Spatial variation in by-catch and energy subsidies generated by a trawl-caught queen scallop (*Aequipecten opercularis*) fishery

Katie Boyle

Supervisor – Professor Michel Kaiser

November 2012

School of Ocean Sciences,
University of Wales Bangor,
Menai Bridge,
Anglesey,
LL59 5AB

Declaration and statements

This work has not previously been accepted in substance for any degree and is not being concurrently submitted for any degree.

This dissertation is being submitted in partial fulfilment of the requirement of M.Sc. 'Marine Environmental Protection'.

This dissertation is the result of my own independent work / investigation, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

I hereby give consent for my dissertation, if accepted, to be made available for photocopying and for inter-library loan, and the title and summary to be made available to outside organisations.

Signed .... (Candidate)

Date ....

Abstract

One of the biggest problems faced by fisheries management is the issue of bycatch and discards. The target species of fisheries are not often spatially isolated and are found in association with other organisms. The indiscriminate nature of many fishing gears means these non-target species become incidental catch or bycatch. There are a number of factors that have been identified as influencing the rate of bycatch and subsequent discarding including seasonality, area and environmental parameters such as depth and temperature. This study aims to assess the composition of bycatch of the otter trawl queen scallop *(Aequipecten opercularis*) fishery in the Isle of Man territorial seas, investigating species composition and quantity of bycatch examining the spatial and environmental variation in bycatch.

The results showed that the rate of bycatch in the fishery as a whole were relatively low at 7.42% ± 0.52 by weight of the total catch, with some variation between fishing grounds. The total bycatch for the fishery was estimated to be 309,199 ± 41,191 kg. There were significant differences found between four fishing grounds in relation to mean catch by weight, mean bycatch by weight, bycatch compositions and species composition; however there was no significant difference found in diversity and species abundance between areas.

The results demonstrate that fishing ground is the dominant factor controlling bycatch variation within the fishery. There were also indications that depth may be a secondary factor, although due to the nature of the sampling this could not conclusively be shown. Results of stomach content analysis showed that *A. opercularis* played a substantial role in the diet of dab, whiting and haddock but not red gurnard, indicating that discards from the fishery may affect the levels of abundance of some teleost fish species. In terms of management to reduce bycatch rates no obvious recommendations can be made as no “hot spots” of bycatch where identified.

Acknowledgments

I would like to thank my supervisors Professor Michel Kaiser and Dr Peter Duncan for their guidance throughout the duration of this project. I would also like to thank the skippers from all boats which allowed me to conduct fieldwork. Without their generous cooperation, this project would not have been possible. I would also like to thank Dr Lee Murray for providing fishing effort and landings data and guidance. I would like to say a special thank you to Stephen Thompson for working with me throughout this project. I would also like to say a special thank you to Andrew Clegg and Niall McGinty for all their support with the analysis and write up for this project. To Rachel Shepherd, David Mizon, Tom Fairchild, and Nathan King thank you for your friendship and support throughout the project.

This project was funded by a research grant from the Fisheries Directorate at the Isle of Man Government's Department of Environment Food and Agriculture, for which I am very grateful.

Contents

List of Figures

List of Tables

1.0 Introduction

The primary goal of fisheries management is to ensure the sustainable use of natural resources while serving the needs of the present, and to do so without compromising the ability of future generations to use this resource. Of the fish stocks recently assessed by the FAO, almost 30% (29.9%) were estimated to be overexploited, with a further 57.4% estimated to be fully exploited. The fully exploited stocks have catches that are already at their maximum sustainable production, with no potential for further expansion in catch rates, and some of these fisheries are also thought to be at high risk of decline if not properly managed (FAO, 2011). The high number of overfished stocks combined with the numerous indirect effects of fishing on marine ecosystems indicates that in a large number of cases management has failed in its goal of sustainability (Botsford *et al*., 1997).

Fishing within European Union countries is managed under the Common Fisheries Policy (CFP), which aims to deliver a thriving European fishing industry while ensuring its long-term sustainability. However, the current CFP has also failed to deliver its key objective of a fishing industry which has minimal impacts on the marine ecosystem whilst also remaining economically viable (URL 1). To this end there has been a significant attempt to introduce radical reform of the CFP to be implemented by 2013. The main priorities have included:

- **Regionalisation** – this will end micro-management at EU level and will ensure that rules are adapted to the specifications of each fishery and sea area (“region”). This will allow member states to build on existing co-operation to implement appropriate management measures (URL 2).
- **Maximum Sustainable Yield –** the new CFP will be based on a Maximum Sustainable Yield (MSY) objective; all fish stocks will have to be brought to MSY by 2015 through

the establishment of long term multi-annual management plans for all fisheries based on the best available scientific advice (URL 3).

- **Transferable Fishing Concessions** - Introduction of Transferable Fishing Concessions (TFCs) an EU wide, rights-based management scheme (URL 4).
- **Discards Ban** – A discards/catch quota will be developed and introduced to end the wasteful practice of discarding by focusing on the total catch, not just landings. The Commission has proposed a gradual approach to the discards ban which will be implemented in three stages; 1) pelagic species in 2014 (including in the Mediterranean), 2) most valuable demersal species (cod, hake and sole) in 2015, and 3) other species in 2016 (URL 5).

This study focuses on issues related to the bycatch in the trawl fishery for queen scallops (*Aequipecten opercularis*) in the Irish Sea.

1.1 Bycatch and discards in fisheries

Due in part to reforms of the CFP the issue of bycatch and discards have come to the forefront of problems faced by fisheries management. The species targeted by fisheries are often not spatially isolated and are found in association with other organisms, but due to the indiscriminate nature of many fishing gears these non-target species become incidental catch or bycatch. Bycatch is defined as incidental catch of non- target marine animals and undersized individuals of target species (Crowder & Murawski, 1998; Garcia et al., 2003; Davies et al., 2009). Discards consist of organisms of commercial and non commercial value that are caught and returned to the sea, often dead or dying (Catchpole et al.,2005a). Discarding occurs for a variety of reasons including 1) that the fish caught may be below minimum landing size, 2) the bycatch may have little or no market value and 3) the catch may be damaged or high-graded (i.e. lower valued individuals or species discarded to maximize profits), or 4) the quota for a species may have been reached (Clucas,1997). However three central causes have been identified for the high levels of discarding in European Union (EU) fisheries; the use of unselective fishing techniques, high levels of fishing effort, and biological and environmental factors affecting the distribution of species (Petter Johnsen & Eliasen, 2011) . As mentioned earlier, a number of other factors can also affect the capture of bycatch and the practice of discarding, such as complex technical (Stratoudakis *et al.*, 2001a; Marie-Joelle & Trenkel, 2005), social (Catchpole *et al.*, 2005b), economic (Alverson & Hughes, 1996; Pascoe,1997; Catchpole & Gray, 2010), and legislative factors (Rochet *et al.*, 2002). The relative importance and effect of each of these factors on the rate of bycatch or discarding varies considerably between different species, vessels, metiers and fleets, and will also vary temporally (Catchpole & Gray, 2010) and spatially (Rochet *et al.*, 2002). The levels of bycatch and discarding are also affected by the individual choices of a fisher, in deciding how and where to fish, as well as which portion of the catch to retain and which to discard (Catchpole *et al.*, 2005b; Catchpole & Gray, 2010). An update of the quantity of discards in the world's marine fisheries by Kelleher (2005) estimated the discard rate was 8% of the total landed weight, with the yearly average discards estimated to be around 7.3 million tonnes. Of this, 50% was accounted for by trawl fisheries for shrimp and demersal finfish which only represented 22% of total landings. The highest discard rate was found in tropical shrimp trawl fisheries and accounted for over 27% of the total estimated discard, whereas demersal finfish trawls accounted for 36% of estimated global discards. Kelleher (2005) also reported that small-scale fisheries in general have lower discard rates than industrial fisheries, with a rate by weight of 3.7%, whilst providing over 11% of total landings.

