous fish are also exploited by small scale fishing vessels and as bycatch from the queen scallop fishery. Please note that from here forth the names King scallops will be used interchangeably representing *P. maximus* and the names queens or queenies for *A. opercularis*.

Since the discovery of stocks of shellfish around the island these have become an important part to the Manx economy. Scallop species are collectively regarded as one of the islands biggest fishing industries, totalling approximately 80% of first sale value of all fishing products on the island (Brand & Prudden, 1997) and directly employing over 150 people. The fleet is composed of small day vessels which land directly to the island. Catch is then transported straight to local processing plants on the island. Scallops from the previous day are processed the following morning ready to ship that day. Demand for scallops on the island and in the UK is low and most exports are directed toward mainland Europe with France being the major buyer. There is no catch limit on *P. maximus* and the amount of catch is usually regulated by availability. *A. opercularis* is only caught to demand and processors may place catch limits to its suppliers depending on demand. If the market was greater there may be sufficient populations to support a greater catch (Kaiser et al., 2008).

The Manx scallop fleet is comprised of approximately twenty five day vessels, although this value fluctuates on a yearly basis. Around half of the fleet land solely to the Isle of Man and the other half land to the island as well as other ports, and may fish in other areas travelling to Ireland, Wales and Scotland for periods of time. However fishing vessels from outside the Isle of Man may also obtain licence to fish in the territorial waters and so sites are often exploited by UK and Irish Vessels.

Legislation and regulation of the fishery began early on in its development with a closed season and minimum catch size regulations in place since 1943 (Brand et al., 2006). Currently the *P. maximus* regulated fishing season runs from the 1st of November until the 31st of May. During this period fishermen mainly fish *P. maximus,* and during the closed season fisherman tend to target *A. opercularis.* All Manx boats exploiting the Scallop fishery must be fitted with a Vessel Monitoring System (VMS). This differs to UK legislation which currently only demands vessels over a certain size to be fitted with these devices. All boats landing to the island must also complete log sheets which must be returned to the fisheries department promptly, which highlights number of hours fishing, type of gear used and total catch and bycatch landed. There has also been a number of closed fishing zones developed which act as refuges for Scallops providing a healthy population of new recruits each year.

2.1.1. King Scallops *Pecten maximus*

P. maximus is the most desirable species of scallop on the island. *P. maximus* can swim when disturbed and often recess in to the sediment (Baird, 1958; Brand, 2006). The *P. maximus* fishery however differs greatly to that of A. *opercularis* utilising dredges to comb the bottom substrate. *P. maximus* is more valuable than A. *opercularis* meat selling approximately £8.63 a kg in the 2008-2009 season.

The most common dredges for *P. maximus* on the Isle of Man are toothed dredges or ‘Newhaven dredges’. The sediment around the island is often rough and so many vessels use spring-loaded dredges. The dredges are set in triangular frames and differ to other dredges as they have no cutting bar or tickler. Instead these are replaced with a toothed bar with steel teeth or ‘tines’. The style which is used on the island consists of smaller dredges approximately 75cm wide with 9 teeth (Dare et al., 1993, 1994). This differs to the Scottish vessels which tend to have longer dredges 2m long with 12 teeth (Chapman et al., 1997). The teeth dig in to the substrate and essentially rake the seabed. Spring-loaded dredges are beneficial as they retain less unwanted material and are better for uneven ground which reflects on fuel consumption and gear wear. However, the dredges are heavier and so this weight may counter balance any fuel savings. Figure 4 illustrates the use of these spring-loaded toothed dredges. The efficiency of dredging is relatively low. Spring loaded dredges have a catch efficiency of approximately 6% on rough ground and 41% on smooth ground (Chapman et al., 1977).

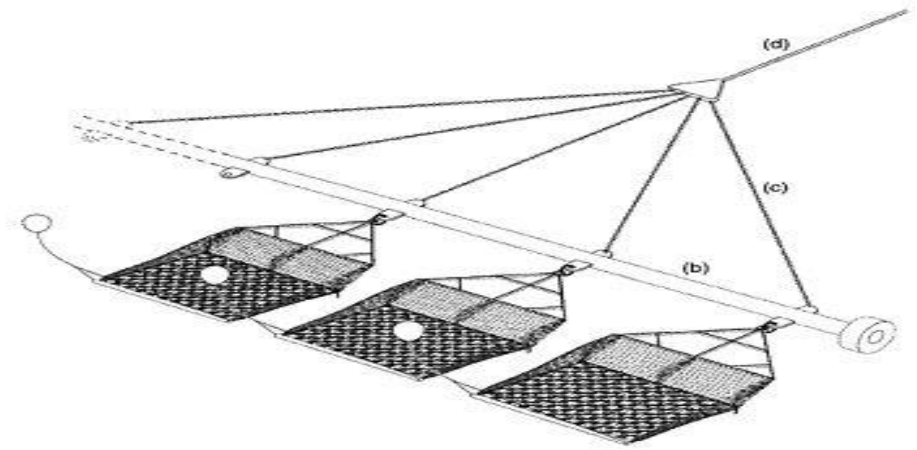


Figure 4. Diagram illustrating the use of a spring-loaded toothed dredge which is used to capture *P. maximus.* Taken from Carew (2010)

2.1.2. Queen Scallops *Aequipecten opercularis*.

A. opercularis is a highly exploited species of bivalve and common to the shores of the UK. *A. opercularis* is a free swimming species; therefore they can be caught in the water column using nets. The most used equipment in the Isle of Man fishery are otter trawl nets and toothless dredges, although some boats without capacity for nets may use toothed dredges. The swimming response of *A. opercularis* is affected by water temperature, with greater temperatures resulting in a more active swimming response (Jenkins et al., 2003). This means that favourable fishing periods using nets are during summer months.

The trawl is towed along the seabed where hydrodynamic pressure pushes the otters outwards opening the net mouth. Otter trawls act like a plough and can dig up to 15cm into the bottom substrate. This only occurs at either end of the net and creates a turbid cloud, this disturbs *A. opercularis* which then swim up and are caught in the net. Figure 5 provides a diagram of this process.

A. opercularis is a less valuable species selling for approximately £3.10 per kg during the 2008-2009 fishing season. However they are less time intensive to catch therefore fisherman often catch large quantities during relatively short fishing days.

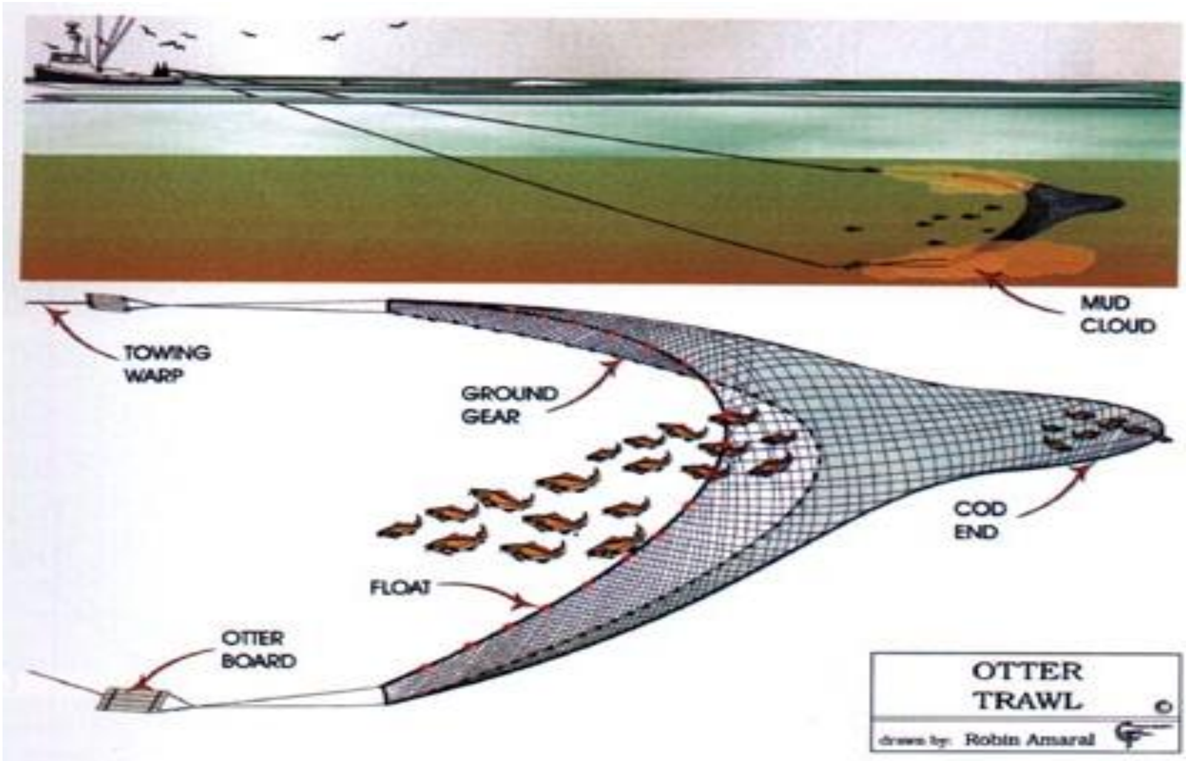


Figure 5. Diagram illustrating the use of an otter trawl which is used to capture *A. opercularis* on the Isle of Man. Taken from Smolowitz (1998).

3. Aims and Objectives

Research Focus

To investigate the direct fuel consumption within the Isle of Man scallop fishery, and to assess the impact of this on global emissions.

Overall Aim

The overall aim of this research is to advance an understanding of direct fuel use and the emission profile of the fishery, whilst investigating ways in which these may be reduced in the future.

Research Objectives

Specifically, within the context of this study, the objectives of this research are to;

1. Identify the fuel consumption of each vessel and to calculate total fishing time, in order to find total fuel consumed over the study period.
2. Evaluate the fuel intensity and the emission profile resulting from this direct fuel use.
3. Examine the journeys and vessels which can be regarded to carry a high fuel/emission footprint and explore the reasons why this may occur.
4. Formulate recommendations which highlight where fuel reductions may be imposed in order to improve the fisheries environmental impact.

4. Methods

4.1. Data Available

Satellite Vessel Monitoring System (VMS) - Received from all Isle of Man registered vessels fishing for *A. opercularis*, and by all vessels >15 m in length. Records are received at two hourly intervals. The data available spanned from June 2007 onwards.

Fisheries Logbooks - Logbooks are returned by all fishers landing into the Isle of Man. Catch and bycatch must be included as well as hours spent fishing, sites visited and gear used.

Live Weight to Meat Ratio - After correspondence with one of the main scallop processors on the island, access was given to records which included live caught weight and sellable meat yield weight that this transcribes too. The processors cliental included 16 out of the total 25 scallop vessels on the island.

Fuel Supplied – From Fisheries Producer Organisation (PO) - Although not all boats use the PO as their main or exclusive supplier, many of the fishing fleet do. This data will be used as an aid and a comparison stage to increase reliability and accuracy of my results.

4.2. Method Development

According to Tydemers (2001), direct fossil fuel use in fisheries accounts for 75-90% of all energy inputs. Therefore it was hypothesised that focusing on direct fuel use would be a viable indicator of emissions. Driscol & Tydemers, (2009) also suggested that the GHG intensity is directly related to the fisheries fuel intensity further backing up the decision that direct fuel use during fishing will provide a good estimate of overall industry GHG emissions.

A study on the fuel consumption of a Swedish cod fishery highlighted what information is needed in order to successfully calculate fuel consumed and the associated emissions, a detailed outline of which can be found in Ziegler & Hansson (2003), figure 1. The inputs which are related to this study are listed below;

- Engine Data
- Fishery statistics
- Fuel consumption
- Bycatch data
- Economic value
- Emission factors

These inputs will be attempted to be identified in the Isle of Man fishery.

4.2.1. Assessing Energy Inputs

The energy inputs and consumption of the fishing fleet will be calculated as accurately as possible based on an individual vessel basis. Estimates for each individual boat in the fleet will be conducted and details surrounding their individual fishing behaviours will be collected. This information will allow for detailed further analysis to be conducted on the fleet, which will be beneficial toward assessing and proposing the integration of fuel management methods in the fishery.

Previous studies of energy consumption in fishing vessels have used one of three methods;

1. Directly obtaining the fuel consumed (Rawitscher & Mayer, 1977), which can be calculated by finding out average fuel consumption and time spent fishing or via finding out the total fuel supplied or amount spent on fuel.

2. Estimating fuel consumed via gear specific averages and landing data (Tydemers et al., 2005; Driscoll & Tydemers, 2010), which may be useful on large scale but when looking at a small fleet may produce very rough estimations as fuel use varies greatly boat to boat.

3. Estimating fuel consumption as a function of engine horsepower and vessel performance data (Tydemers, 2001; Eyring et al., 2005; Schau et al., 2009). This technique could be applied using the engine manufactures specifications. Fuel curves may be available which can be converted into KWh or used along with speed data to estimate engine RPM which the directly relates to the fuel

curve date. Figure 6 shows an example fuel curve for one of the common engine types among the fleet the Cummings NT855.

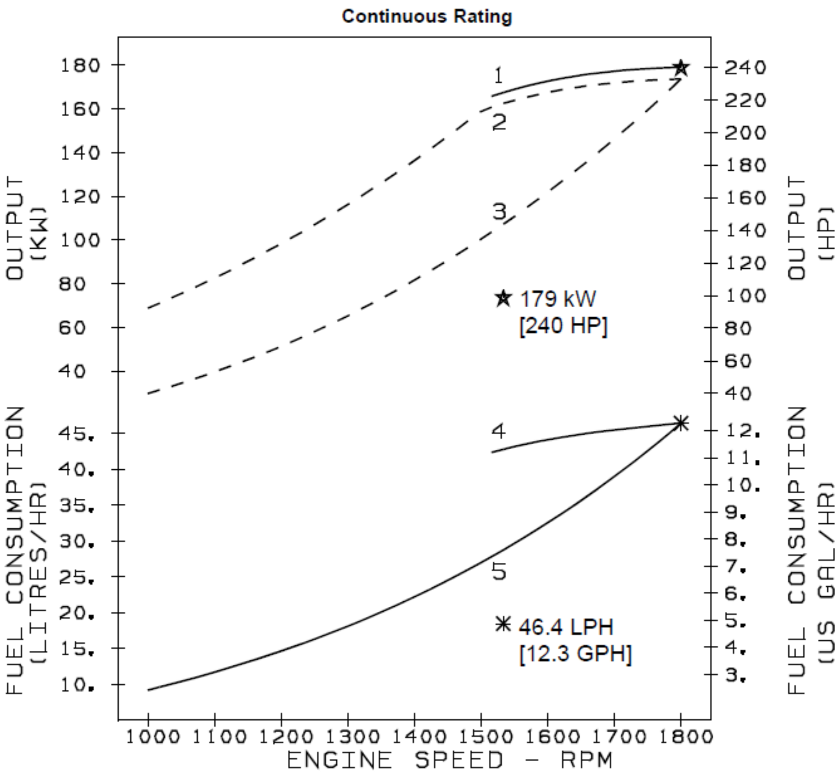


Figure 6. Fuel curve data for the Cummings NT855 engine taken from the manufactures factsheet the data which is of value are the propeller power curves represented by lines 3 and 5. Line 5 gives values of fuel consumption in litres per hour (l/h), line 3 gives values of energy produced in kilowatts (KW).

However after initial research applying this method to the data set available it was found that it is very difficult to estimate the engine RPM based on speed and that this method would entail detailed analysis into each boat and time consuming data handling sessions in order to categorise specific actions. It was therefore decided that this method will not be applied when looking at the whole fleet but may be useful in looking in detail at a specific vessel later in the study.

It was decided that the best way to obtain total fuel consumption would be via direct solicitation with the fisherman to obtain an average fuel consumption value whilst performing different types of fishing activities.

4.3. Questionnaire development

To gain more insight on how the questions for the questionnaire should be structured, an interview was set with one of the skippers from the fleet. This enabled clarification of terms that should be used in the questionnaire, what units should be asked for, and how knowledgeable each skipper should be about these details of his vessel. A breakdown of the topics covered and responses received in the interview is included in Appendix A.

Observation trips were organised which allowed an observer onboard during fishing trips in order to gain a greater insight into the physical processes, technical jargon and basic trip procedures. This allowed appropriate terminology to be applied whilst setting questions and gave an understanding of the necessities and limitations of the industry.

The questionnaires developed from this discussion are shown in Appendix B and C. The first questionnaire developed was aimed specifically at inferring an estimate fuel consumption value for each boat whilst dredging and trawling. The second questionnaire was developed to highlight fishermen's concerns, interests and willingness surrounding fuel consumption and fuel reduction methodologies.

However for some vessels it was not possible to obtain details about fuel consumption in this way, due to factors beyond control. For these vessels it was decided that the fuel consumption would be estimated by matching it with similar engines and identifying a relationship between fuel consumption and dredges towed aside. This will give reasonable estimates of possible consumptions, however fuel consumption is often linked to the way the boat is used and so may not be definitive resemblances of what the boat actually used in this year.

4.3.1. Fuel Consumption

For vessels where fuel consumption from questionnaires was not obtained a range of techniques were used to infer and estimate fuel consumption. Information about each vessel was available such as engine make, engine horsepower and how many dredges aside are usually towed (included in Appendix J). For boats where several other vessels utilise the same or similar engines a comparison was made in order to infer estimated fuel consumption based on dredges aside. For queenies which do not dredge, an average fuel consumption of the most similar vessels was used.

The most common engine in the fleet was the Cummings NT855. Six of the questioned vessels had this engine with a range gear used. This enabled a good spread to produce a graph which related fuel consumption to the number of dredges (shown in Appendix E).

For vessels with Gardner engines there were two different models. These two models were compared against each other and it was found that the performance was very similar (see Appendix F). This enabled the data for both engines to be pooled together to be used for fuel consumption estimations. As with the Cummings engine, the dredges aside were compared against fuel consumption and plotted on a graph for both King scallops and Queenies for the Gardner engines (shown in Appendix G).

The final common engine was Caterpillar branded, however the models varied and there was no performance information available on the manufactures website for comparison. When the different vessels are compared however, they display a very close relationship with fuel vs. dredges aside (see Appendix H). Therefore it will be assumed that all caterpillar branded engines have similar performance and were pooled together.

This methodology provided estimations of fuel consumption for six out of the eight unknown vessels. However the final two had very different engines which were not comparable with this information alone. Engine horsepower was another parameter which was available, it was decided that for the remaining two vessels the fuel consumption would be estimated based on the closed matched vessel comparing horsepower and dredges aside (shown in Appendix J).

For vessel M, which had the lowest engine horsepower of the fleet, the closest match was vessel L which also carries the same number of dredges aside. For vessel G the closest vessel match based on engine horsepower are vessels H and T. However both of these vessels tow six dredges aside, where vessel G tow's eight. Vessel H uses a caterpillar engine, and vessel T, a Cummings NT855. Using calculated r^2 equations it is possible to interpolate forwards and estimate fuel consumption at eight dredges aside. An average of which was used to estimate vessel G's fuel consumption.

4.3.2. Total Catch and Meat Yields

Total weight of live catch and the corresponding ratio to meat yielded was identified using the logbook data and the data provided from processing plants. Logbook data was all computerised and allowed easy establishment of daily catch in kg of *P. maximus* and *A. opercularis.* Logbooks also allowed comparison of bycatch caught compared to total scallops caught. This is important to identify as when bycatch is landed, the total fuel consumed is not all directed in to scallop yield but also into other fish catch adding a value of uncertainty into our calculations.

Meat yields obtained from processor factories were used to identify and estimated the ratio of live weight compared to meat yield. Sixteen out of the total twenty five fishing vessels in the study, landed to one main processor. By comparing live weight to meat yielded for these sixteen vessels it will be possible to identify and average live weight to meat yield ratio which can then be transferred toward the remaining nine vessels, which data was not obtained for. It is important to infer both these values as it allows us to standardise the emission impacts per kg caught and/or per kg of meat yielded. Unfortunately this data was not obtainable for Queenies as the processor log sheets work on a different system to king scallops where catch is paid via live weight instead of meat weight. However after conversation with the owner of the processer it was found that his recent review of the catch had found Queenies to yield at a live weight to meat yield ratio of 7.6 approximately 13.2%

4.4. Economic Value

The value of the catch was estimated using the prices paid from processors log sheets. The values recorded for king scallops were presented as price per kg of meat yield. The value for queenies however was given as price per kg of live weight. Using the calculated live weight to meat yield ratios this value was turned in to an estimated price per kg of meat yield. An average value for each vessel was calculated and then further averaged to get price per catch species (see Appendix K). This gave an end estimate of £8.80 per kg king scallop meat and £3.04 per kg of queenie meat.

The cost of fuel was estimated via looking up fuel prices during the study period. Research from a range of sources show that during the study period fuel prices were very variable The estimations used from this study come from a fuel checker forum (British Farming Forum, 2010), where users from around the country update the price of their recent purchases, this enabled a month by month estimation of fuel and therefore a more reliable average over the study period. Other sources were not as detailed as this and often had one price during the study periods. Fuel companies could be contacted as well as the fuel suppliers on the island to try to get a more accurate estimation of fuel costs over the study period if further studies were conducted. An average fuel price value of £0.42 per litre was estimated for the study period (see Appendix L).

Some by catch species were observed, but these represented a negligible percent of the total catch and so were not thought to impact fuel consumption or value as they are not sold but rather discarded or eaten by the boat crew (see Appendix D)

4.5. Data Analysis

As there is a complete set of data available, the study does not involve statistical analysis but rather revolves around calculations to infer the desired values. Statistics can be utilised to infer relationships across a sample from a population. However as there is the complete population of vessels and data available, data must be transformed and organised, so that calculations can be performed in order to achieve the results sought after.

The raw data was obtained in Microsoft Excel 2007 (Microsoft Corp, Redmond, Washington) spreadsheets. In order to allow calculations to be performed quickly and accurately over the large data set, Data was re-organised in to databases in Microsoft Access 2007 (Microsoft Corp, Redmond, Washington). The first stage was to organise the VMS data and to separate the entries from outside of the fishing area and from when boats are in port. To do this, port coordinates were identified and all entries falling within a range classified as a port were assigned a number. This was achieved using the query and update functions, and by assigning criteria for each port. This meant that all entries that were outside of ports were labelled with a zero.

The ports in the fishing area were then identified. The Isle of Man consists of four main ports; however some surrounding ports on the coast of Ireland and Scotland are also used to land catch if vessels are over quota to land to processors on the island. These were included in the study but only when fishing activities had occurred in Manx waters. The data was then organised to count how many zeros were encountered on each date. This value was multiplied by two to represent the two hours at sea that each zero represents. The completed table identifies how many hours were spent at sea on each date.

Data then had to then be linked to journeys where catch was recorded. To do this catch data was inputted into a new database. Then a new query was designed which merged this data with the VMS data based on a date tag. The result was a new database where for each day where a catch was recorded, the fishing hours calculated in the VMS database was assigned in to an adjacent column.

New columns were then added which assigned the fuel consumption of each vessel for each fishing method to each data row. The average value paid per kg of meat yield was also added, as well as the price of fuel. The data was then further processed and queries designed to calculate fuel used per kg of catch caught, meat yield, value of catch and cost of fuel. Once the database was completed simple queries could be designed which worked out the sum of values which was needed such as the total fuel, the total value of catch and the total fishing time. These could all be calculated over the whole fleet, per vessel and on a month by month basis.

Further studies were then carried out in Arc GIS 9.3 (ESRI, Redlands, California. Here VMS data was put back in to Microsoft EXCEL 2007, where it could then be added in to a new geodatabase in ARC Map. A map of the UK and Isle of Man was acquired via the DIGIMAP (EDINA, Edinburgh) online database. The VMS coordinates then had to be transformed from the global geographic coordinate system to the British national grid format in which most data from DIGIMAP comes in. Once transformed, coordinates from daily trips were identified from the dataset. These were then exported in to different layers on a month by month basis. This resulted in a map in which locations of fishing trips in each month over the study period could be identified. This was then used to make comparisons with monthly differences in fuel and variations in the price for the catch which is representative of the size and quality of scallops caught.

4.5.1. Emission Factors

To build the emission profile for this fishery a number of resources were drawn upon. The fuel type used was marine or red diesel. Government recommended emission websites such as The Greenhouse Gas Protocol (2010), DEFRA (2009) and The Carbon Trust (2010) all have guidelines and calculations for calculating emissions from electricity, fuel and the production of common materials such as steel. However none of these have specific calculations for red diesel. A review of the literature found several values which were used to illustrate emissions from red diesel. Caslake & Garrett (2009) provide a value of 2.25 tonnes of CO_2 produced for every tonne of fuel burned. However the source of this value was not cited and although contact with the authors was attempted it was not possible to locate the origin of this value. It was decided that the calculations provided by DEFRA for Diesel would be used as a guideline for actual emissions produced (DEFRA, 2009), these can always be altered in a future study if sufficient data is found for a more accurate analysis of red diesel.

4.5.2. Sensitivity analysis

The main sources of error from this study arise from fishing time and fuel consumption. Fishing time was calculated by the out of port VMS logs, however these log at two hour intervals and so there is possibly two hours of variability at both leaving and entering port times. To include this into the analysis, an extra set of columns were added in the access database; - a maximum fishing time which added four hours on to the fishing time, and a minimum fishing time which subtracted four hours from the fishing time. These values were then combined with the fuel consumption data to produce new values for maximum fuel used and minimum fuel used. These values were also combined into the emission calculations to give an indication of the confidence of the results.

For the fuel consumption estimating, variation is a lot more difficult. Many factors influence the fuel consumption, from the age of the engine, to the behaviour of the skipper. It was not possible to identify an appropriate variance that may be entailed from fuel consumption estimations. However a range will be used of 10% and 25% to see whether this makes a significant impact on the results and to identify whether this is an area which may need development of a more accurate estimation methodology.

5. Results

5.1. Total Catch

Table 1. Total catch of scallops from the period November 2008 - October 2009.

	Total catch (Tonnes)	
Vessel	**King Scallops**	**Queenies**
A	82.89	112.84
B	27.30	16.13
C	40.45	1.10
D	33.84	14.95
E	44.75	0.73
F	64.57	74.71
G	72.17	0.11
H	73.31	183.33
I	44.94	120.83
J	40.30	141.58
K	42.82	0.00
L	26.00	14.36
M	17.43	23.42
N	58.23	30.23
O	60.24	103.28
P	86.08	96.15
Q	53.04	0.64
R	99.48	0.00
S	29.86	29.80
T	19.12	35.13
U	63.52	120.41
V	5.34	48.27
W	53.18	53.93
X	49.40	97.15
Total	1188.22	1319.07

Table 1 shows the total catch of each species in kg per vessel as calculated from the database. The largest individual vessel king scallop catch was achieved by vessel R netting 99.48 tonnes of live catch over the study period, the vessel which caught the least amount was vessel V at 5.34 tonnes of live weight over the study period a 95% difference. In the queenie fishery the largest catch was achieved by vessel H with 183.33 tonnes of live catch and the lowest was from vessels which did not catch queenies or only caught small numbers as bycatch. All vessels participated in the king scallop fishery, however not all the vessels partook in queenie fishery. This is likely due to the lower selling price of queenies and low daily quotas. This means that for some vessels it is not very profitable for them to stay and fish queenies as they could move to an open scallop fishing ground and catch more valuable king scallops. Currently there is no legal quota on queenie fishing, the quotas imposed are enforced by the processors and linked to market demand (Vause, 2007). Some vessels did catch small values of queenies as bycatch; these were vessels C, G. E and Q.

5.1.1. Live Weight to Meat Yield

The live catch to meat ratio was inferred using the data provided by the processors; these results are highlighted in table 2. The averages obtained for king scallops resulted in a live catch to meat weight ratio of 5.96, approximately 16.79%. Queenies were found to yield a live weight to meat yield ratio of 7.6 approximately 13.2%. Using the live catch to meat yield ratios it is possible to estimate the meat yield for each boat using the total catch results from table 1. These will result in new values of total catch but in relation to meat yielded. These results are shown in table 3. From the live weight to meat yield ratios we can see that the values can be variable between the vessels. Vessel K yielded the greatest average at 4.38 or 22.83% whilst vessel P yields the least at 7.58 or 13.19%.

Differences in yield may be attributed to the fishing behaviours and partly by luck. Large yielding scallops are older and likely to be in areas which have not been fished for a long period of time. Smaller yielding scallops are likely to be those that are only newly within the allowable catch size and so the meat inside is smaller. Skippers keep records on where they have caught many undersize scallops before and will wait until they estimate they reach size class before going to fish the area again. There is high competition between fisherman and skippers may decide to visit these sites as early as possible in order to reduce the risk that other fishermen are also waiting for the same scallops. To find large scallops, fisherman may need to take more risks fishing in new areas hoping to stumble across previously undiscovered scallop beds. However this behaviour is risky as fisherman may only find poor beds and catch low volumes making the journeys less profitable. Fishing vessels achieving higher yield may attribute this to experience on finding profitable scallop beds or on luck.

Table 2. Live catch to meat weigh ratios for 16 vessels which land to the main processing plant. Vessels with values N/A use other factories for which data was not obtainable.

Vessel	King Scallops Live Catch to Meat	Percentage (%)
A	5.96	16.78
B	N/A	N/A
C	N/A	N/A
D	N/A	N/A
E	5.89	16.98
F	N/A	N/A
G	6.16	16.23
H	5.35	18.69
I	N/A	N/A
J	6.49	15.41
K	4.38	22.83
L	N/A	N/A
M	N/A	N/A
N	6.90	14.49
O	5.65	17.70
P	7.58	13.19
Q	5.30	18.87
R	6.33	15.80
S	5.69	17.57
T	N/A	N/A
U	5.83	17.15
V	5.46	18.32
W	6.61	15.13
X	5.82	17.18
Average	**5.96**	16.78

Table 3 shows the new calculated values for the total meat yield produced from each vessel over the study period. Even though the total catch of king scallops was less than that of queenies, as king scallops yield higher meat, the total meat yield is greater. Although the average meat yields were variable across boats, these calculations were achieved using the same average value from across the fleet. This is due to the queenie values not being available. An interesting further study would be to obtain the average yields per vessel for queenies as well as king scallops and then to calculate the total meat yields per vessel utilising their own individual vessel yields and to see how this impacts the total meat yield per vessel and therefore their individual emissions per kg of meat yield per vessel.

Table 3. Total meat yield from the period November 2008 - October 2009, using the averages of 16.79 for king scallops and 13.2% for queenies.

	Total Meat Yield (Tonnes)	
Vessel	**King Scallops**	**Queens**
A	13.91	14.85
B	4.58	2.12
C	6.79	0.15
D	5.68	1.97
E	7.51	0.10
F	10.83	9.83
G	12.11	0.01
H	12.30	24.12
I	7.54	15.90
J	6.76	18.63
K	7.18	0.00
L	4.36	1.89
M	2.92	3.08
N	9.77	3.98
O	10.11	13.59
P	14.44	12.65
Q	8.90	0.08
R	16.69	0.00
S	5.01	3.92
T	3.21	4.62
U	10.66	15.84
V	0.90	6.35
W	8.92	7.10
X	8.29	12.78
Total	199.37	173.56

5.2. Questionnaire Results

Of the 25 vessels in the study, 18 completed questionnaires. The remaining vessels were un-contactable either due to being away fishing or in certain cases due to boats no longer being in operation. Table 4 summarises the results received from conducting the fuel consumption questionnaire, and for the estimations for those where fuel consumption was not obtained via the methods described in section 4.3.1.

The questionnaire results identified a range of differences among the fleet both in gear amounts and fishing behaviour. The gear aside ranged from 4 to 8 dredges, these are relatively small values compared to the larger vessels belonging to international fleets which may tow up to 14 dredges aside (FRS, 2008). Fishing RPMs also are variable with steaming power ranging from 1350 to 1700 RPM speeds which can have large impacts on fuel consumption. Looking back at figure 9 we can see that for this engine the difference in these two revolution speeds for fuel consumption is approximately 19 to 38 litres per hour, a two fold increase.