1.2 Factors influencing discards

Environmental conditions have been shown to be a major influence on discard quantity and composition in several studies. Seasonality has been found to influence amounts of discards in a number of fisheries (Liggins & Kennelly, 1996; Machias *et al.*, 2001), as well as the species composition or diversity of discards (Trujillo & Pereda, 1997; Castriota *et al.*, 2001; Stratoudakis, *et al.*, 2001a) and the length composition of discard species (Stratoudakis *et al.*, 2001a). A number of studies have also shown that discards vary considerably between areas. For example Murawski (1996) found that species composition and diversity were a significant function of area, while Bergmann *et al.*, (2002) found significant differences in bycatch composition between samples from the north and south Clyde Sea areas. Water depth has also been found to have a significant influence on discard quantity (Moranta *et al*., 2000; Allain, *et al*., 2003; Sánchez *et al*.,2004), discard rates (D onghia *et al.*, 2003), species (Blasdale & Newton, 1998; Allain *et al*., 2003), and species length composition (Stratoudakis *et al*., 1998). The importance of such environmental conditions is the basic rationale underlying studies that aim to identify 'hot spots' –i.e., areas or times with high discard rates (Perkins & Edwards, 1996). The latter studies can assist in providing management information to prevent high bycatch and discarding by indicating appropriate seasonal or area closures.

1.3 Biological and ecological Impacts of bycatch and discards

Bycatch and discards have a number of potential environmental and fisheries impacts which can range in significance and scale; there exists a great deal of literature demonstrating that bycatch and discards are contributing to biological overfishing and have been found to alter marine ecosystem structure. Also, there have been a number of studies that have found that bycatch and discards are negatively impacting the population levels of target species and non-target species (Alverson, 1994). High discard rates of undersized target species have been identified as a contributing factor to population declines in a number of fisheries. Therefore estimating bycatch and discards are essential for assessing the full impact of fisheries upon fish populations and upon the ecosystem in which they operate. Furthermore, discarding has been found to have wider implications such that ecosystem functioning and its biodiversity are negatively affected (Anon, 2007). A number of studies have indicated that discarding can alter the ecosystem functioning of some seabird (Votier *et al.*, 2004; Votier *et al.*, 2010) and benthic communities by causing changes in prey and predator abundances and species assemblages (Jennings & Kaiser, 1998). In terms of fisheries management discarding may be a substantial but under-reported component of fishing mortality due to the fact that survival of discarded organisms can be low (Evans *et al.*, 1994). Despite this, discarding is usually not accounted for in stock assessments. In a report by the International Council for the Exploration of the Sea (ICES) of 41 fish stock assessments, only 12 included discard data (ICES, 2004).

1.4 The Isle of Man Queen Scallop fishery

A fishery for queen scallops (*A .opercularis)*, has operated in the Isle of Man's territorial waters since 1969. At this time there was already a well-established dredge fishery for king scallop, *Pecten maximus*, but a period of decline in the late 1960s resulted in the fleet diversification into queen scallops. This fishery utilised previously un-fished stocks and was very profitable with landings of 4,530 tonnes in the Isle of Man in 1969. When the fishery first began only local boats fished for queen scallops in the waters surrounding the Isle of Man, however since the 1970s increasing numbers of other vessels particularly Scottish boats have begun to join the fishery. The total landings of queen scallop for the North Irish Sea (ICES Area VIIa) are variable from year to year, mostly due to variable recruitment. The highest recorded landing for the Isle of Man was 5,632 tonnes recorded in 1983. There was a decline in landings in 1988 which was primarily due to poor market demand. The lowest recorded landings were in 1994 at 1,455 tonnes; this was due to the exceptionally poor recruitment of the 1992 year class on all fishing grounds (Brand & Wilson, 1996). During the peak of the fishery in 1984 there was a maximum of 70 registered boats fishing for king and queen scallops, this number has since fallen to < 30 in recent years. As well as the Isle of Man fishing fleet there are also a number of other UK and Irish boats that fish for queen scallops each year in the north Irish Sea. The most significant of these are the Scottish vessels which are purpose-built dredges with modern gear and catch–handling facilities on board, which are very efficient (Andrews *et al*., 2010).

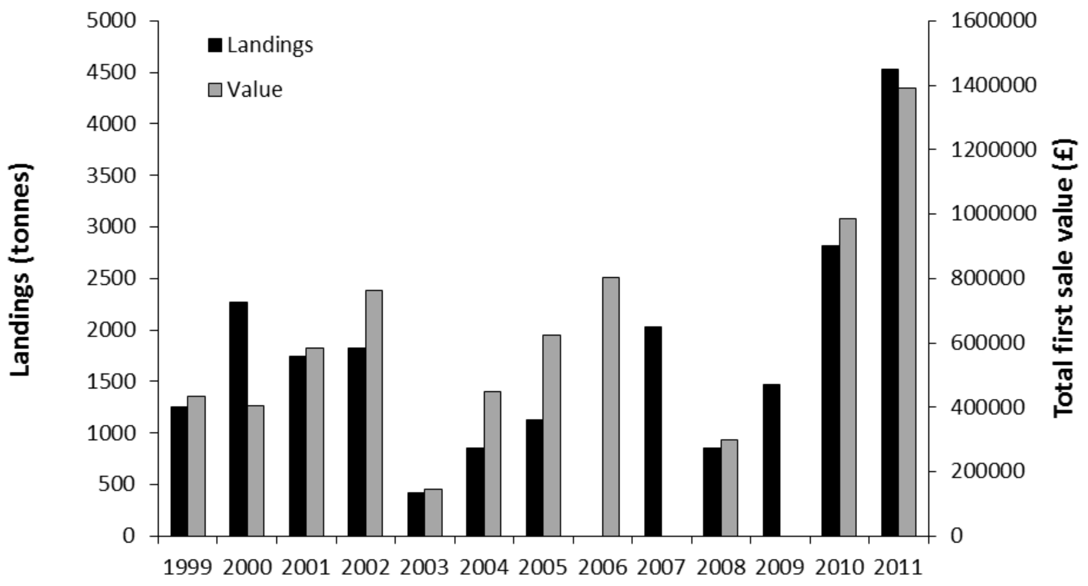

Figure 1: Landings and first sale values of queen scallop *Aequipecten opercularis* in the Isle of Man. Data sourced from the Fisheries Directorate, Department of Food Environment and Agriculture, Isle of Man.

The queen scallop fishery is in 2012 the Isle of Man's second most important fishery next to king scallops with total landing in 2011 of 4,529 tonnes and a first sale value of £1,389,904 (Figure 1). The traditional gear used in the queen scallop fishery was tooth dredges or skid dredges, however most Isle of Man vessels now fish for queen scallops with otter trawls. There are a number of management measures that govern the fishery which include a minimum landing size of 50mm, a closed season and areas where dredging is not allowed (Sea-Fisheries Act 1971, The Isle of Man Sea-Fisheries (queen scallop fishing) by-laws 2010. Statutory document No. 668/10).

All of these management measures helped the Isle of Man trawl fishery become Marine Stewardship Council (MSC) certified in April 2011. The MSC certification processes have a number of principles and criteria for sustainable fisheries, these from the standard against which the fishery is assessed. They are organised in terms of three principles:

1. “A fishery must be conducted in a manner that does not lead to over-fishing or depletion of the exploited populations and, for those populations that are depleted, the fishery must be conducted in a manner that demonstrably leads to their recovery.”

2. “Fishing operations should allow for the maintenance of the structure, productivity, function and diversity of the ecosystem (including habitat and associated dependent and ecologically related species) on which the fishery depends.”