The questionnaire results in average fuel consumption of 21.81 l/hr for king scallop dredging, 19.20 l/hr for queenie trawling and 27.73 l/hr for queenie dredging. From these results we can see that the there are benefits in regards to fuel consumption from queenie trawling rather than dredging of a 40% reduction in fuel use.

Table 4. Results from the fuel consumption questionnaires. Vessels which are highlighted are those for which questionnaires were unable to be conducted or fuel consumption was unknown.

				Dredging			Trawling			Steaming	
Vessel	**Engine**	**Dredges**	**Fuel from**	**Speed**	**RPM**	**Fuel**	**Speed**	**RPM**	**Fuel**	**Speed**	**RPM**
A	Cummings NT855	6		2.0-3.0	1200-1450	25	2.0-3.0	1100-1350	22	7.5	1500
B	Gardner 6LXB	4	Yes	2.0-3.0	1200-1500	13.8	2.0-3.0	1200-1500	10.5	6.5	1500
C	Cummings NT855	5				18.4			18.2		
D	DAF 116M	5	No	2.8-3.0	1400	23	2.5	1300	20.7	7.0-8.0	1700
E	Cummings NT855	7	Yes	2.5	1400	20.5	2.5	1400	27.4	8	1500
F	Cummings NT855	7				24			25		
G	Mitsibishi	8	No	2.1	1100-1300	31	2.5	1100	23.25	7.5-8	1500
H	Cat	6				26			27.5		
I	Gardner 6LXB	5				16.15			15.2		
J	Cummings NT855	7	Yes	2.2-2.4	1100-1400	27	2.4-2.6	1100-1400	24	7.5-8	1400-1500
K	Cat 3406	6 or 5	No	2.5-2.7	1200	27	2.5-2.7	1200	27	8.5	1350
L	Gardner 6LXB	4	Yes	2.0-2.8	1400-1500	17.5	2.0-2.8	1250-1400	15.8	6.5	1550
M	Thorneycroft	4				15.2			15.2		
N	Gardner 6L3B	6	Yes	2.1	800-850	15.2	2.1	800-850	15.2	7.0-8.0	1000
O	Gardner 6L3B	5	No	1.8-2.7	800-1000	18	1.8-2.7	800-1000	18	6.5-8.5	
P	Cummings NT855	5 or 6	Yes	2.0-2.5	1300-1400	19.54	2.0-2.5	1300-1400	19.54	7	1450
Q	Cummings NT855	7				24			25		
R	Cummings KTA19	8	Yes	2.5	1200-1500	43.75	3	1200-1500	39.58	7.5	1500
S	Cummings	5	Yes	2.5	1200	19.5	2.4-2.5	1100	16	7	1250
T	Cummings NT855	6	No	2.5	1200	19	2.5	1200	19	8.5	1500
U	Volvo TMP 102A	5	Yes	2.2	1350	27	2.6	1300	18	7.5-8	1500
V	Gardner	6				16.15			16.6		
W	Cummings NT855	5	No	2.4	1200	16.28	2.4	1200	18	7.4	1500
X	Cat 220	5	Yes	2.3	1200	20.5	2.4	1300	27.4	7.5	1300

5.2.1. Fuel Consumption

Fuel consumption of the vessel is influenced by the amount of gear towed and the engine horsepower (Figure 7 and 8). Many of these relationships are interlinked, for example the amount of gear towed is influenced by vessel size (Appendix I), which also influences the engine horsepower. A broad generalisation can be drawn that smaller engine vessels tend to tow less gear and larger engine vessels tow more (Appendix J). However in the mid ranges this relationship is more variable and the gear towed may be more related to skipper preference.

The amount of gear towed and the engine size consequently impact the fuel consumption, the extent of which is illustrated in figures 7 and 8. Fuel consumption in scallop dredging vessels is correlated to the engine horsepower (R^2=0.51), the amount of gear towed aside (R^2=0.52) and more weakly linked to the size of the vessel (R^2=0.36). Fuel consumption in queenie trawling vessels is correlated to the engine horsepower (R^2=0.51) and weakly to the size of the vessel (R^2=0.41). R^2 values show the correlation coefficient, giving an indication of how well the values fit the linear trend line. A value of 0.5 is not statistically significant value but does indicate that the values are following an upward trend. From these it can be identified that the main influence over fuel consumption is the size of the vessel and for dredging also the amount of gear towed aside.

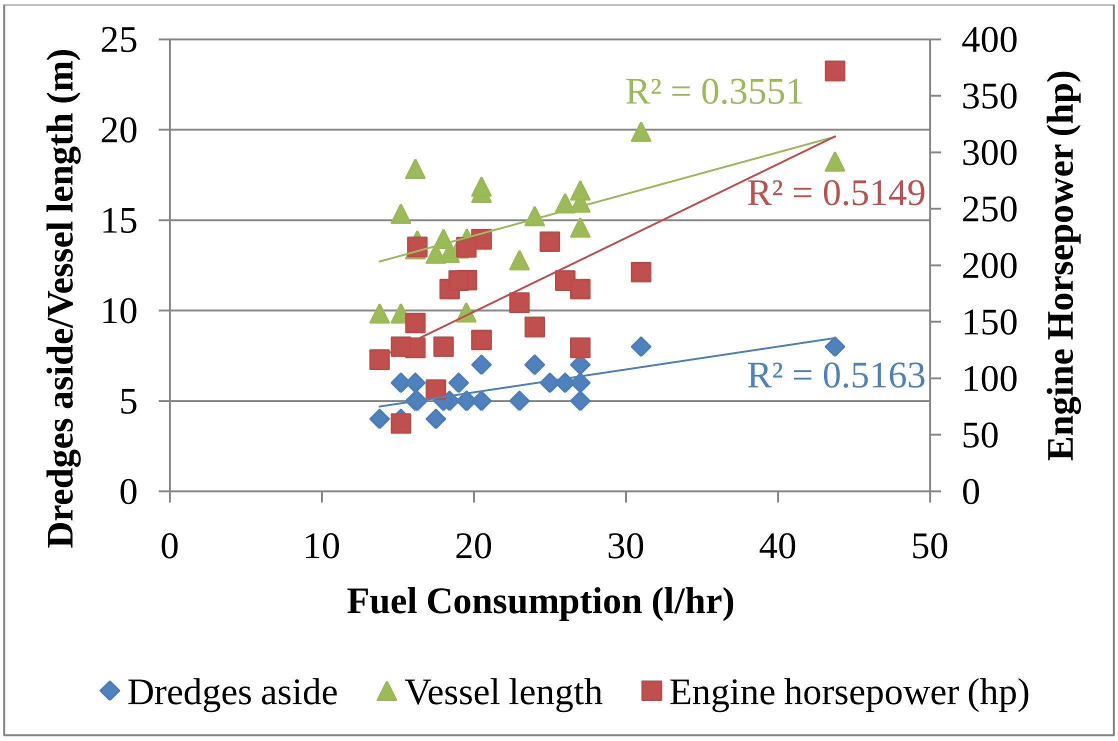


Figure 7. Fuel consumption of scallop dredging compared to increasing gear usage, increasing vessel length and increasing engine hp.

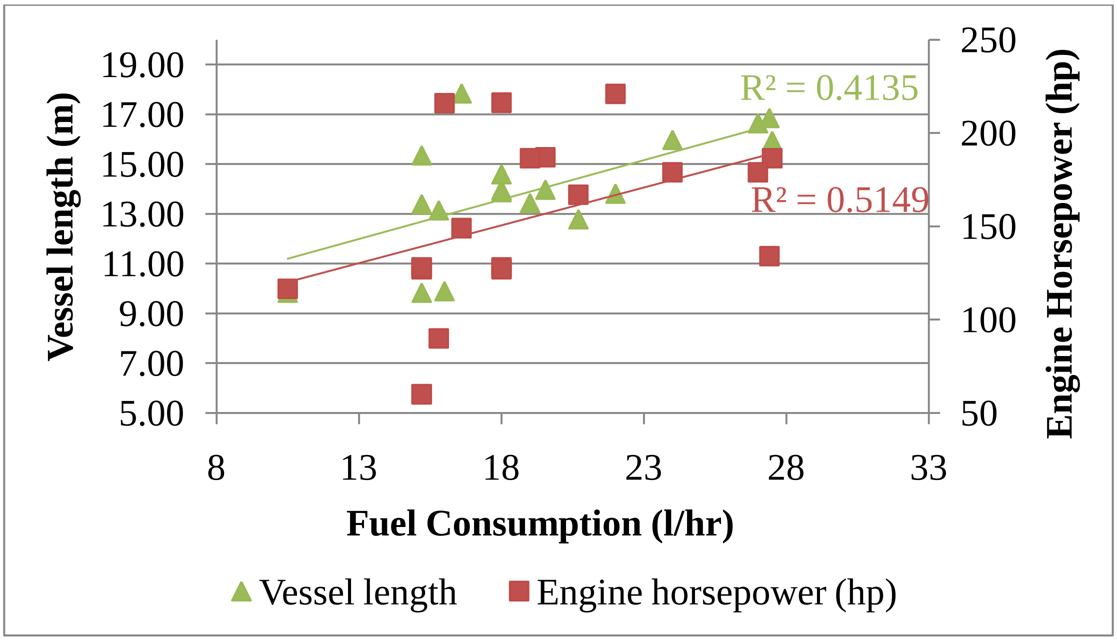


Figure 8. Fuel consumption of queenie trawling compared to increasing vessel length and increasing engine hp

The total fuel used, live weight landed and hours spent fishing is shown in figure 9. The graph shows that the amount of fuel used is directly related to fishing time. However, neither the amount of fuel used nor fishing time corresponds to the total catch. The fuel used is also not completely linear with fishing time; this is because of the variable fuel consumptions among vessels e.g. vessel R has a very high fuel consumption so the total fuel used is disproportioned compared to other vessels.

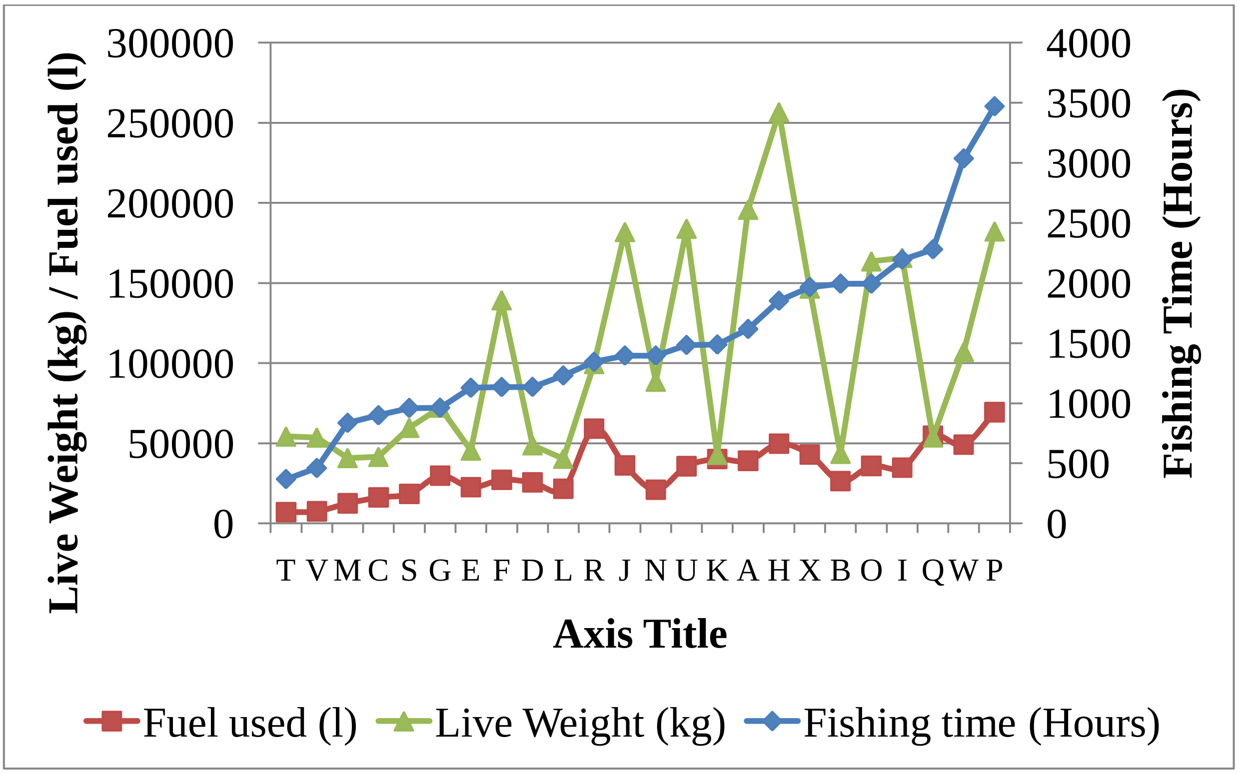


Figure 9. Total fuel used, live weight of catch and hours spent fishing per vessel over the study period, Nov 2008 - Oct 2009. Results shown in order of ascending hours spent fishing.

We can break the results down further into the amount of fuel needed to obtain one unit of catch. Table 5 shows the results of these averaged over the whole study period. The average fuel used per kg of catch of king scallops was 0.54l/kg and for queenies 0.11 l/kg. From these we can see that king scallops are a much more fuel intensive species where as queenies are much more fuel economical.

Table 5. Total fuel used per kg of king scallops and queenies caught. Those highlighted represent the vessels which used tooth dredges to capture queenies.

	King Scallops			Queens		
Vessel	**Total Catch (kg)**	**Total Fuel (l)**	**Fuel per kg (l/kg)**	**Total Catch (kg)**	**Total Fuel (l)**	**Fuel per kg (l/kg)**
A	82888	28925	0.35	112840	10120	0.09
B	27301	22456	0.82	16132	3900	0.24
C	40450	14382	0.36	1102	1800	1.63
D	33838	19987	0.59	14945	5586	0.37
E	44749	15680	0.35	732	6880	9.40
F	64565	19008	0.29	74710	8208	0.11
G	72165	29388	0.41	105	434	4.13
H	73306	35218	0.48	183331	14492	0.08
I	44940	29264	0.65	120830	5490	0.05
J	40298	21168	0.53	141580	14958	0.11
K	42822	40176	0.94	0	0	
L	25997	17856	0.69	14364	3808	0.27
M	17428	9270	0.53	23415	3270	0.14
N	58233	18180	0.31	30229	2760	0.09
O	60235	27792	0.46	103280	8100	0.08
P	86075	64880	0.75	96150	4520	0.05
Q	53040	48240	0.91	640	6480	10.13
R	99479	59136	0.59	0	0	
S	29860	15360	0.51	29796	3072	0.10
T	19120	3724	0.19	35125	3268	0.09
U	63518	26946	0.42	120410	8748	0.07
V	5336	4192	0.79	48274	3366	0.07
W	53179	43552	0.82	53928	5652	0.10
X	49400	28440	0.58	97150	14562	0.15
Total	**1188220**	**643220**	**0.54**	**1319068**	**139474**	**0.11**

The data provided by the PO gave a total number of litres of fuel that was purchased by the scallop fleet over the study period. This value totalled 649701 litres of fuel. However when questioned not all vessels said they bought their fuel exclusively from the PO. If we compare this with the total volume of fuel estimated from the database, 782,694 litre of fuel we can see that the values are within 20% of each other. This 20% may well be due to not all fishing boats buying all their fuel from the PO. This comparison however does provide evidence that the value achieved from the questionnaires and database is a realistic value.

However the table does hold some anomalous values. Some vessels dredge for queenies (vessels C, E, F, G and Q), and several vessels caught queenies as a bycatch of dredging for king scallops (vessels H, J, N and X). The vessels which dredge for queenies will be included as the fuel consumption is known and these are good values for comparison. The queenies caught as bycatch however will not be included in the fuel consumption; this is because the total amount is only a very small percentage of the total (see Appendix M). However as the bycatch queenies are still bringing an economic benefit to the fishery their economic worth will still be included.

In the queenie fishery the majority of vessels entirely utilise trawls, and a small number of vessels entirely utilise dredges. As dredging is a more fuel intensive procedure it should be noted that these values are different to the rest of the fleet. Once taking into account the vessels dredging for queenies we can split the data set so that out of the vessels which trawl for queenies the fuel consumptions range from 0.05 to 0.37 l/kg and the vessels that dredge for queenies range from 0.11 to 10.13 l/kg. This shows that dredging can still be economical; vessel F which dredges for queenies caught large amounts in short periods, therefore using smaller volumes of fuel.

When comparing king scallops to queenies we can see that the vessel which uses the least fuel to catch king scallops is not also the vessel which performs most economically for queenies. The same is seen for the vessels which are the most un-economical fuel users.

Looking at the fuel used whilst dredging for king scallops, Q and K, are in amongst the vessels with the highest fuel consumptions, in the top 40%. However, they are not the vessels with the greatest fuel consumptions. If we look at vessel F, it has the same fuel consumption as vessel Q but utilises the second least fuel per unit of catch. What is more interesting is the fact that both vessels have the same engine, have the same fuel consumption and tow the same number of dredges aside. This indicates that the differences are entirely based on the fishing time and the amount of catch. The reasons why vessel F's fishing time is so low is unknown, maybe the vessel only fishes close to ports and has short travel times, or maybe the skipper is very experienced and good at finding sites with high landings and so finds them in less time.

5.3. Economic Value

The estimated value of catch was calculated using the average value of each product obtained from the processors weekly breakdowns (see Appendix K). These were combined with total catch to give the estimated value of catch for the study period (Figure 10). The highest earning vessels are those which fish both king scallops and queenies, vessels A, H and P. However these values only account for catch landed to the Isle of Man, vessels such as R which landed no queenies may have fished elsewhere during the closed season and therefore total year earnings may be far greater. However, we are unable to establish that during the course of this study, although it is feasible to conduct as many vessels will continue to fill in catch log sheets even when landing off the island, and VMS systems still log wherever the vessel may be.

The total value of the fishery was calculated to be £2,258,567, with £ 1,720,526 from king scallops and £538,040 from queenies.

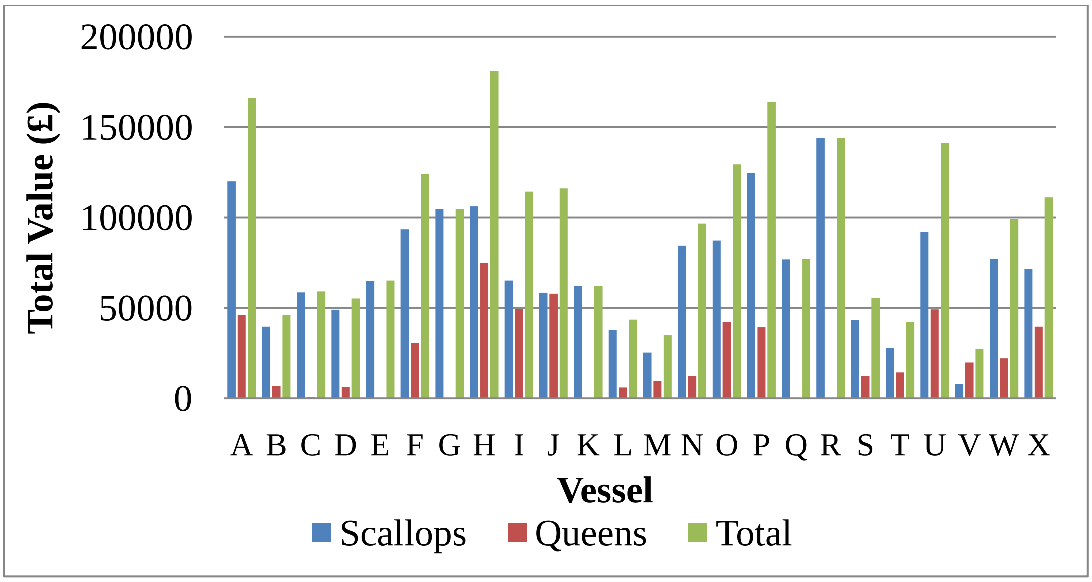


Figure 10. Total estimated value of catch for each vessel during the study period, Nov 2008 - Oct 2009.

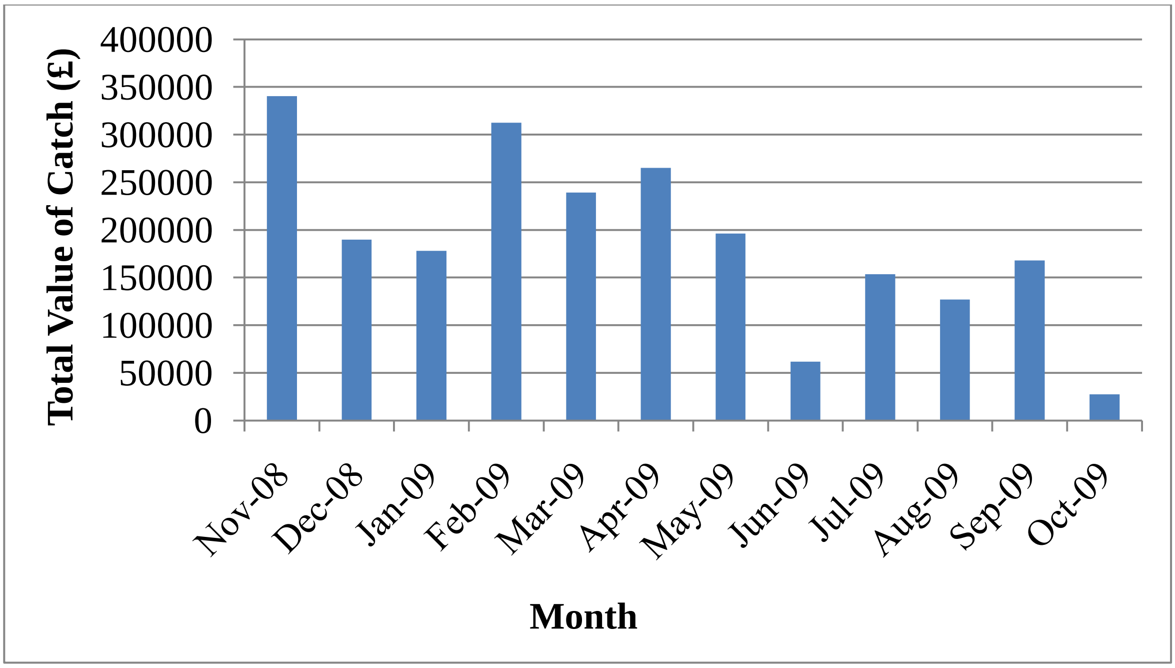


Figure 11. Total value of catch over fleet on a month by month basis over the study period Nov 2008 - Oct 2009.

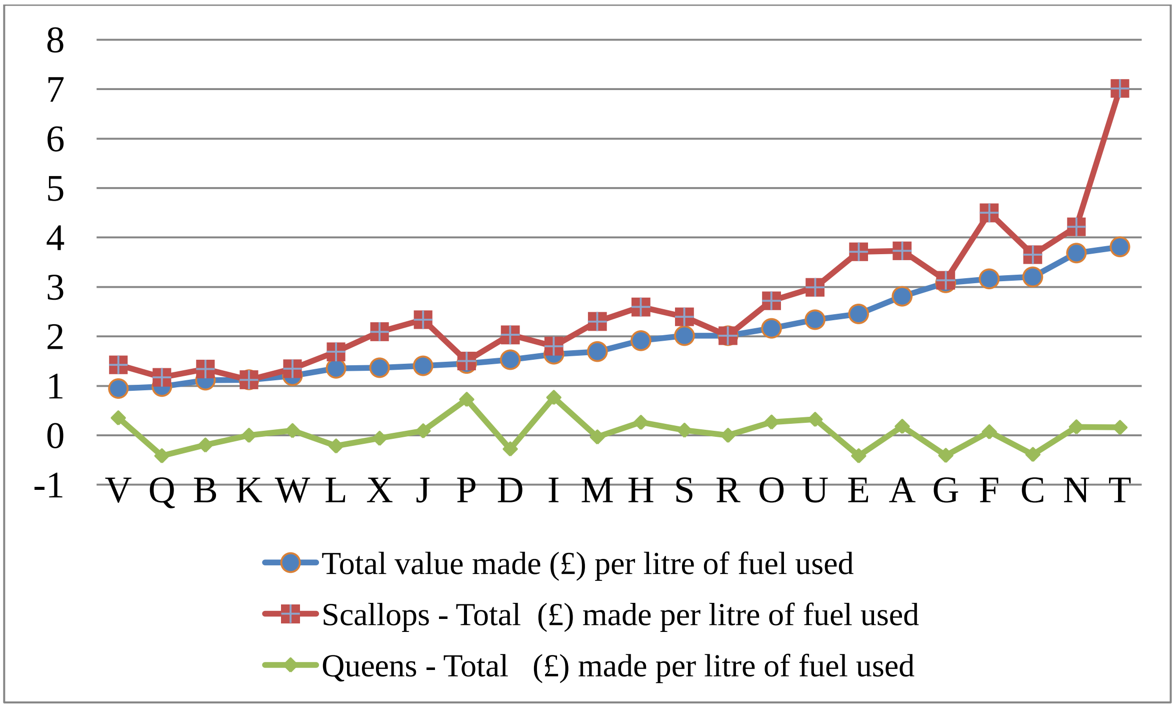


Figure 12. Total estimated value made per litre of fuel used for each vessel during the study period, Nov 2008 - Oct 2009. The cost of fuel has been deducted from this value giving a net value after deducting fuel costs.

The total value was separated in to monthly totals (figure 11). These identified that the most profitable months were November at £340,330 followed closely by February at £312,373and the April at £196,338.

The total value was compared with the total fuel to calculate net value achieved per litre of fuel used. The cost of fuel was then applied to this to see how this impacted the net earnings (figure 12). The fuel cost calculations are shown in Appendix L.

5.4. Emission Footprint

Emissions were calculated using the emission factors provided by DEFRA (2009). These provided calculations to find the CO_2, CH_4 and N_2O emissions from diesel. The calculated emissions from the fuel used during fishing are shown in Table 6. Here Greenhouse gases are given volumes in CO_2 equivalents, the concentration of CO_2 that would cause the same level of radiative forcing as the given greenhouse gas. A breakdown on a vessel by vessel basis for king scallops and queenies is included in Appendix N and O.

The results show that the total emissions created by direct fuel use in the king scallop fishery over the study period was 1697 tonnes of CO_2, 1.22 tonnes CO_2e of CH_4 and 18.22 tonnes of CO_2e of N_2O, a total GHG emission value of 1717 tonnes of CO_2e per year. Per kg of live catch this transcribed to 1.43 kg of CO_2, 0.0010 kg CO_2e of CH_4 and 0.015 kg of CO_2e of N_2O a total of 1.45 kg CO_2e per kg of live catch. Which further resulted in a per kg of meat yield emission profile of 8.51 kg of CO_2, 0.0061 kg CO_2e of CH_4 and 0.091 kg of CO_2e of N_2O a total of 8.61 kg CO_2e.

In the Queen scallop fishery the total emissions created by direct fuel use over the study period was 368 tonnes of CO_2, 0.26 tonnes CO_2e of CH_4 and 3.95 tonnes of CO_2e of N_2O, a total GHG emission value of 372 tonnes of CO_2e per year. Per kg of live catch this transcribed to 0.28 kg of CO_2, 0.00020 kg CO_2e of CH_4 and 0.0030 kg of CO_2e of N_2O a total of 0.28 kg CO_2e per kg of live catch. Which further resulted in a per kg of meat yield emission profile of 2.12 kg of CO_2, 0.0015 kg CO_2e of CH_4 and 0.0037 kg of CO_2e of N_2O a total of 2.15 kg CO_2e.

Table 6. Total Emissions overall and total emissions per kg catch, of CO_2, CH_4 N_2O and GHG's for each species over the study period**.**

			CO_2			CH_4			N_2O			Total GHG	
Vessel	Fuel (l)	x	kg CO_2	Total kg CO_2	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq	Total kg CO_2eq	x	kg CO_2eq per unit	Total kg CO_2eq
Total King Scallops	643220	x	2.64	1697548	x	0.0019	1216	x	0.028	18222	x	2.67	1717011
Per kg Live Weight King Scallops	0.54	x	2.64	1.43	x	0.0019	0.0010	x	0.028	0.015	x	2.67	1.45
Per kg Meat Yield King Scallops	3.23	x	2.64	8.51	x	0.0019	0.0061	x	0.028	0.091	x	2.67	8.61
Total Queens	139474	x	2.64	368091	x	0.0019	264	x	0.028	3951	x	2.67	372312
Per kg Live Weight Queens	0.11	x	2.64	0.28	x	0.0019	0.00020	x	0.028	0.0030	x	2.67	0.28
Per kg Meat Yield Queens	0.80	x	2.64	2.12	x	0.0019	0.0015	x	0.028	0.023	x	2.67	2.15

Table 7. Sensitivity analysis of Total Emissions overall and total emissions per kg catch for each species over the study period. Maximum values include four hours of extra fishing time on each journey and minimum values reduce fishing time by four hours per journey.

			CO_2			CH_4			N_2O			Total GHG	
Vessel	Fuel (l)	x	kg CO_2 per unit	Total kg CO_2	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq	Total kg	x	kg CO_2eq	Total kg CO_2eq
King Scallops Total Max	811364	x	2.64	2141271	x	0.0019	1542	x	0.028	22962	x	2.67	2165855
King Scallops Total Min	475076	x	2.64	1253773	x	0.0019	903	x	0.028	13445	x	2.67	1268168
Per kg King Scallops Max	0.68	x	2.64	1.79	x	0.0019	0.0013	x	0.028	0.019	x	2.67	1.82
Per kg King Scallops Min	0.40	x	2.64	1.06	x	0.0019	0.00076	x	0.028	0.011	x	2.67	1.07
Per kg Meat Yield Max	4.07	x	2.64	10.74	x	0.0019	0.0077	x	0.028	0.12	x	2.67	10.86
Per kg Meat Yield Min	2.38	x	2.64	6.29	x	0.0019	0.0045	x	0.028	0.067	x	2.67	6.36
Queens Total Max	194326	x	2.64	512846	x	0.0019	369	x	0.028	5499	x	2.67	518734
Queens Total Min	84622	x	2.64	223326	x	0.0019	161	x	0.028	2395	x	2.67	225890
Per kg Queens Max	0.15	x	2.64	0.40	x	0.0019	0.00029	x	0.028	0.0042	x	2.67	0.40
Per kg Queens Min	0.06	x	2.64	0.16	x	0.0019	0.00011	x	0.028	0.0017	x	2.67	0.16
Per kg Meat Yield Max	1.12	x	2.64	2.95	x	0.0019	0.0021	x	0.028	0.032	x	2.67	2.99
Per kg Meat Yield Min	0.49	x	2.64	1.29	x	0.0019	0.00093	x	0.028	0.014	x	2.67	1.30

5.5. Sensitivity Analysis

Table 7 shows the range of values calculated during sensitivity analysis on the VMS data. This includes the maximum fishing time and the minimum fishing time which could have been attributed to the fishery. The range of values encountered gives us a variability range of plus or minus 26% for king scallops and plus or minus 39% for queenies. Figure 13 shows the total fuel values resulting from sensitivity analysis on fishing time. While figure 14 shows how, whilst applying this analysis, a range of variability is found across the fleet depending on the number of fishing trips taken. Those vessels with greater variability made more fishing trips and so had a greater number of hours of possible variance. The percentage variability represents the plus and minus values on top of the calculated total fuel estimated by the sensitivity ranges. For example vessel Q with a percentage variability of 20% identifies that the maximum and minimum possible values lay at 20% either side of the calculated total fuel.