3. “The fishery is subject to an effective management system that respects local, national and international laws and standards and incorporates institutional and operational frameworks that require use of the resource to be responsible and sustainable.” (MSC, 2010).

Eco-labelling programs such as the certification program operated by the MSC are becoming increasingly popular for the promotion of sustainable fishery products and have been found to demand a price premium over products from non MSC-certified fisheries (Roheim *et al*., 2011). Gutiérrez *et al.*, (2012) found that MSC-certified stocks are on average more likely to meet or surpass MSY-based target reference points, finding that 74% of certified fisheries analysed were above biomass levels that would produce MSY, compared to uncertified fisheries with only 44%. Similarly the average biomass of MSC-certified stocks increased by 46% over the period from 2002 to 2012, compared to uncertified fisheries which increased by just 9%.

However to maintain the MSC certification a fishery needs to demonstrate that it has minimal impacts on the wider marine ecosystem and that its levels of bycatch are within an acceptable level. An assessment of the queen scallop fishery bycatch completed in 2009 found that the levels were relatively low (Duncan, 2009), with the overall rate by weight, relative to target species, being estimated at 3.36%, which is low compared to other fisheries. By contrast, Borges *et al*., (2005) estimated the rate of discards in the Irish Sea (ICES division VIIa) for the Irish beam trawl fleet to be 67%, and the otter trawl fleet for *Nephrops norvegicus* at 25%. Similarly the *N. norvegicus* trawl fishery in the Clyde in the west of Scotland has a reported mean discard rate of 62%, an equivalent fishery in the North Sea was 45%, while the North Sea flatfish beam trawl fisheries was as high as 80% (ICES, 2006). The Isle of Man queen scallop fishery also compares favourably to other scallop fisheries elsewhere in the world; the Canadian Georges Bank dredge fishery for *Placopecten magellanicus* was estimated to have a bycatch level of 6% (DFO, 2007; DFO, 2008).

1.5 Variability in bycatch amounts

When trying to interpret variation in bycatch distribution it is important to consider all aspects which may be influential. For example variations in habitat suitability are understood to influence differences in demersal fish distribution (Hinz *et al.*, 2003), and a combination of biotic and abiotic factors over varying spatial scales is thought to control habitat selection (Moranta *et al.*, 1998; Genner *et al.*, 2004) Some of these factors, such as depth and temperature, can vary over large scales, while other relevant factors vary over smaller scales, e.g. behavioural and ecological interactions including predation (Werner *et al.*, 1983), competition (Werner & Hall, 1979; Hixon & Jones, 2005), habitat complexity (Angel & Ojeda, 2001; Almany,2004), and prey availability (Pinnegar *et al.*, 2003; Hinz *et al.*, 2005). Johnson *et al*., (2012) presented a strong case to support their hypothesis that demersal fish abundances are higher in areas of high prey abundance for a number of species in the waters surrounding the Balearic Island in the western Mediterranean. The importance of prey in regulating the distribution, abundance and size of predators has become widely recognised in marine ecology (Gilinsky, 1984; Hixon & Carr, 1997) and understanding these predator-prey relationships is an important factor to consider when interpreting differences in abundances of bycatch species.

1.6 Dab scavenging behaviour

When trying to understand the indirect impacts of fishing, it is important to consider the effects that fishing activities, such as trawling and subsequent discarding, may have on non-target species. It is well known that fishing gears such as beam trawls (Bergman & Hup, 1992), otter trawls (Van Dolah *et al*., 1987; Rumohr & Krost, 1991; Van Dolah *et al*., 1991) and dredges (Van der Veer *et al*., 1985; Eleftheriou & Robertson, 1992) cause increased local mortality of some epifaunal and infaunal benthic organisms. Subsequently, this may lead to an increase in opportunistic feeding by invertebrates (Wassenberg & Hill, 1987) and fish species (Kaiser & Spencer, 1994), which may result in aggregations of these species in recently trawled areas (Kaiser & Spencer, 1994; Kaiser & Hiddink, 2007). Attraction to these recently trawled areas may increase the likelihood of being caught by subsequent passes of the fishing gear (Bradshaw *et al*., 2000). Fishery discards may act as a food supply that helps maintain fish populations, however the extent of this is unclear. Some studies suggest that fisheries discards allow for more abundant fish population than under natural resource levels (Polis & Strong, 1996), although others have argued that these discards simply sustain populations, rather than lead to population growth (Groenewold & Fonds, 2000). For example, it has been shown that recently trawled areas attract scavengers due to the increase in available food, and in the Irish Sea and North Sea, dab (*Limanda limanda*) are one of the first scavengers to aggregate in these areas (Kaiser & Spencer, 1996).However, the bycatch mortality of dab populations in the North Sea may be somewhat mitigated by the benefits of increased food produced through fishing activity (Kaiser & Ramsay, 1997b). Some studies have shown that discards from fisheries form a large component of fish diet when available and some fish species have been shown to feed on the discards from scallop fisheries (Link & Almeida, 2002).

1.7 Aim of this study

The aim of this study was to assess the composition of bycatch of the otter trawl queen scallop *(A. opercularis*) fishery in the Isle of Man territorial sea, in order to maintain the Marine Stewardship Council (MSC) accreditation of the sustainability of the fishery. The study will elaborate upon the discard sampling work that was conducted by Duncan (2009). The work will identify the species composition and quantity of bycatch and discards that occur in this fishery in relation to the target catch composition. The spatial (fishing grounds) and environmental (depth, temperature and Chlorophyll-a) variation in bycatch will be examined in order to identify key parameters that contribute to differences in bycatch abundances and composition.

To further investigate explanatory factors relating to the abundance of teleost fish in bycatch, the stomach contents of several fish species from the four fishing grounds were examined, in order to determine whether this may be a relevant factor. Further to this the stomach contents of dab (*Limanda limanda*) were examined from various tows throughout replicate fishing days to examine if fishing activities, such as disturbance of the seabed and discarding is having a significant impact on the feeding behaviour of dab.

1.8 Specific Objectives and Hypotheses

- That the catch composition by weight of retained queen scallops, unretained queen scallops and bycatch will vary between fishing grounds.

It is likely that the catch composition will differ between areas with some fishing grounds having a better catch rate of sizeable queen scallops than others.

- The mean bycatch abundance and biomass will vary between fishing grounds.
- The species diversity of the bycatch will vary between fishing grounds.

The bycatch abundance, biomass and diversity may show variability between fishing grounds with some areas having higher rates of biomass, abundance and diversity.

- The species composition of the bycatch will vary between fishing grounds.
- Environmental variables will correlate to explain variation in bycatch species composition.

Variability in species abundance may be caused by a number of environmental factors.

In a number of studies prey availability has been shown to affect fish abundances, and differences in diet and stomach fullness may be one component that helps explain variation in bycatch fish species.

- The stomach fullness of dab, Haddock (*Melanogramus aeglefinus)*, Whiting (*Merlangius merlangus)* and Red Gurnard (*Aspitrigla cuculus*) will vary between fishing grounds.
- The diet of Dab, Haddock, Whiting and Red Gurnard will vary between fishing grounds.

Discards from fisheries have been shown to influence species abundances due to increased availability of food, and a number of species including dab have been shown to exhibit scavenging behaviour in recently trawled areas.

- Dab abundances will increase with increase in tow number (e.g. as the day progresses).
- Dab stomach fullness will increase with increase in tow number.
- Queen scallops will be the prey item responsible for the increase in stomach fullness.