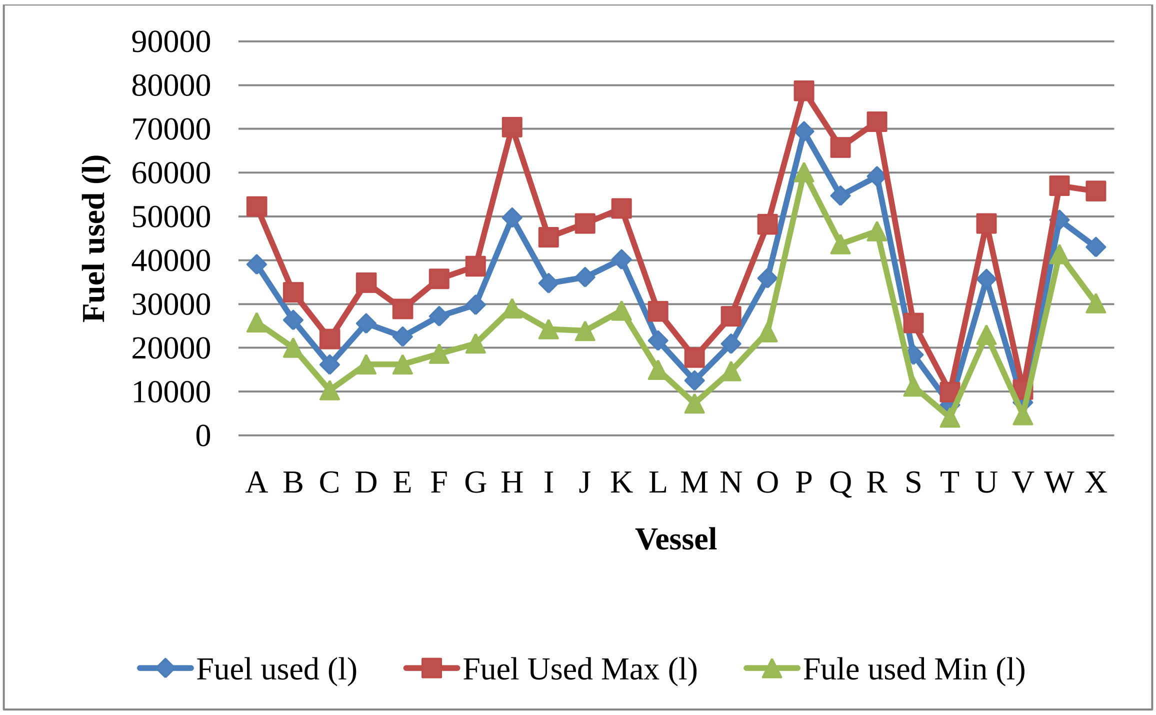


Figure 13. Sensitivity analysis highlighting the total change in fuel used when ± two hours fishing time is added to the beginning and the end of each journey.

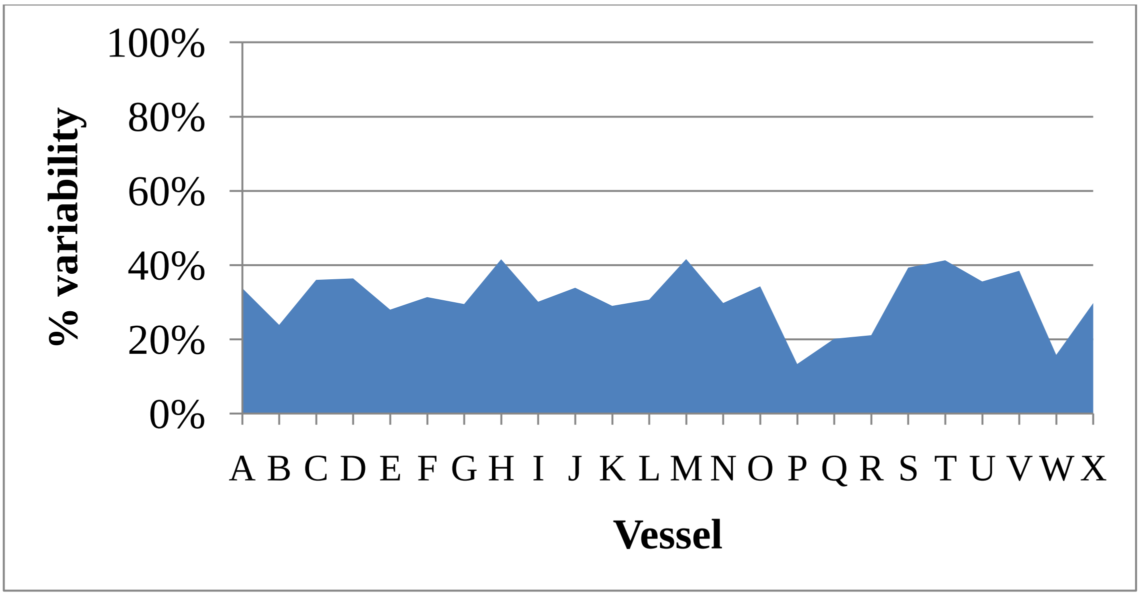


Figure 14. Sensitivity analysis percentage variance for total fuel used per vessel over the study period.

Figure 15 shows the results from the sensitivity analysis carried out for fuel consumption results gathered from questionnaires. It shows that adding or subtracting 10% to each vessel's individual fuel consumption, results in the same percentage change to the overall total values of fuel use over the entire fleet.

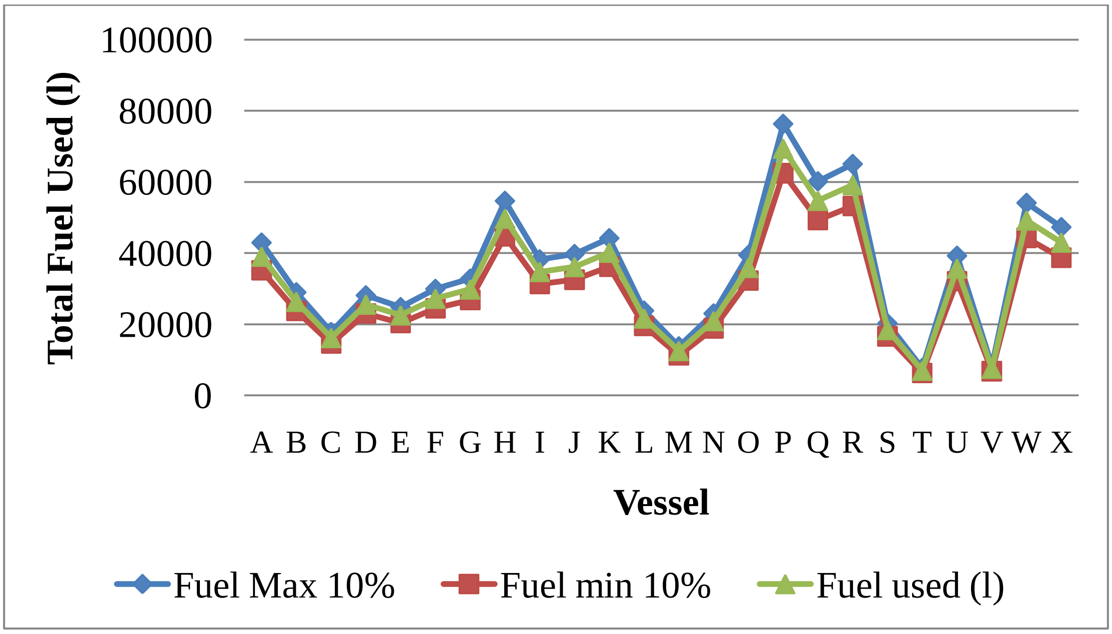


Figure 15. Sensitivity analysis highlighting ±10% of estimated fuel consumptions collected from questionnaires

5.6. Fuel Reduction

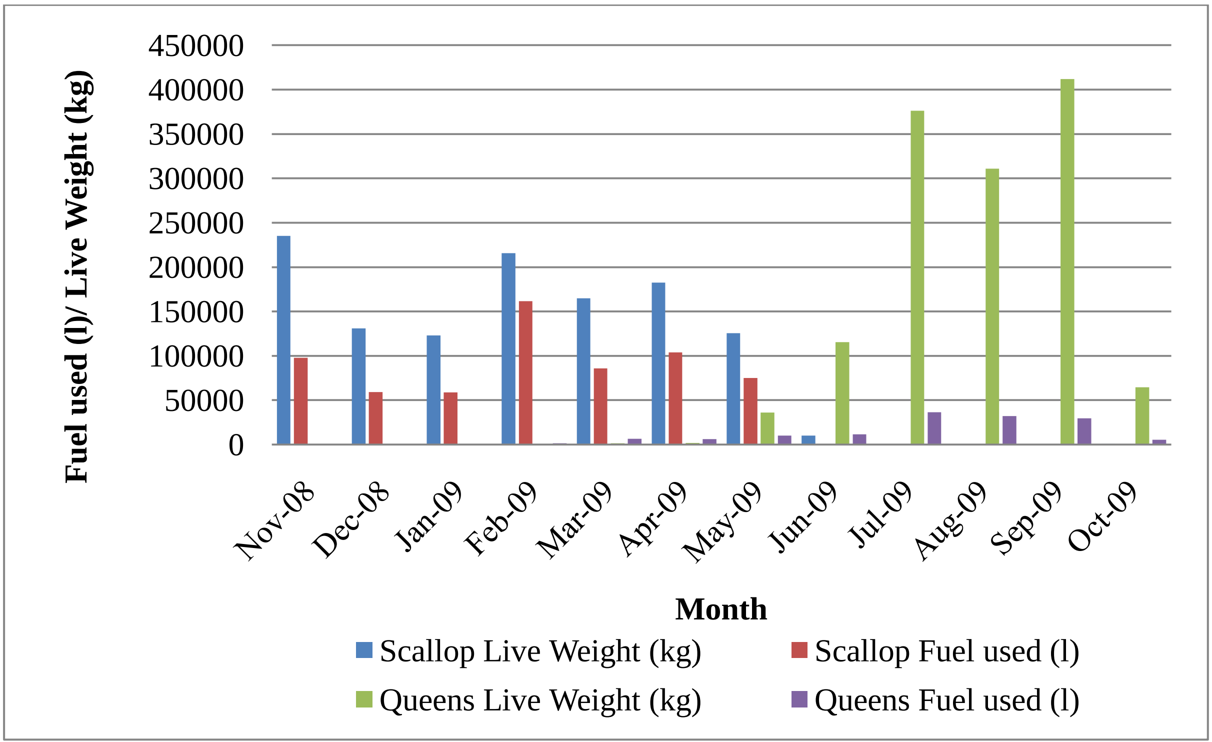


Figure 16. Total Live weight and Total fuel used on a month by month basis and by species.

In order to assess how fuel can be reduced among the fleet, we must first identify where fuel is being used most. Figure 16 highlights which months are the most fuel intensive. February 2009 is the most fuel intensive month, followed by November 2008 and April 2009. The highest fuel intensities are all found to be linked to dredging for king scallops. July to September 2009 hold the highest catches with very low fuel consumptions, this is in the queenie season and is most likely linked to shorter fishing trips. One interesting note is that November 2008 and February 2009 have very similar catches in kg. However there is a big difference in fuel consumption with around sixty thousand litres of fuel less being utilised in November, a saving of around 40%.

The reasons for which may be linked to the sites fished. At the beginning of the season there is a rush and all vessels travel to the most productive sites. As the season progresses and catch declines vessels are forced to search further for productive catches. Using ARC GIS this relationship was initially investigated. However due to the time consuming nature and the absence of population data for sites this was unable to be completed. Another issue was that the site plotted included all satellite data for each day and it was unsure at which of these actual fishing occurred. Figure 17 shows an example for vessel N of how this research was initially started, and an example of how this study could be progressed in the future.

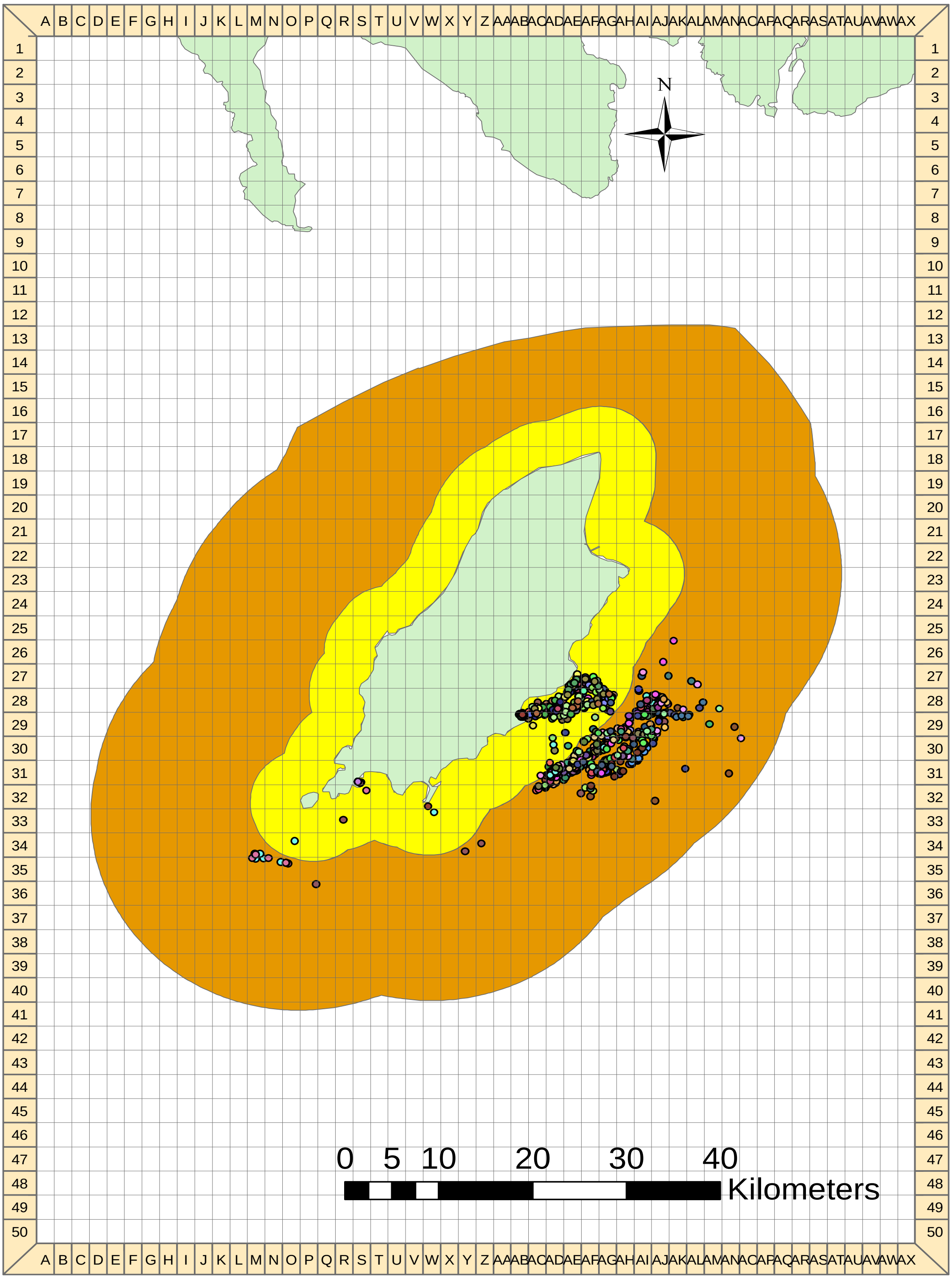


Figure 17. Total sites visited for vessel N over the study period Nov 08- Oct 09

The second questionnaire carried out surrounded the opinions of fishermen and their attitudes toward fuel reduction strategies (see appendix P). The results indicated that over 88% of those questioned have already undertaken fuel reducing measures such as; reducing steaming speeds, installing propeller nozzles, cleaning hull more frequently. The results also found that 88% of participants would be willing to attend a workshop which highlighted ways in which they could reduce their fuel consumption, and provided a cost benefit analysis of measures. 82% would be willing to undertake low cost fuel reduction measures and 82% would undertake more costly measures if financial return was shown to be achievable within a foreseeable future.