2.0 Materials and Methods

2.1 Sampling

Sampling was conducted aboard 7 commercial fishing boats from 25th of June to the 26th of August, during the course of their normal fishing activities. Fishing took place on 4 different fishing grounds colloquially known as Targets, Douglas, Chickens and Ramsey, all located within the territorial waters of the Isle of Man (Figure 2). On each day between 3 and 6 tows were performed depending on a number of factors such as weather conditions, quantity caught per tow or a catch limit set by the fish producers. A total of 58 tows were sampled; 16 from Targets, 15 from Douglas, 14 from Chickens and 13 from Ramsey (Figure 2). The fishing gear used in this fishery is a single net rockhopper otter trawl. A foot rope which holds a number of rubber rollers rolls along the seabed while a head rope is made more buoyant using hollow spherical floats. Occasionally a light tickler chain is used, located in front of the foot rope. The catch is sorted on deck through the use of a mechanical riddle consisting of fixed diameter steel rings and bars. The queen scallops are transferred into the rotating riddle, which removes undersized queen scallops and small bycatch automatically. The undersized catch is forced through the steel rings by a constant stream of seawater into a pipe or chute that flows directly overboard. Queen scallops of sufficient commercial size and larger bycatch which come out are retained and the larger bycatch is then typically removed overboard.

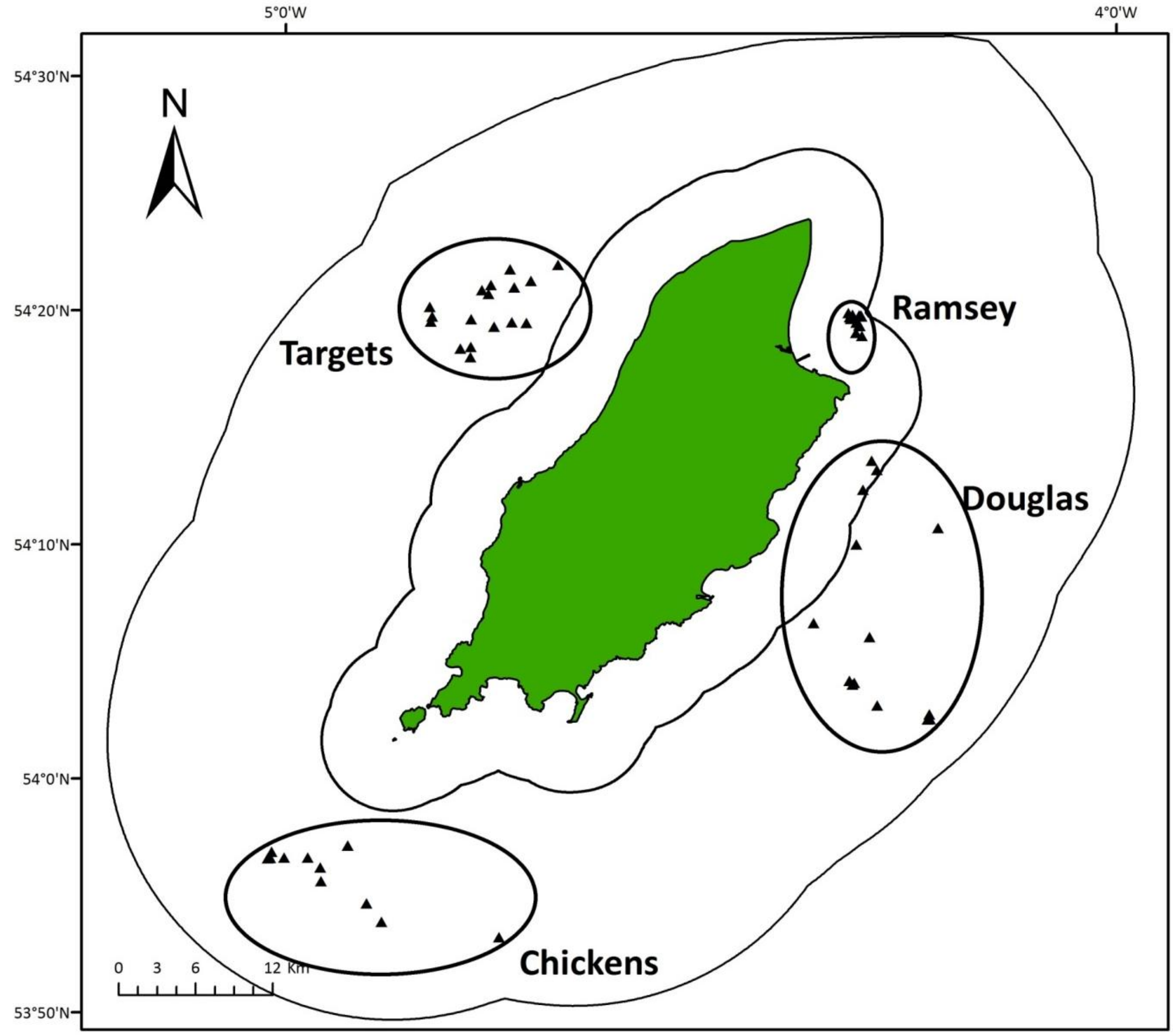

Figure 2: Map of study area, points indicating start position of tows included in the analysis. The boundaries of the fishing grounds used in this study, and the 3 and 12 nautical mile limits are also shown.

The gear specifications differed slightly between each vessel and gear parameters were recorded for each including the foot rope length, cod-end mesh size (mm), and whether a tickler chain was used. For each tow the boat track was recorded using a Garmin e Trex H handheld GPS, with the start and end points of the tow marked using the waypoint function. The track function was used to record the vessel position at 1 minute intervals. Tow duration, speed and distance were then calculated from the GPS data using Garmin – Mapsource, Trip and Waypoint manager V5. The swept area per tow was calculated from dimensions of vessels gear and the tow data, using the method described by Courtney *et al*., (2007).

$$1)\quad \text{Area Swept} = \frac{F \times NSF \times D}{10{,}000}$$

Where F = footrope length (metres), NSF = net spread factor (=0.75 (Sterling, 2005))and D = distance trawled (converted to metres using 1 nautical mile = 1852m).

Environmental factors such as sea state, wind speed, tidal state and direction were also recorded.

2.2 Bycatch abundance and composition

To calculate the abundance and composition of bycatch as a component of a typical commercial catch, the catch was deposited onto the deck of the fishing vessel and coarsely separated into broad taxonomic categories (e.g. teleost fish or elasmobranchs). Any remaining fish encountered during the riddling process were also collected. Due to the large size of the commercial catch a subsample (38.03kg ± 0.74 mean subsample weight) was taken to investigate the invertebrate bycatch composition of the catch. These subsamples were weighed and divided into target species (queen scallop *A. opercularis*), bycatch species and debris. The weight of each of these components was recorded. All bycatch was identified to species level whenever possible and the number and weight of individuals were recorded. In order to calculate the weight of unretained queen scallops as a proportion of the total catch the total weight of queen scallops in the subsample was recorded, these were then passed through the riddler and the weight of the retained queen scallop recorded. The number of bags of retained queen scallops (containing approximately 40 kg each) per tow was also recorded. Using the total catch of queen scallops for the entire season (data provided by DEFA) the total bycatch for the entire fishery was calculated. This was done using the % bycatch to catch for each of the four areas.

2.2.1 Statistical Analysis

In order to calculate the total bycatch as a proportion of the total catch including unretained queen scallops the following method was used:

$$2)\ QU_t = (QR_t/QR_s)*QU_s$$

$$3)\ I_t = (QR_t/QR_s)*I_s$$

Where QR = weight of retained queen scallops, QU = weight of unretained queen scallops and I = weight of invertebrate bycatch, with t indicating a tow and s indicating a subsample. The number of invertebrate individuals in the subsample was multiplied by the invertebrate weight proportion I_t/I_s to give an estimate of the number of individuals in the tow.

This first aim was to determine whether the mean biomass and abundance of bycatch differed across fishing grounds. Secondly, the study also aimed to determine whether the bycatch assemblage structure (i.e. species composition and relative abundance of each species) differed across fishing grounds. Observed environmental data was tested to determine whether it contributed as an explanatory factor to any observed differences. Water depth was the mean water depth for each tow, habitat type was taken from a survey conducted in 2008 which classified the habitats surrounding the Isle of Man into forty significant biological groups (White 2008). SST values were extracted from the Global High Resolution Sea Surface Temperature (GHRSST) dataset (Reference: http://journals.ametsoc.org/doi/abs/10.1175/BAMS-88-8-1197). Chlorophyll-a values were extracted from remote sensed images taken by the MODIS sensor (data provided by NEODAAS).

To test whether mean biomass and abundance of bycatch differed across fishing grounds, a univariate approach was taken by using a one-way analysis of variance (ANOVA) to compare the mean number of bycatch individuals and biomass levels between fishing grounds. Total abundances N (n ha^{-1}) and biomass B (kg ha^{-1}) were standardised by swept area. The data was checked for homogeneity of variance using the Levene's test and if this assumption was not met a number of transformations were applied to the data. If the transformed data still did not meet the necessary assumptions the non-parametric equivalents (Kruskal-Wallis followed by pair-wise Mann-Whitney U tests) were used. This procedure was applied throughout this study for univariate analysis.

The bycatch abundance data including all species were used to examine differences in species diversity between fishing grounds. Species diversity was measured by examining the Shannon Wiener and Simpson's index and univariate analysis was used to test for differences between fishing grounds.

The bycatch abundance data was then separated into invertebrate and vertebrates (fish and elasmobranch), due to the differing methods of sampling used on these groups. Once separated, the abundances for each species were ranked in terms of their percentage contribution to the total abundance of all species. To remove any statistical bias caused by rarer species, the species that contributed to less than 0.5% of the total abundance were excluded (Zuur, 2010). Data was initially square root transformed and was clustered according to Bray-Curtis indices of similarity in order to gauge the level of similarity between samples. The Bray-Curtis resemblance matrix was also used to produce Multi-Dimensional Scaling (MDS) ordination plots of bycatch data. An Analysis of Similarity (ANOSIM) routine was performed to determine the effects of fishing ground on the community structure of samples. Pairwise ANOSIM testing was used to determine differences between fishing grounds. SIMPER analysis was used to determine which species contributed most to the similarity within fishing grounds and the dissimilarity between fishing grounds. The species identified by SIMPER as causing differences between fishing grounds were then analysed in greater detail.

Water depth, sea surface temperature (SST), chlorophyll-a concentrations and habitat type for each tow were related to the grouping of abundance data using the BEST routine in order to explore which environmental variables contribute greatest to any patterns observed within the data.

2.3 Teleost stomach contents

Teleost fish were collected from the last tow of the day on selected days of sampling. These fish were then kept in a cool box onboard and immediately frozen on return to shore for later analysis. The total length (TL) was measured to a precision of 1mm, and the round body weighed to a precision of 1 g. The sex and maturity stage were verified macroscopically using an appropriate scale for each fish species (see appendix). The stomachs were removed and weighed with excess moisture removed by blotting with absorbent paper. Stomach fullness was estimated on a scale of 1-7:

1. Empty
2. Trace of prey
3. Trace to 25%
4. 25% to 50%
5. 50% to 75%

6. 75% to 100%

7. Stomach distended

The stomach was then dissected and the contents examined under a stereoscopic microscope. Each prey item was identified to the lowest possible level of taxonomic resolution, counted and weighed wet. The aim was to investigating whether stomach fullness and the composition of stomach contents varied between different fishing grounds.

2.3.1 Stomach content Analysis

A non- parametric Kruskal- Wallis test was used to investigate differences in stomach fullness between fishing grounds. This was performed for each of the four species, dab, whiting, red gurnard and haddock, to determine if stomach contents and diet varied between fishing grounds.

For each identified taxa, the following indices were calculated for each of the fishing grounds including the percentage of occurrence (%O_i: (Mohan & Sankaran, 1988)):

4) $$\%Oi = \frac{n_i}{\sum_{i=1}^{i=n} n_i} \times$$

Where n_i is equal to 1 if the taxa occurs in the fish, and 0 otherwise.

Percentage of weight (%W_i):

5) $$\%W_i = \frac{W_i}{\sum_{i=1}^{i=n} W_i} \times 100,$$

Where W_i is the weight of item i and $\sum_{i=1}^{i=n} W_i$ is the aggregated weight of all items in the stomach.

The Weighted Resultant Index (%R_W : (Mohan & Sankaran, 1988)):

6) $$\%\,R_W = \frac{Q\sqrt{\%\,W_i^2 + \%\,O_i^2}}{\sum Q\,\sqrt{\%\,W_i^2 + \%\,O_i^2}} \times 100\,,$$

Where $Q = \frac{45-|\theta-45|}{45}$ and $\theta = \tan^{-1}\left(\frac{O_i}{W_i}\right)$

To examine differences of the Weighted Resultant Index of taxa between fishing grounds for each of the four fish species an ANOSIM analysis was conducted on the Bray – Curtis similarity index data for each stomach being grouped first by host species then by fishing grounds. If differences were found, pairwise comparisons were performed to determine where the differences lay between fishing grounds. SIMPER analysis was also performed to identify which prey items were responsible for causing these differences.

2.4 Investigation of Dab scavenging behaviour

Preliminary stomach content analysis revealed that the stomachs of several fish species including dab and whiting contained a high proportion of queen scallop meat. It was thus hypothesised that these species may have been feeding on queen scallops discarded from previous tows throughout the day, as all fish sampled were collected from the last tow of the day and fishing activity tended to be in a relatively small area in any day of fishing (Figure 3). To test this hypothesis dab was selected as the prime species to be examined due to its ubiquity in all fishing areas with an average abundance of 18.05 ± 2.77 fish per tow. The individuals were collected on five days of sampling from Douglas, Ramsey and Chickens and dab from each consecutive tow were retained and labelled separately. Samples were stored and analysed in the same manner as in section 2.3. Therefore, we wished to investigate whether the stomach contents, particularly the presence of queen scallop changes throughout the day.