5. Discussion

6.1. Total Catch and Yield

In 2008 the total global landings of *A. opercularis* and *P. maximus*, equalled 2,174,345 tonnes (FAO, 2010). Therefore, the Isle of Man scallop fishery provides 0.12% of the total global scallop landings. The total landings in Europe, for 2008, equalled 52 836 tonnes of *P. maximus* and 11 681 tonnes of *A. opercularis*. This totals the Isle of Man's contribution at 2.25% of the total European *P. maximus* fishery and 11.29% of the total European *A. opercularis* fishery. The total catch of the fishery is relatively large in comparison to the size of the country and the fishing fleet. If we compare it to countries such as Scotland whose total scallop catch for 2008 was 10,000 tonnes (Seafood Scotland, 2010). The Isle of Man landed 10% of the total landings in Scotland, for a country that is less than 1% of the size. Scallops are the second most valuable shellfish species in Scotland worth approximately £25.1 million in 2008 (Seafood Scotland, 2010). This comparison highlights the economic importance scallops are to the Isle of Man and reinforce the importance to manage a sustainable fishery.

However, these values only represent the total catch in Isle of Man waters by Manx vessels, and are not an indication of the total fished from this area. This is because the Isle of Man fishing grounds attract a large international fleet, whose vessels are larger and have processing and storage capabilities. This means that large amounts of catch may be taken and landed at ports all over the UK and even to Mainland Europe. Therefore to get a more accurate representation of the total volume of catch taken from these waters, these vessels must be taken into consideration. This may mean cooperation with other governments in order to obtain catch log sheets. There is however going to be a move in 2011 within the European Union to computerise log sheets which will make it much easier to collate data of this sort (OPSI, 2010).

According to the FAO, *P. maximus* live weight to meat yields should range between 10-16%; this differs to *A. opercularis* which should yield in the region of 12-15% (Hardy & Smith, 2001). If we compare the scallops caught on the Isle of Man we can see that *P. maximus* are at the high end of the scale averaging approximately 16.79%, representing a high quality catch around the island. *A. opercularis* are more in the middle at 13.2%. This indicates that if the Isle of Man wishes to have its scallops associated with high quality and value, then the queenie size restrictions should be increased to pull up the average yield.

From discussions with fishermen and looking at the catch logs, it seams that queenies are in more abundant supply and that quotas are caught relatively quickly. If a study assessed the size classes it may show that there is indeed room to increase size restrictions.

6.2. Questionnaires

Most skippers had some knowledge of how they used fuel, but the accuracy of this is unknown. Fuel consumption changes on a daily basis due to tides, weather and grounds. This means that unless the skipper assesses the fishing time and fuel used regularly the consumption estimated may not be very accurate. However due to the high proportion of overall costs that fuel represents in the scallop dredging and trawling, we would assume that most fishermen would have an idea of how much they are using and think about ways to reduce it. Conversations with skippers found that fuel costs can sometimes reach up to 50% of their total outgoings.

If a good understanding is not known then it would be beneficial for the fishery and to the fishermen to gain a better understanding. This might be achieved by including fuel consumption in to log sheets. However to achieve this, a more accurate fuel gauge may be needed on the vessels as fuel gauges are often unmarked from full to empty. Another possibility would be to install fuel flow meters which give real time fuel consumption data which would not only provide a better understanding to the skipper of the fuel used, but also allow the skipper to power the boat in the most fuel economical way. Fuel studies have found that the maximum engine RPM uses an uneconomical rate of fuel, and by making reductions vessels can save considerable amounts. But how much reduction leads to an optimal fuel consumption is variable. Fuel consumption changes during different operations and environmental conditions. Real time fuel flow meters would enable skippers to find the most economical speeds for the particular mode of operation they are currently in (Seafish, 2009). Some studies have concluded that it is possible for fuel flow meters to pay for themselves within six months of installation via savings in fuel costs (Seafish, 2010).

Some skippers which may be coming close to the end of their career in the fishery are less likely to want to monitor and make costly changes to their vessels in order to reduce fuel as benefits may not be seen during the remainder of their career. Therefore the fuel consumptions from these fishermen may be less reliable and they may also be less willing to change old habits such as reducing steaming speeds.

6.3. Fuel intensity

The fuel intensity of a fishery is the total fuel consumed per kg of catch landed. This is calculated by dividing the total quantity of fuel by the total weight in landings. For the Isle of Man scallop fishery, the fuel intensity for *P. maximus* over the study period was 0.54 l/kg or 541.33 l/t. For the *A. opercularis* fishery the fuel intensity was 0.11 l/kg or 105.73 l/t. We can compare these values to other fisheries. Tydemers (2001) calculated and collated data on a number of fisheries producing values for energy intensity per tonne. Among these, three scallop fisheries were included: two in Canada and one in Iceland both utilising dredges. The Canadian fishery results were from 1999 and estimated the fuel intensity to be at 339 l/t for the first fishery and 358 l/t for the second. The Icelandic fishery had a lower fuel intensity of 293 l/t. Unfortunately there was no data to compare a trawl fishery for queen scallops, however many shrimp fisheries also utilise otter trawls (Coale et al., 1994) and there were several studies that provided energy intensity for shrimp trawl fisheries. In Tydemers (2001) eight shrimp trawl fisheries are studied, with fuel intensities ranging from 377 to 2342 l/t. These comparisons suggest that the king scallop dredging has greater fuel intensity than other fisheries whilst the queenie trawl fishery has lower fuel intensity than other fisheries.

The results indicate that the main focus of fuel reduction should be directed toward the *P. maximus* fishery. The results showed that the most fuel intensive periods are the in November and between February and April. Management techniques could be used to help alleviate this impact through restrictions which may also benefit stock. At the beginning of the season there is a rush, many international vessels also come to the island which are much better equipped to work longer hours and through rougher weather, making every hour important to ensure the best catch possible. November is also the most valuable month with a total value of £340,330. Many fisherman make most of their profits during a few of the highest earning months and then barely break even at other times, they need these high takings in order to counterbalance losses at other times during the year. However a more sustainable solution would be to try and break this boom bust habit and try to maintain a steady catch throughout the year. The way to do this may be to impose stricter restrictions at the beginning of the season, which lessen as the season progresses. This may be able to prevent over fishing at the beginning and also discourage large numbers of international vessels from all coming at the beginning of the season.

It is important to continue to monitor fuel intensity as it will allow comparison over time and highlight the success of any fuel reduction techniques. Monitoring may also provide insight to scallop populations, a decrease in fuel intensity may indicate stock population increases.

6.4. Emissions

It has been suggested that the total GHG emissions per unit of catch landed, or GHG intensity, is directly related to the fisheries fuel intensity, or the amount of fuel used per unit of catch landed (Driscol & Tyedmers, 2009). This is because a large percentage of the direct fuel used during fisheries capture, contributes to the total energy inputs (Tyedmers, 2001). Because of this, fuel has been used as a direct indicator of GHG emissions from fishing. This also suggests that making changes to fuel consumption only, may still have considerable impacts on the fisheries overall emission profile.

There have been some o published values for GHG emissions from fisheries around the world. Zeigler & Hansson (2003) found that in the Swedish cod industry 2400g of CO_2 is produced per kg of cod landed. In the Isle of Man fishery king scallops produced 1430g of CO_2 per kg of live catch landed and 8510g of CO_2 per kg of meat yield. For queenies this is even less at 280g CO_2 per kg of live catch landed and 2120g of CO_2 per kg of meat yield. The results for Zeigler & Hansson (2003) only included direct fuel use, the only difference was that they included engine load, which was not included in this study. It is unsure how much of a difference this would make to the emission values as no details were provided in the study. From these results we can see that the emissions produced from the Isle of Man king scallop fishery are significantly lower for queenies and the live catch of king scallops. However the emissions produced per kg of meat yield of king scallops is significantly higher than the Swedish cod industry. For Queenies this relates back to figure 2 which identified that the fuel intensity of dredging and trawling may be less than other fisheries due to long journeys to fishing grounds, long periods at sea, and large volumes of bycatch, all of which increase the energy input per unit of catch (Hospido & Tyedmers, 2005). We can conclude that the emissions produced in the *A. opercularis* fishery are very low compared to other fisheries. However due to the large difference in live weight to meat weight in the *P. maximus* fishery the emissions associated with each kg of sellable product is much greater than other fisheries.

6.5. Economic Value

The total worth of the fishery from first sale value over the study period was £2,258,567. This consists of £ 1,720,526 from *P. maximus* and £538,040 from the *A. opercularis* fishery. However these values do not take into account costs incurred such as labour, insurance and fuel, which can be of large percentage values.

We estimated the cost of fuel and deducted this from the total value of the fishery. The results showed that king scallops always provide a net benefit of value; queenies however may result in a deficit. This is an issue that needs to be addressed, and the most likely cause is the limits on catch imposed due to market demand (Vause, 2007). This means that vessels are restricted to the volume of catch they can obtain and as queenies sell for a lower value meaning that daily fishing trips do not break even. Currently there are no legal limits on queen scallop catches; therefore if market demand increased, potentially each vessel catch can also increase. However it is important to regulate the fishery to ensure limits on the amount of vessels which have access and the amount of effort in order to prevent over exploitation.

6.6. Limitations

The main limitations of this study surround the certainty of the fuel consumption data. As previously discussed it is hoped that fishermen would have a good understanding of their consumption due to the large costs incurred to them. However this may depend on the experience of the fishermen and also at what stage they are in their career. The results of the behaviours and attitudes questionnaire showed that many fishermen had already undertaken fuel reducing techniques and were able to talk about the savings they had achieved via these. We would expect therefore, that these fuel consumption estimations would be more accurate than those who had not undertaken any fuel reductions. The only way to gain more accurate fuel consumption data would be to accurately record the exact litres of fuel used for fishing trips and exclude any fuel use from non-fishing activity. This however would be difficult as vessels fill up on average once a week up to 1000 litres and have very basic fuel gauges. Another way would be to install fuel flow meters and have skippers record their average consumption during different stages of the day and also record the time periods that these account for. However this may be a very time consuming task and fisherman may be reluctant, however some financial benefits could be proposed such as subsidised installation as long as data is recorded for a two year period.

Other limitations surround the fishing time calculations. Port co-ordinate ranges were estimated and it would be useful to get more accurate co-ordinates by visiting sites with a GPS to get more accurate boundaries, as vessels may fish very close to the ports and could possibly be identified within port ranges. Once including sensitivity analysis of ± two hours the variability became very large. It would be beneficial to go through the data set more accurately and find out exactly whether this ± two hours is applicable or not, it maybe that the records have a variability of more like ± one hour and this would half the variability. A manual calculation of fishing time for vessel A found the total fishing time to be in the region of 1966.5 hours, the access data set calculation estimated fishing time to be 1617 hours a difference of 18%. This suggests that the access dataset calculations may produce underestimates, which may be caused due to the port coordinate boundaries as described before. Therefore it is recommended that the true values lie between total fishing time and maximum fishing time calculated in the sensitivity analysis.

6.7. Conclusions

The results have shown that a substantial amount of fuel is utilised in the fishery, with an overall emission equivalent per year of over fifty 2009 ford transit vans, driving 100,000 miles in the same period (Carbon Footprint, 2010). However, only a small part of this total, just over 20%, can be attributed to the queen scallop fishery. As the total catch of queenies actually exceeds that of scallops, it can be concluded that the emission footprint of products produced in the queenie fishery are of a low environmental impact, in terms of GHG’s, and that they can be said to have a low carbon footprint compared to products from other fisheries.

However, queenies are not always profitable due to the restrictions placed on the daily catch. If the fishery was managed appropriately, and investment carried out in to increasing market demand, it is likely that a sustainable and profitable fishery could be established. The king scallop fishery however has high associated fuel cost and emissions per kg of live catch. Investment in trying to reduce this impact will not only produce environmental benefits but also produce financial benefits to the fishermen, in terms or reduced fuel costs.

This study has demonstrated the ways in which available data can be utilised to assess fuel use and emission profiles of a fishery. Fisheries around the world are highly variable in their fuel use due to differences in gear and distances to locations. Fisheries must be individually assessed by local governing bodies to ensure an accurate and comprehensive review of activities. There is a need to continue research in to fuel reducing techniques in fisheries, to ensure their sustainability in the future.

6.7.1. Fuel Reduction Recommendations

In conclusion to this study, the following recommendations are being proposed in order to progress research and move toward lowering fuel use and therefore associated emissions with the fishery;

- Direct effort toward reducing the boom bust nature of the *P. maximus* fishery. This will not only reduce over exploitation over shot periods, but also help to create a more stable economy throughout the year for the fisherman employed in the fishery.
- Invest in research which tests fuel reducing methodologies in order to provide evidence of savings which are possible within the fleet.
- Perform cost benefit analysis of the costs of fuel saving technologies vs. the potential savings over time.
- Organise a workshop where low cost fuel reduction techniques can be discussed and advice given to fishermen on how they can best utilise these to their advantage.

- Minimal reductions in engine RPMs may provide large benefits in regard to fuel consumption. Attention should be directed toward educating fishermen in the ways they can best achieve this.
- Reducing fuel consumption by 10% will knock 10% of the total fuel and therefore the total emissions created by fishing vessels.
- Identify appropriate fuel reduction technologies and offer reduced installation costs in return for data collection on fuel consumption.
- Ensure profitability of queenie fishery to make investment in trawling equipment more profitable. This may be done by increasing market demand by increasing catch restrictions to increase the quality of the catch, and by publicising the low associated emissions.
- Over exploited stocks will incur increased fuel intensities. Management should therefore, be directed toward the sustainable management of scallop populations.

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14. Appendix

A. Interview Transcript
B. Questionnaire – Vessel Fuel Consumption.
C. Questionnaire – Fisherman Attitudes and Behaviours.
D. Bycatch encountered.
E. Cummings NT855 fuel consumption vs. Dredges towed aside.
F. Engine RPM plotted against fuel consumption per unit of energy produced.
G. Gardner fuel consumption vs. dredges towed aside.
H. Caterpillar fuel consumption vs. dredges towed aside.
I. Dredges aside vs. vessel length.
J. Vessel horsepower data and gear towed aside during scalloping.
K. Average sale price of product from fisherman to processor.
L. Red diesel price per litre.
M. Total queenie catch from dredging and trawling.
N. Total Emissions per Vessel for Scallops.
O. Total Emissions per Vessel for Queens.
P. Results from behaviours and attitudes questionnaire shown in Appendix C

Appendix A

Transcript from questionnaire development interview.

The first topic of discussion was clarification of the materials used on the boats. It was identified that as there are only two fuel suppliers on the island, all engines would take Red Diesel. Also that the weight of the boats wont change much each week, stating that the boats either run on empty or full tanks refuelling once a week as they need to have their weight and gear configured to maintain stability of the boat.

The conversation was then directed toward dredging for *P. maximus* specifically. It was identified that this was a lot more fuel intensive than fishing for *A. opercularis*, due to the more physical nature of the dredges and the terrain and composition of the seabed. Maintenance of gear was also discussed. The skipper identified that due to the cost of maintaining dredges much of the work was done by himself, but that some other skippers may not repair gear but rather renew it each year. His own gear if kept in good repair will last 5-6 years. However dredges used toothed drags and these teeth are worn very quickly. This gear is replaced on average once every week but is very dependent on grounds which are being fished at that particular time. This uses a lot of steel and so will impact upon the emission contribution of *P. maximus* fishing. The skipper stated that he can average his own fuel consumption quite accurately at 25 litres of diesel used per hour, this value averages over a journey differences between greater and less fuel intensive demands. He stated that he calculates his total each week and it is never more than 20 litres different from his estimates, averaging at approximately 2-3 litres difference per journey. The skipper was able to give me details about his average engine RPM and speeds during an average fishing trip. During steaming to fishing sites an average engine RPM of 1500rpm is used which equates to a speed of approximately 7 Knots. During towing dredging gear including variation in the gear towed, he averaged his RPM would be around 1350rpm average equating to speeds of in between 2-3 Knots.