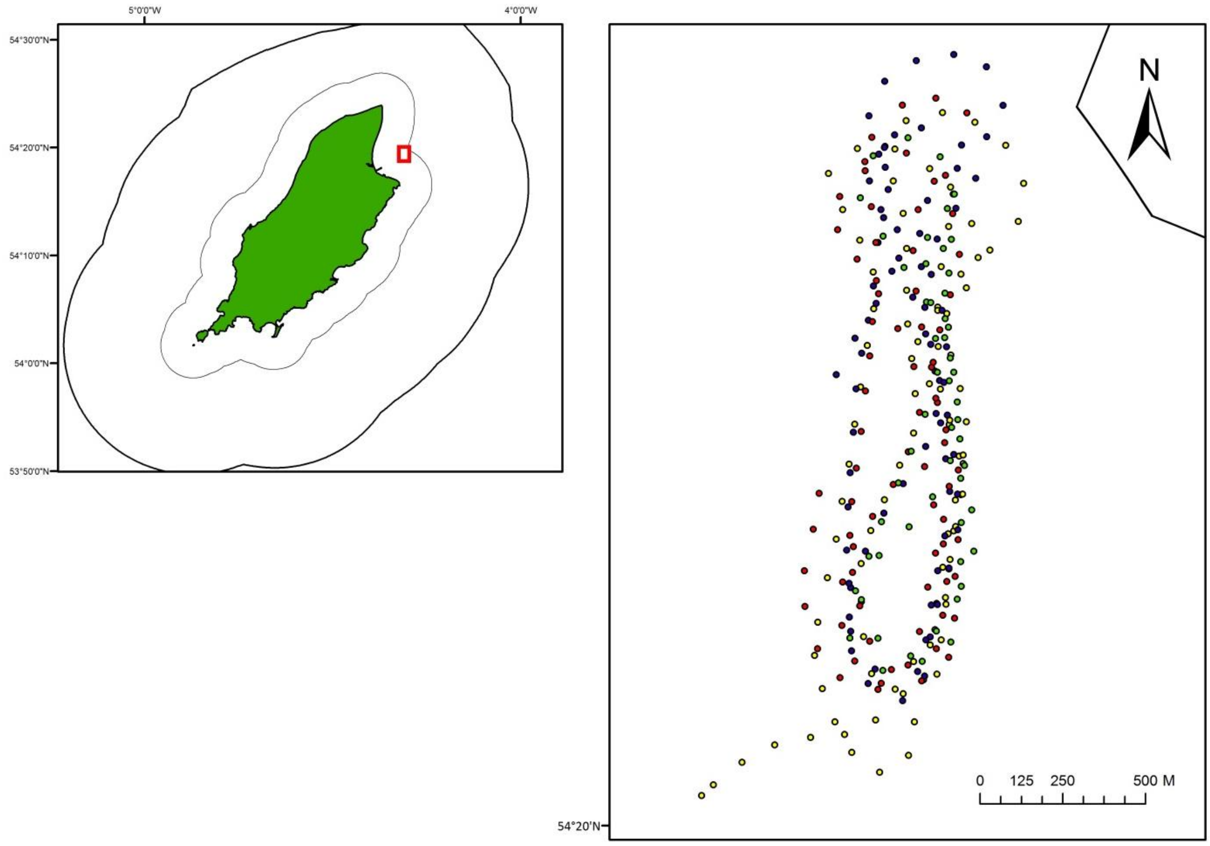

Figure 3: Map of the track points of tows from the 13th of September of which dab where collected from each tow, each point represents a point on the tow track, each tow track is clearly marked with a distinct colour.

2.4.1 Analysis

An ANOVA test was used to test for differences in the number of dab per ha per tow (n ha^{-1} tow^{-1}) and whether this difference was related to time. A non–parametric Kruskal–Wallis test was used to investigate differences in stomach fullness between tows. The $\%R_w$ for each prey item was also calculated in the same manner as in section 2.3.1 with the stomachs of dab being grouped by tow rather than by fishing ground. This was used to determine if queen scallops were responsible for any differences observed in stomach fullness between tows. The mean cumulative weight of undersized queen scallops that were discarded during each tow was also calculated to give an approximation of the amount of available queen scallops as food for dab.

2.5 Length frequency / length – weight Relationship

The length frequency of the teleost fish caught as bycatch was calculated by recording the total length (TL) to the nearest cm for each fish. To calculate the length-weight relationships for a number of teleost fish species a subsample ranging in length was taken ashore. The total length (TL) and the weight (W) were recorded for each fish sampled. A function of the form:

$$W = aL^b$$

Was fitted to the data, where W is the weight (g), L is the TL (mm) and a and b are constants.

3.0 Results

3.1 Bycatch abundance and composition

The mean percentage weight of bycatch to target species catch across all four fishing grounds was 7.42% ± 0.52. This differed slightly between fishing grounds with Douglas having the highest bycatch to catch ratio of 8.41% ± 1.15, then Targets with 8.11% ± 0.83, followed by Chickens with 6.60% ± 1.33 and finally Ramsey with 6.30% ± 0.7. Figure 4 shows the mean weight of retained Queen scallops, unretained (undersized) Queen scallops and total bycatch per hectare in each of the four fishing grounds. There was a significant difference in the mean weight per hectare of retained Queen scallops between fishing grounds ($F_{3,54}$ = 5.655, p = 0.002) with the highest value in Douglas (Table 1), which is significantly greater than both Ramsey and Targets ,but not Chickens (Table 2). There was also a significant difference between the mean weight per hectare of unretained Queen scallop between fishing grounds ($F_{3,54}$ = 4.513, p = 0.007) with the highest value in Ramsey (Table 1) with significant differences between Ramsey and Targets (Table 2) and Chickens and Targets (Table 2). The total bycatch for the entire fishery over the entire season including all fishing grounds was estimated to be 309,199 ± 41,191 kg.

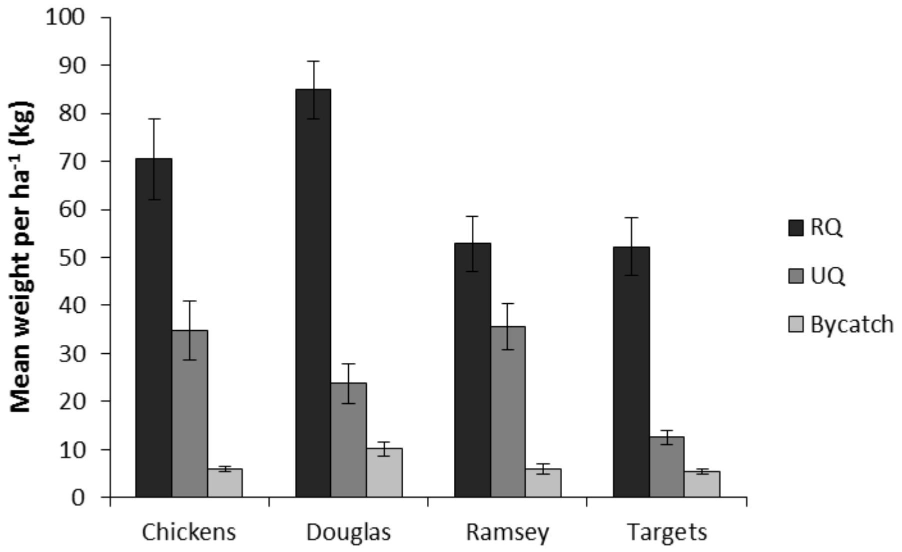

Figure 4: Mean (±SE) weight (kg) per hectare of retained Queen scallops (RQ), unretained Queen scallops (UQ) and total bycatch in each of the four fishing grounds. Taken from 58 tows.

Table 1: Mean (±SE) weight (kg) per hectare of retained Queen scallops (RQ), unretained Queen scallops (UQ) and total bycatch in each of the four fishing grounds.

Fishing grounds	RQ	UQ	Bycatch
Chickens	70.45 ± 8.48	34.77 ± 6.03	5.97 ± 0.54
Douglas	84.88 ± 6.08	23.71 ± 4.12	10.11 ± 1.50
Ramsey	52.90 ± 5.73	35.67 ± 4.84	5.94 ± 0.96
Targets	52.19 ± 6.00	12.49 ± 1.41	5.40 ± 0.63

Table 2: ANOVA/Kruskal-Wallis tests performed on retained Queen scallops (RQ), unretained Queen scallops (UQ) and total bycatch also shown are the P values of post- hoc tests. All tests had 3, 53 degrees of freedom. Letters of post – hoc tests identify fishing grounds C = Chickens, D = Douglas, R = Ramsey and T = Targets.

				Post-hoc					
		F/ χ^2	**P**	**C, D**	**C,R**	**C,T**	**D,R**	**D,T**	**R,T**
RQ	-	5.655	**0.002**	0.425	0.284	0.211	**0.008**	**0.004**	1.000
UQ	Log10	4.513	**0.007**	0.631	0.875	**0.046**	0.224	0.446	**0.007**
Bycatch	K –W	9.578	**0.023**	0.067	0.770	0.087	0.134	**0.008**	0.119

Significant differences were observed in the mean bycatch biomass between fishing grounds (χ^2_3 = 53.202, p < 0.023). Figure 5, Table 1 and Table 2 shows the mean bycatch biomass is highest in Douglas (10.07kg ± 1.49), which differs significantly from Targets (5.05kg ± 0.57), however no other significant difference were found between any other areas.

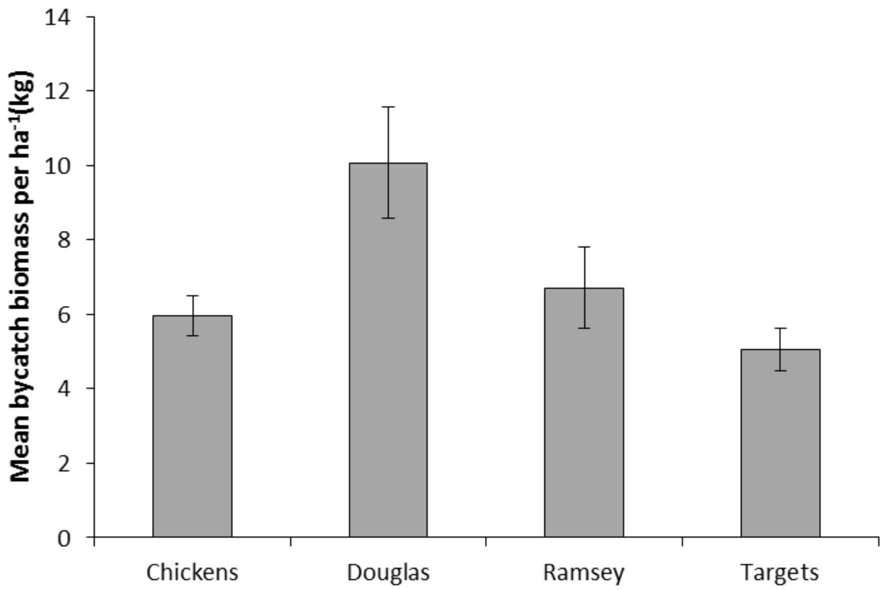

Figure 5: Mean (±SE) bycatch biomass (kg) per hectare swept in each of the four fishing grounds. Taken from 58 tows.

The highest mean bycatch abundance was found in Douglas with 285.44 ± 56.86 individual bycatch organisms per hectare swept (Figure 6) and the lowest mean abundance was found at Chickens with 121.66 ± 13.54. Despite this there was no significant differences in bycatch abundance between fishing grounds ($\chi^2_3 = 3.21$, $p = 0.360$).

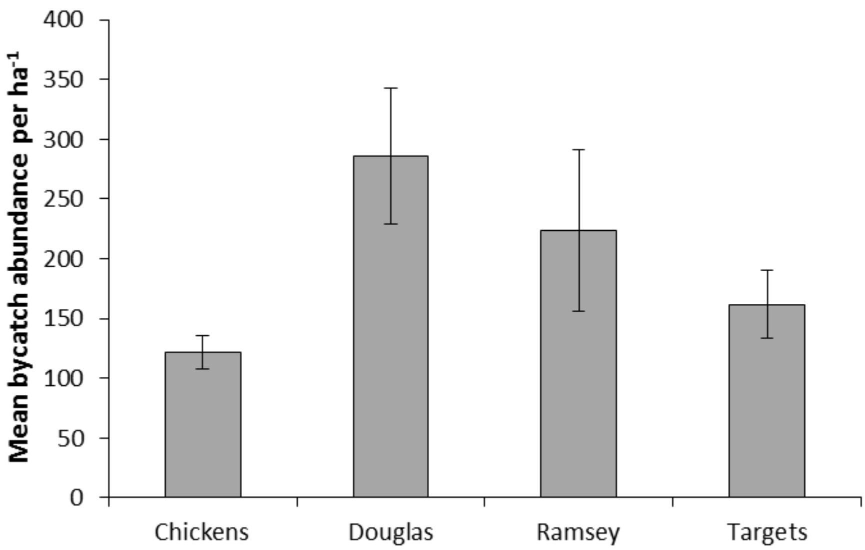

Figure 6: Mean (±SE) bycatch abundances per hectare at each of the four fishing grounds. Taken from 58 tows.

3.1.1 Bycatch Composition

The mean weight per hectare of teleost fish, elasmobranchs and invertebrates all differed significantly between fishing grounds ($F_{3,54} = 11.163$, $p < 0.001$;$F_{3,54} = 4.156$, $p = 0.01$; $\chi^2_3 = 21.340$, $p < 0.001$) (Figure 7). The highest mean weight for teleost fish was found in Chickens (2.59 kg ±0.16) which differed significantly from that of Douglas (1.19kg ± 0.1), Ramsey (0.53kg ± 0.09) and Targets (0.92kg ± 0.10). There was also a significant difference in mean fish between Douglas and Ramsey (Figure 7). Although there was an overall difference in mean elasmobranch weight between areas, the only pair that showed a significant difference was between the Douglas (2.35kg ± 0.37) and Targets (0.85kg ± 0.13) areas. The mean weight of invertebrates was highest in Douglas (6.53kg ± 1.19) which was significantly higher than that of the Chickens (1.38kg ± 0.16) area while the mean weight in Ramsay and Targets differed significantly from Chickens but do not differ from Douglas (Figure 7).

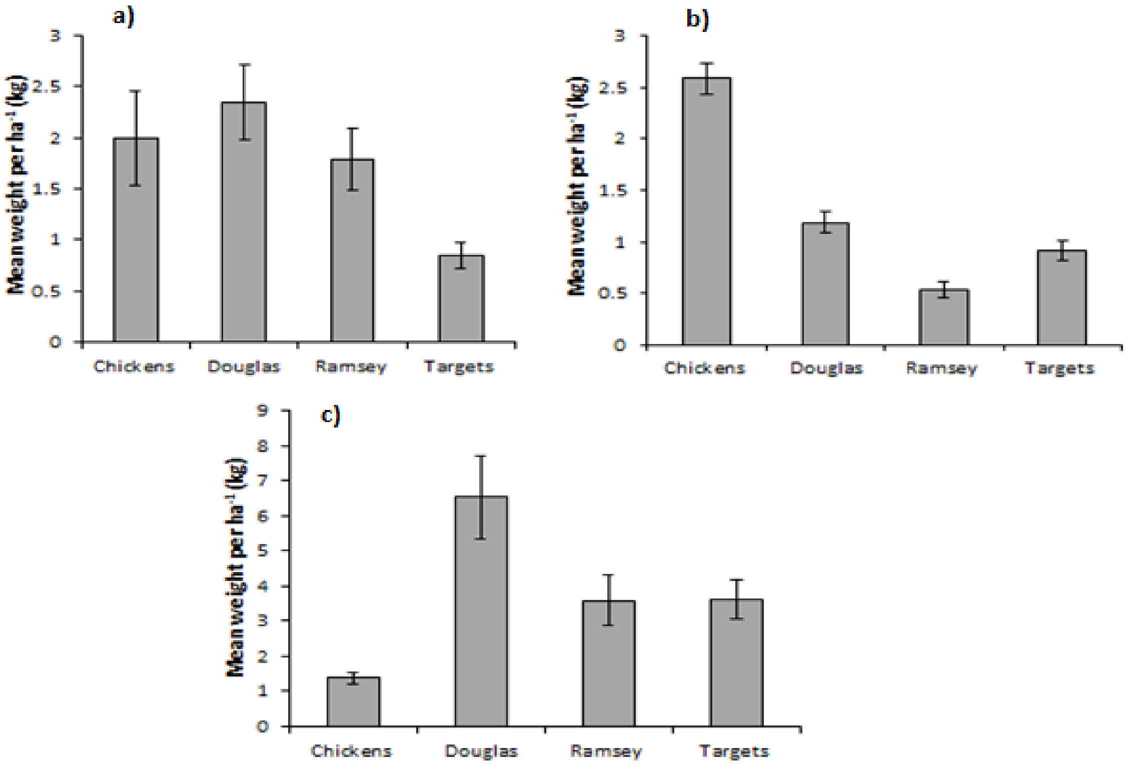

Figure 7: Mean (± SE) weight per hectare of a) elasmobranchs, b) teleost fish and c) invertebrates in each of the four fishing grounds. Taken from 58 tows.