In discussion about *A. opercularis* fishing it was found that this is less fuel intensive than *P. maximus* fishing. *A. opercularis* fishing uses nets which are dragged against the tide. However due to constantly fishing into the tide does increases the fuel consumption and he estimated it would be a few litres less an hour that *P. maximus* fishing at approximately 22 litres and hour.

The discussion finished with talks about his percentage cost breakdowns and his attitudes toward fuel reduction. The skipper identified that fuel and wages were his biggest costs entailed each week, with fuel estimated at approximately 25-35% of his total costs. He stated that as he has three deck hands wages contribute a lot more of his costs, but other boats may only have one deck hand and so their costs will be a lot less. Because of this he stated he is very conscious about fuel costs, and that he works them out weekly in order to check that his trips are profitable. He also stated that he would like to be able to tell his real time fuel consumption so he would be able to identify where he can make speed reductions in order to always be at the most economic fuel consumption level. However due to the dynamic nature of fishing and the differences in day to day wind, tide and gear differences it would not be possible to just pinpoint a value of engine effort that is economic. The only way to establish these economic levels would be to install fuel meters which can identify fuel consumption in real time allowing each journey to be tailored to the environmental variables of each specific trip.

Appendix B

Fishery Fuel Use Questionnaire

May 2010 - Isle of Man - DEFA

Thank you for taking the time to complete this questionnaire. Your results will help me to understand fuel use across the Manx Queenie and Scallop fleet. The Department is hoping that defining the carbon footprint of the Queenie fishery, in particular, will provide marketing benefits to the industry. It is likely that the carbon footprint of a fleet of small day boats, landing locally and using light trawl gear, will be much smaller than that of our competitors, a fact that will appeal to a growing number of customers. I hope recommendations as to how fuel consumption can be reduced across the fleet will lead to measures which can be easily adopted reducing fuel costs and therefore increasing profits.

All answers are confidential and will only be used for the purpose of this study. Individual results will not be passed on to the department but only used as averages across the fleet. For more details please contact Andy Read of the Department of Environment, Fisheries and Agriculture on 01624 686045.

All Questions relate to the fishing period November 2008 until end of October 2009.

Please Confirm Your Vessel Name:
____

Please confirm the make and model of your engine including model number e.g. Cummings NT855: ____

In the period Nov 2008 - May 2009, how many dredges a side did you usually tow? ____

In the period Nov 2008 - Oct 2009, did you buy all your fuel from the Producer Organisation (PO)? ____

The following questions relate to fishing for Scallops or Queenies using a DREDGE based technique.

At approximately what towing speed would you use on average when fishing (in Knots): ____

What value of engine RPM would you need to achieve this speed e.g. between 1200-1350 rpm: ____

Would you be able to estimate and overall average figure for total fuel consumption whilst dredging for scallops, averaging across differences in steaming and fishing, e.g. my fuel consumption each week averages to approximately 20 litres an hour? ___________________________________

The following questions relate to fishing for scallops using a TRAWL based technique e.g. during Queenie fishing:

At approximately what towing speed would you use on average when fishing (in Knots): ____

What value of engine RPM would you need to achieve this speed:

____

Would you be able to estimate and overall average figure for total fuel consumption whilst trawling for Queenies, averaging across differences in steaming and fishing. ____

The following questions relate to travelling to and from fishing sites. They relate to average conditions of wind direction and wave height:

What speed (In Knots) will you typically steam at? ______________________

What value of engine RPM would you need to achieve this speed:

____

What is your approximate Fuel consumption in litres per hour while steaming?

____

Thank you for your participation, all results are confidential and nothing will be disclosed about your own personal practices or attitudes. The results are being used to highlight the fisheries current environmental impact and to form recommendations for management in the future.

All Results will only be used as an average across all boats and so will in no way be relatable to your particular vessel.

Appendix C

Fishery Fuel Reduction Questionnaire

May 2010 - Isle of Man - DEFA

Increasing fuel prices are one of the major limitations being placed on fisherman today. As fuel prices increase, profits decrease due to rising costs. Rising fuel prices can also cause an increase in overfishing due to the need to catch greater volumes in order to gain a sustainable profit. These questions relate to your attitudes and behaviour towards these rising costs and will help me to identify measures which may be beneficial to the fleet in the future.

Thank you for taking the time to complete this questionnaire. Individual results will not be passed on to the department only averages based on the fleet. Your results will help me to produce recommendations to the department which will enable the fleet to reduce its fuel consumption using relatively easy measures. All answers are confidential and will only be used for the purpose of this study. For more details please contact Andy Read of the Department of Environment, Fisheries and Agriculture on 01624 686045.

Would you say that you have taken measures to help reduce your fuel consumption in response to rising fuel costs?

Please tick the box which applies.

Yes ☐ No ☐ Unsure ☐

What measures, if any, have you undertaken to try and alleviate these impacts?

E.g. Upgrading engine, reducing towing or steaming speed, planning fishing trips around tides and wind direction etc. ______________________________

____

____

____

If a workshop was organised which gave information and cost benefit analysis of different fuel reducing techniques for fisherman, would you be interested in attending?

Yes ☐ No ☐ Unsure ☐

Imagine that you have attended such a workshop and during the event it was shown that simple techniques, which cost initially, provided a greater return due to reduction in fuel consumption within the first few years.

After receiving this information do you feel that you would consider undertaking such measures?

Yes ☐ No ☐ Unsure ☐

If a scheme was introduced which allocated funding toward fuel reducing schemes, do you feel you would be more willing to install devices or take measures to reduce your fuel consumption?

Yes ☐ No ☐ Unsure ☐

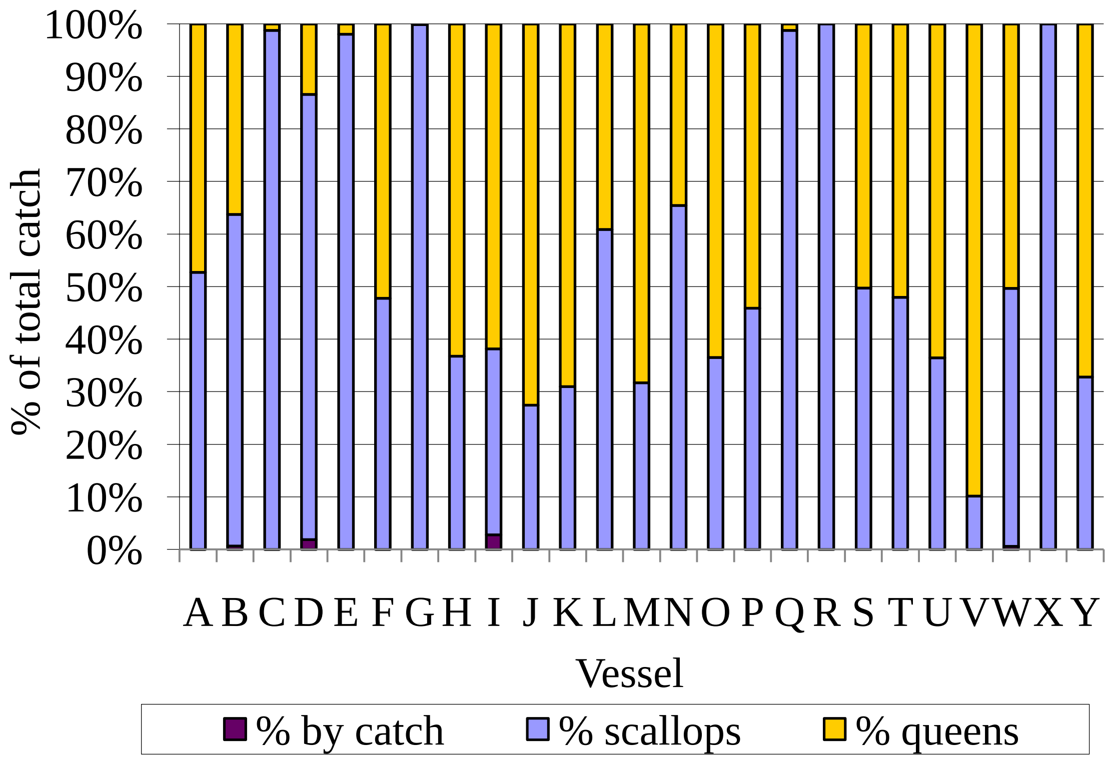
What if it was shown that with no extra costs it was possible to reduce your fuel consumption by better planning of trips and reductions in towing speeds? If you were given the necessary information to help you carry out these measures, do you feel you would implement them?

Yes ☐ No ☐ Unsure ☐

Thank you for your participation, all results are confidential and nothing will be disclosed about your own personal practices or attitudes. The results are being used to highlight the fisheries current environmental impact and to form recommendations for management in the future.

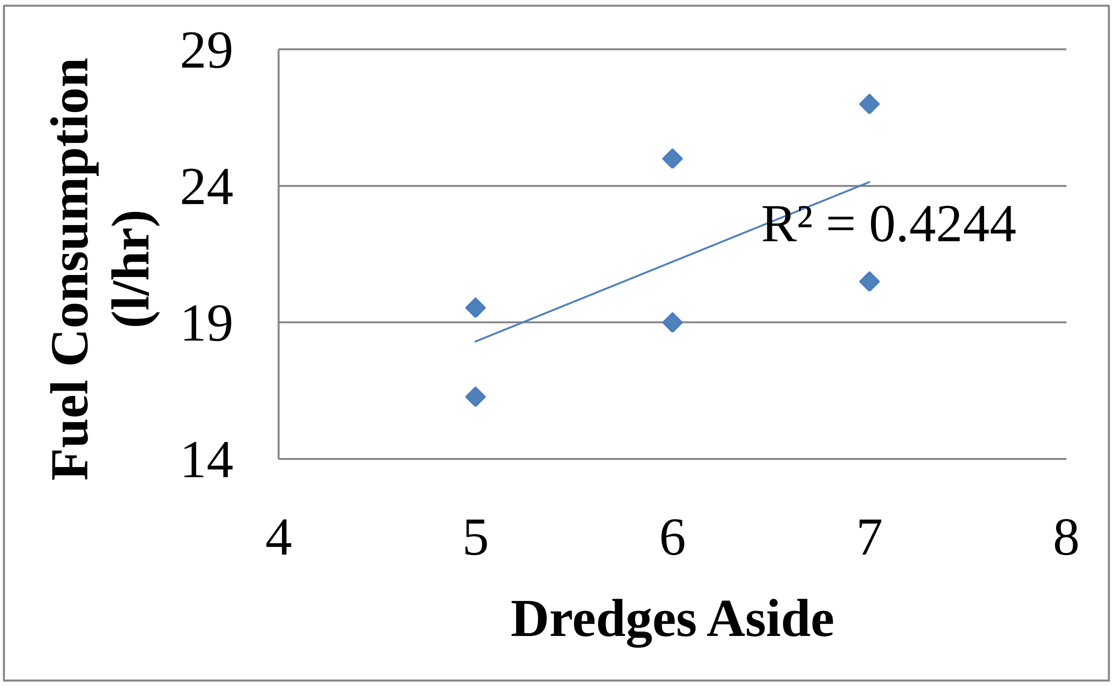
All Results will only be used as an average across all boats and so will in no way be relatable to your particular vessel.

Appendix D



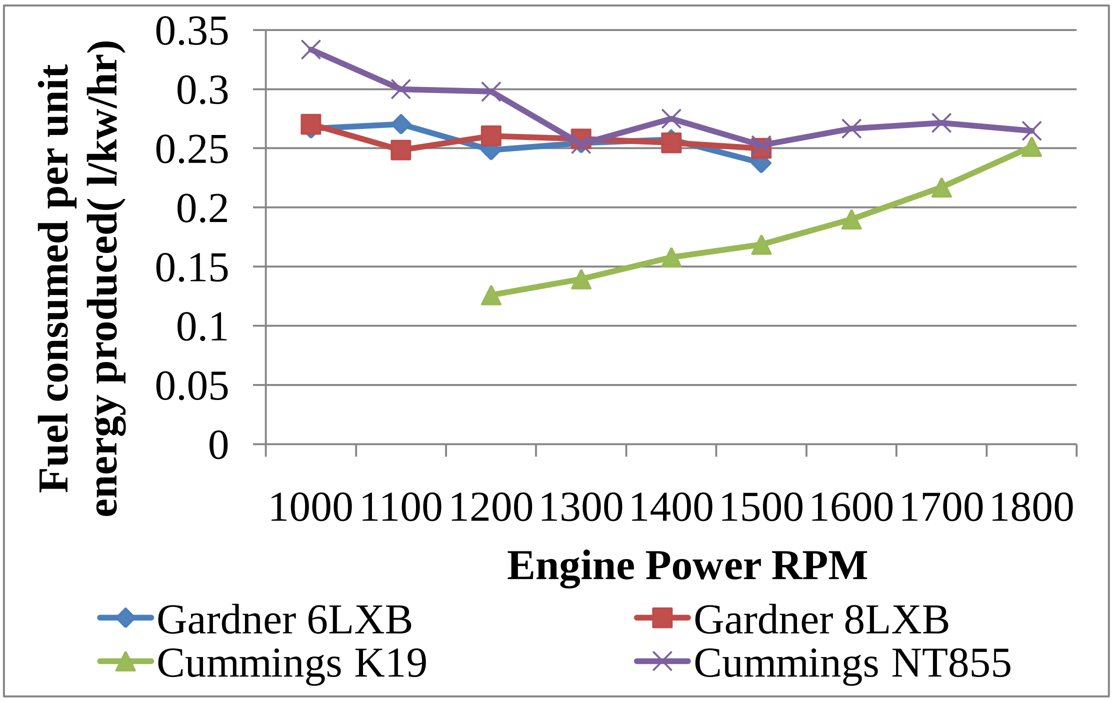
Total catch breakdown, percentage of each species including bycatch. Bycatch only represents a negligible percentage of the total amount.

Appendix E



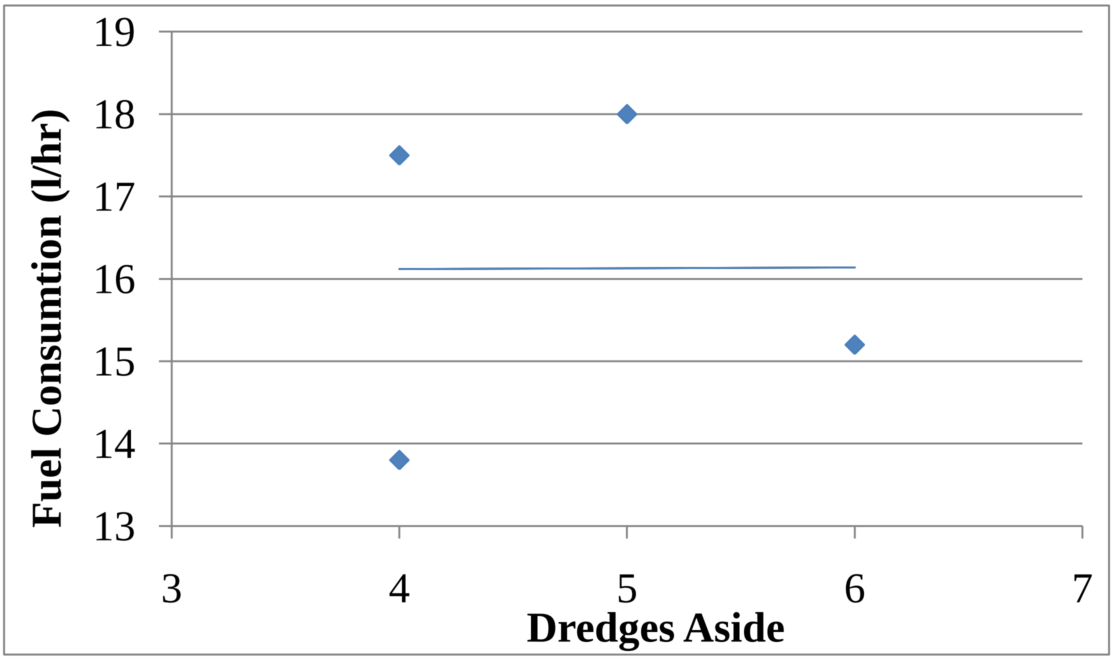
Cummings NT855 fuel consumption vs. Dredges towed aside. Line of best fit plotted to serve as estimation for unknown vessels.

Appendix F



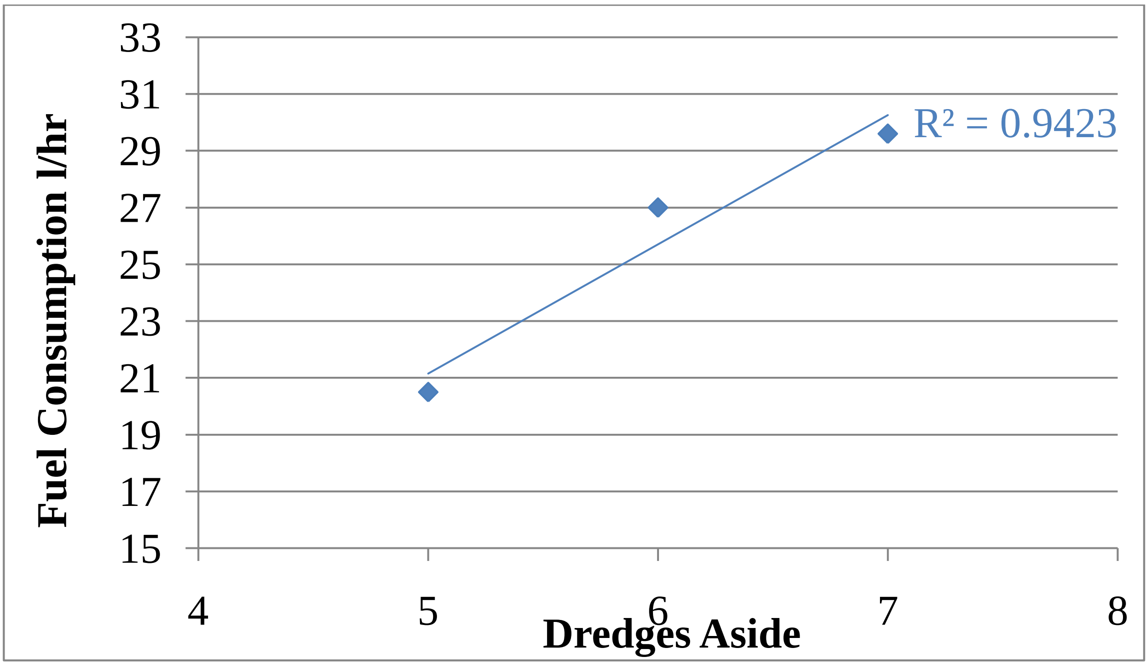
Engine RPM plotted against fuel consumption per unit of energy produced.

Appendix G



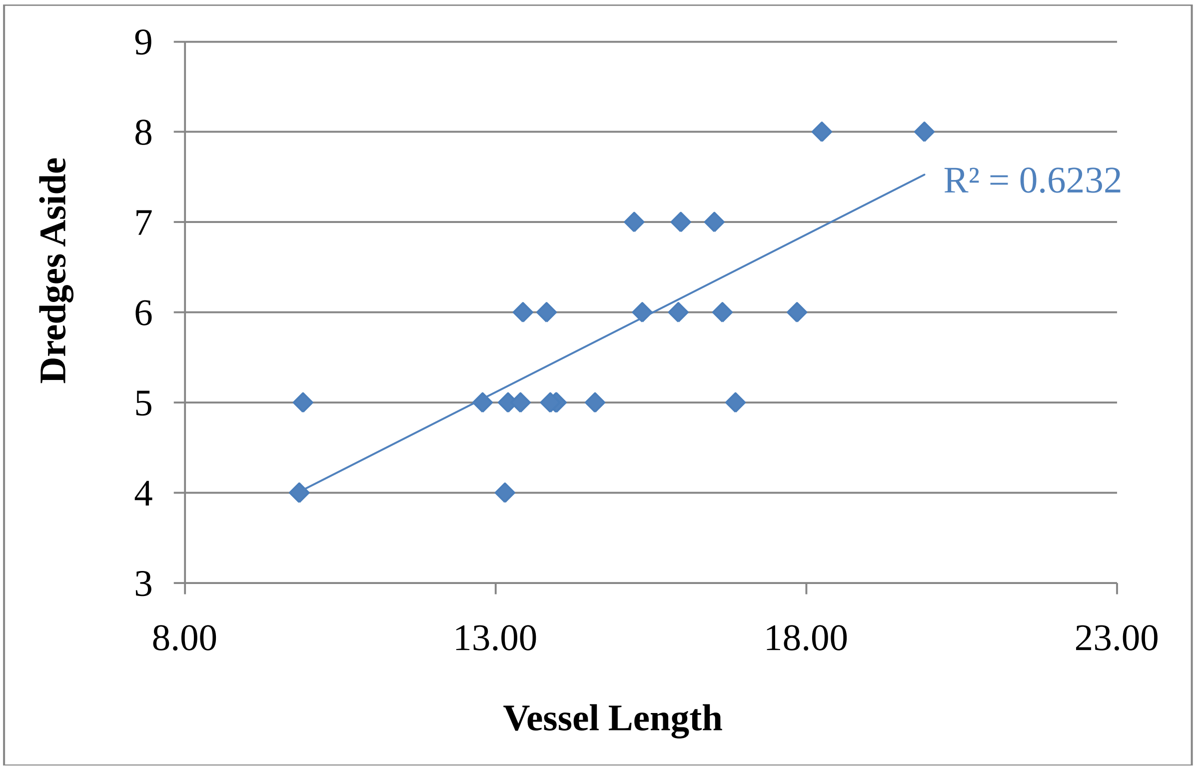
Gardner fuel consumption vs. dredges towed aside. Line of best fit plotted to serve as estimation for unknown vessels.

Appendix H



Caterpillar fuel consumption vs. dredges towed aside. Line of best fit plotted to serve as estimation for unknown vessels.

Appendix I



Dredges aside vs. vessel length, Comparison of active scallop vessels in the fleet. R^2 value shows correlation is of a good fit.

Appendix J

Vessel horsepower data and gear towed aside during scalloping. Those highlighted in red are the two vessels for which estimations were unable to be inferred via comparison with similar engine models. Values are ordered from the lowest horsepower to the greatest.

Vessel	Engine horsepower (hp)	Dredges Aside	Engine
F	unknown	7	Cummings NT855
M	60	4	Thorneycroft
L	90	4	Gardner 6LXB
B	116.5	4	Gardner 6LXB
I	127	5	Gardner 6LXB
U	127	5	Volvo TMP 102A
O	128	5	Gardner 6L3B
N	128	6	Gardner 6L3B
X	134	5	Caterpillar 220
Q	145.47	7	Cummings NT855
V	149	6	Gardner
D	167	5	DAF 116M
C	179	5	Cummings NT855
K	179	6	Caterpillar 3406
J	179	7	Cummings NT855
H	186.5	6	Caterpillar
T	186.5	6	Cummings NT855
P	187	5	Cummings NT855
G	194	8	Mitsubishi
S	216	5	Cummings NTE296
W	216.24	5	Cummings NT855
A	221	6	Cummings NT855
E	223	7	Cummings NT855
R	372	8	Cummings KTA19

Appendix K

Average sale price of product from fisherman to processor per vessel over the study period November 2008- October 2009.

Vessel	Scallops Average Value (kg)	Queenies Average Value (kg)
A	8.71	
B		
C		
D		
E	8.58	
F	8.80	3.04
G	8.58	
H	8.64	2.43
I		
J	8.60	2.96
K	8.61	2.58
L		
M		
N	8.62	
O	8.64	3.50
P	8.62	3.57
Q	8.60	
R	8.64	
S	8.62	
T		3.12
U	8.49	3.42
V	8.63	
W	8.63	2.89
X	8.63	3.50
Average	8.63	3.10

Appendix L

Red diesel price per litre over study period November 2008- October 2009, values obtained from fuel tracker forum British Farming Forum. (2010).

Month	Price (ppl)
Nov-08	0.45
Dec-08	0.4
Jan-09	0.4
Feb-09	0.35
Mar-09	0.4
Apr-09	0.42
May-09	0.45
Jun-09	0.4
Jul-09	0.42
Aug-09	0.45
Sep-09	0.45
Oct-09	0.48
Average	0.4225

Appendix M

Total queenie catch from trawling and from dredging over the study period November 2008-October 2009. Catch of each in kg and then calculated as a percentage of total from dredging.

Vessel	kg catch OTB	kg catch DRB	Total	% DRB
A	112840	0	112840	0
B	16132	0	16132	0
C	0	1102	1102	100
D	14945.4144	0	14945.41	0
E	0	732	732	100
F	0	74710	74710	100
G	0	105	105	100
H	182646	684.5	183330.5	0.37
I	120830	0	120830	0
J	138960	2620	141580	1.85
K	0	0	0	0
L	14364	0	14364	0
M	23415	0	23415	0
N	30184.25	45	30229.25	0.15
O	103280	0	103280	0
P	96150	0	96150	0
Q	0	640	640	100
R	0	0	0	0
S	29796.0768	0	29796.08	0
T	35125	0	35125	0
U	120410	0	120410	0
V	48273.75	0	48273.75	0
W	53928	0	53928	0
X	97114	36	97150	0.04

Appendix N Total Emissions of CO_2, CH_4 N_2O and GHG's per Vessel for Scallops over the study period

			CO_2			CH_4			N_2O			Total GHG	
Vessel	Fuel used per year (l)	x	kg CO_2 per unit	Total kg CO_2	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq per unit	Total kg CO_2eq
A	28925	x	2.64	76337	x	0.0019	54.67	x	0.028	819.45	x	2.67	77212
B	22456	x	2.64	59265	x	0.0019	42.44	x	0.028	636.18	x	2.67	59944
C	14382	x	2.64	37956	x	0.0019	27.18	x	0.028	407.44	x	2.67	38391
D	19987	x	2.64	52749	x	0.0019	37.78	x	0.028	566.23	x	2.67	53353
E	15680	x	2.64	41382	x	0.0019	29.64	x	0.028	444.21	x	2.67	41856
F	19008	x	2.64	50165	x	0.0019	35.93	x	0.028	538.50	x	2.67	50740
G	29388	x	2.64	77559	x	0.0019	55.54	x	0.028	832.56	x	2.67	78448
H	35218	x	2.64	92945	x	0.0019	66.56	x	0.028	997.73	x	2.67	94011
I	29264	x	2.64	77232	x	0.0019	55.31	x	0.028	829.05	x	2.67	78117
J	21168	x	2.64	55865	x	0.0019	40.01	x	0.028	599.69	x	2.67	56506
K	40176	x	2.64	106030	x	0.0019	75.93	x	0.028	1138.19	x	2.67	107246
L	17856	x	2.64	47125	x	0.0019	33.75	x	0.028	505.86	x	2.67	47665
M	9270	x	2.64	24465	x	0.0019	17.52	x	0.028	262.62	x	2.67	24745
N	18180	x	2.64	47980	x	0.0019	34.36	x	0.028	515.04	x	2.67	48530
O	27792	x	2.64	73347	x	0.0019	52.53	x	0.028	787.35	x	2.67	74188
P	64880	x	2.64	171227	x	0.0019	122.62	x	0.028	1838.05	x	2.67	173191
Q	48240	x	2.64	127312	x	0.0019	91.17	x	0.028	1366.64	x	2.67	128772
R	59136	x	2.64	156068	x	0.0019	111.77	x	0.028	1675.32	x	2.67	157858
S	15360	x	2.64	40537	x	0.0019	29.03	x	0.028	435.15	x	2.67	41002
T	3724	x	2.64	9828	x	0.0019	7.04	x	0.028	105.50	x	2.67	9941
U	26946	x	2.64	71114	x	0.0019	50.93	x	0.028	763.38	x	2.67	71930
V	4192	x	2.64	11063	x	0.0019	7.92	x	0.028	118.76	x	2.67	11190
W	43552	x	2.64	114940	x	0.0019	82.31	x	0.028	1233.83	x	2.67	116258
X	28440	x	2.64	75057	x	0.0019	53.75	x	0.028	805.71	x	2.67	75918

Appendix O Total Emissions of CO_2, CH_4 N_2O and GHG's per Vessel for Queens over the study period

			CO_2			CH_4			N_2O			Total GHG	
Vessel	Fuel used per year (l)	x	kg CO_2 per unit	Total kg CO_2	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq per unit	Total kg CO_2eq	x	kg CO_2eq per unit	Total kg CO_2eq
A	10120	x	2.64	26708	x	0.0019	19.13	x	0.028	286.70	x	2.67	27014
B	3900	x	2.64	10293	x	0.0019	7.37	x	0.028	110.49	x	2.67	10411
C	1800	x	2.64	4750	x	0.0019	3.40	x	0.028	50.99	x	2.67	4805
D	5586	x	2.64	14742	x	0.0019	10.56	x	0.028	158.25	x	2.67	14911
E	6880	x	2.64	18157	x	0.0019	13.00	x	0.028	194.91	x	2.67	18365
F	8208	x	2.64	21662	x	0.0019	15.51	x	0.028	232.53	x	2.67	21910
G	434	x	2.64	1145	x	0.0019	0.82	x	0.028	12.30	x	2.67	1159
H	14492	x	2.64	38246	x	0.0019	27.39	x	0.028	410.56	x	2.67	38685
I	5490	x	2.64	14489	x	0.0019	10.38	x	0.028	155.53	x	2.67	14655
J	14958	x	2.64	39476	x	0.0019	28.27	x	0.028	423.76	x	2.67	39929
L	3808	x	2.64	10050	x	0.0019	7.20	x	0.028	107.88	x	2.67	10165
M	3270	x	2.64	8630	x	0.0019	6.18	x	0.028	92.64	x	2.67	8729
N	2760	x	2.64	7284	x	0.0019	5.22	x	0.028	78.19	x	2.67	7368
O	8100	x	2.64	21377	x	0.0019	15.31	x	0.028	229.47	x	2.67	21622
P	4520	x	2.64	11929	x	0.0019	8.54	x	0.028	128.05	x	2.67	12066
Q	6480	x	2.64	17102	x	0.0019	12.25	x	0.028	183.58	x	2.67	17298
S	3072	x	2.64	8107	x	0.0019	5.81	x	0.028	87.03	x	2.67	8200
T	3268	x	2.64	8625	x	0.0019	6.18	x	0.028	92.58	x	2.67	8724
U	8748	x	2.64	23087	x	0.0019	16.53	x	0.028	247.83	x	2.67	23352
V	3366	x	2.64	8883	x	0.0019	6.36	x	0.028	95.36	x	2.67	8985
W	5652	x	2.64	14916	x	0.0019	10.68	x	0.028	160.12	x	2.67	15087
X	14562	x	2.64	38431	x	0.0019	27.52	x	0.028	412.54	x	2.67	38872

Appendix P

Results from behaviours and attitudes questionnaire shown in Appendix C

Vessel	Have Taken Measures	Would be willing to attend workshop	Would be willing to uptake measures that were low cost	Would be willing to uptake costly measures if benefits were proved
A	N	Y	Y	Y
B	Y	Y	Y	Y
C				
D	Y	Y	Y	Unsure
E	Y	Y	Y	Y
F				
G	Y	Unsure	Y	Y
H				
I				
J	Y	Y	Y	Y
K	Y	Y	Y	Y
L	Y	Y	Y	Y
M				
N	Y	Y	Y	Unsure
O	Y	Y	Y	
P	Y	Y	Unsure	Y
Q				
R	Y	Y	Y	Y
S	Y	N	N	N
T	Y	Y	Y	Y
U	Y	Y	Unsure	Y
V				
W	N	Y	Unsure	Y
X	Y	Y	Y	Y