Mean diversity indices calculated using DIVERSE showed no significant differences in species assemblages between fishing grounds. Neither Shannon- Wiener diversity index ($F_{3,54}$= 0.261, p = 0.853) nor Simpson's dominance index ($F_{3,54}$ = 0.154, p = 0.927) showed any significant differences (Figure 8).

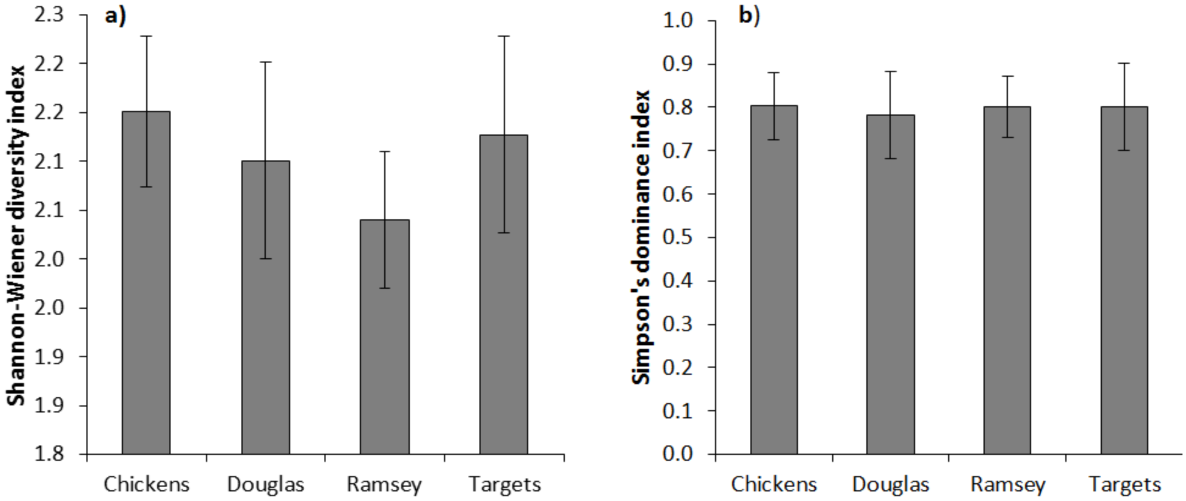

Figure 8: The mean (±SE) a) Shannon-Wiener diversity index and b) Simpson's dominance index in each of the four fishing grounds taken from abundance bycatch data from all 58 tows.

3.1.2 Invertebrate bycatch assemblages

The MDS plot shown in Figure 9 illustrates the similarity between samples on a two-dimensional ordination where the degree of similarity is represented by the distance between points. It is apparent from the ordination in Figure 9 that there is similarity in invertebrate bycatch assemblages within fishing grounds, and despite some variability there are differences between fishing grounds which were confirmed by the result of an ANOSIM analysis of similarities which revealed significant differences in invertebrate bycatch assemblages between fishing grounds (ANOSIM, $R = 0.432$, $p = 0.001$). Multivariate pairwise ANOSIM tests showed significant differences between all fishing grounds (Table 3).

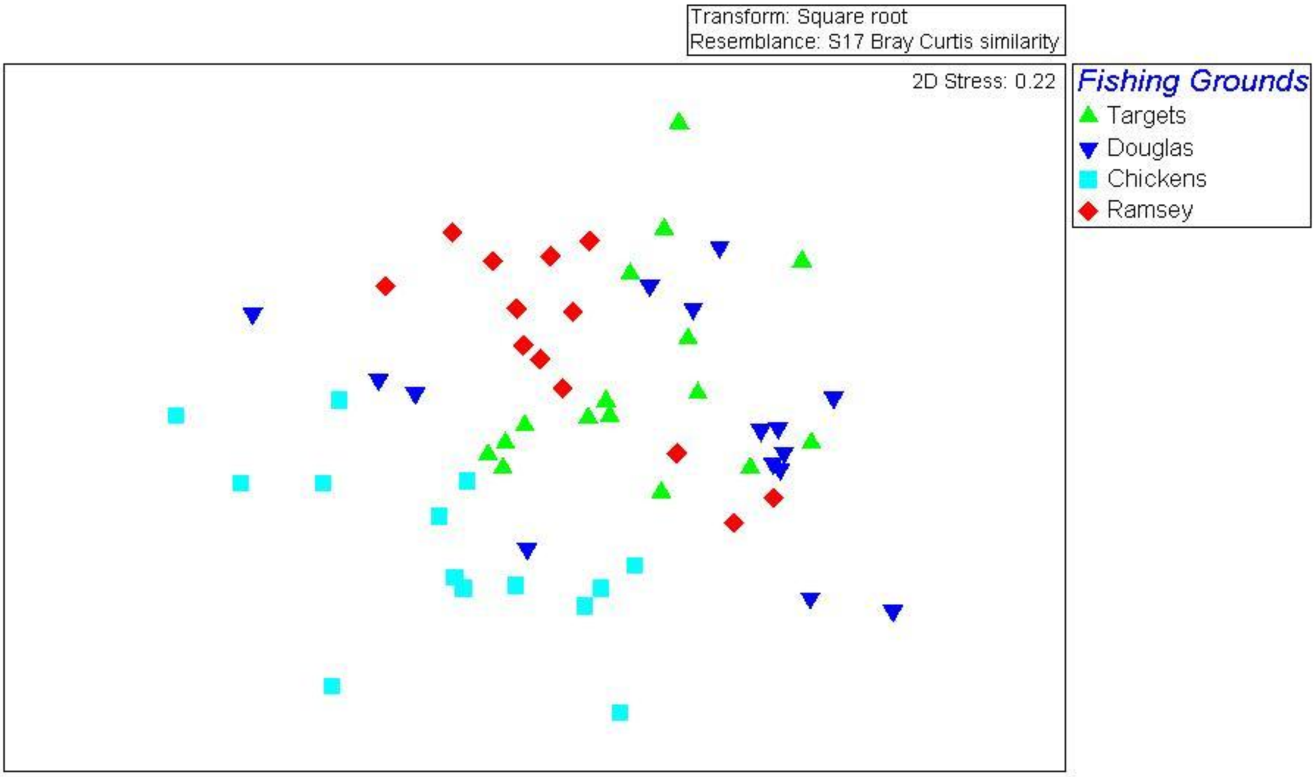

Figure 9: MDS plot of invertebrate bycatch assemblages, within the different fishing grounds based on Bray-Curtis similarity of square root transformed standardised (per ha per tow) abundance data from 58 tows conducted as part of this survey.

Table 3: ANOSIM pair-wise comparisons of invertebrate bycatch species composition between fishing grounds. from 58 tows conducted as part of this survey.

Fishing ground	R statistic	P value
Targets v Douglas	0.434	0.001
Targets v Chickens	0.436	0.001
Targets v Ramsey	0.369	0.001
Douglas v Chickens	0.55	0.001
Douglas v Ramsey	0.393	0.001
Chickens v Ramsey	0.456	0.001

SIMPER analysis was used to examine similarities within and dissimilarities between fishing grounds. The species that contributed most to the similarity in invertebrate bycatch assemblages within fishing grounds and the average similarity of each of the grounds can be seen in Figure 10.

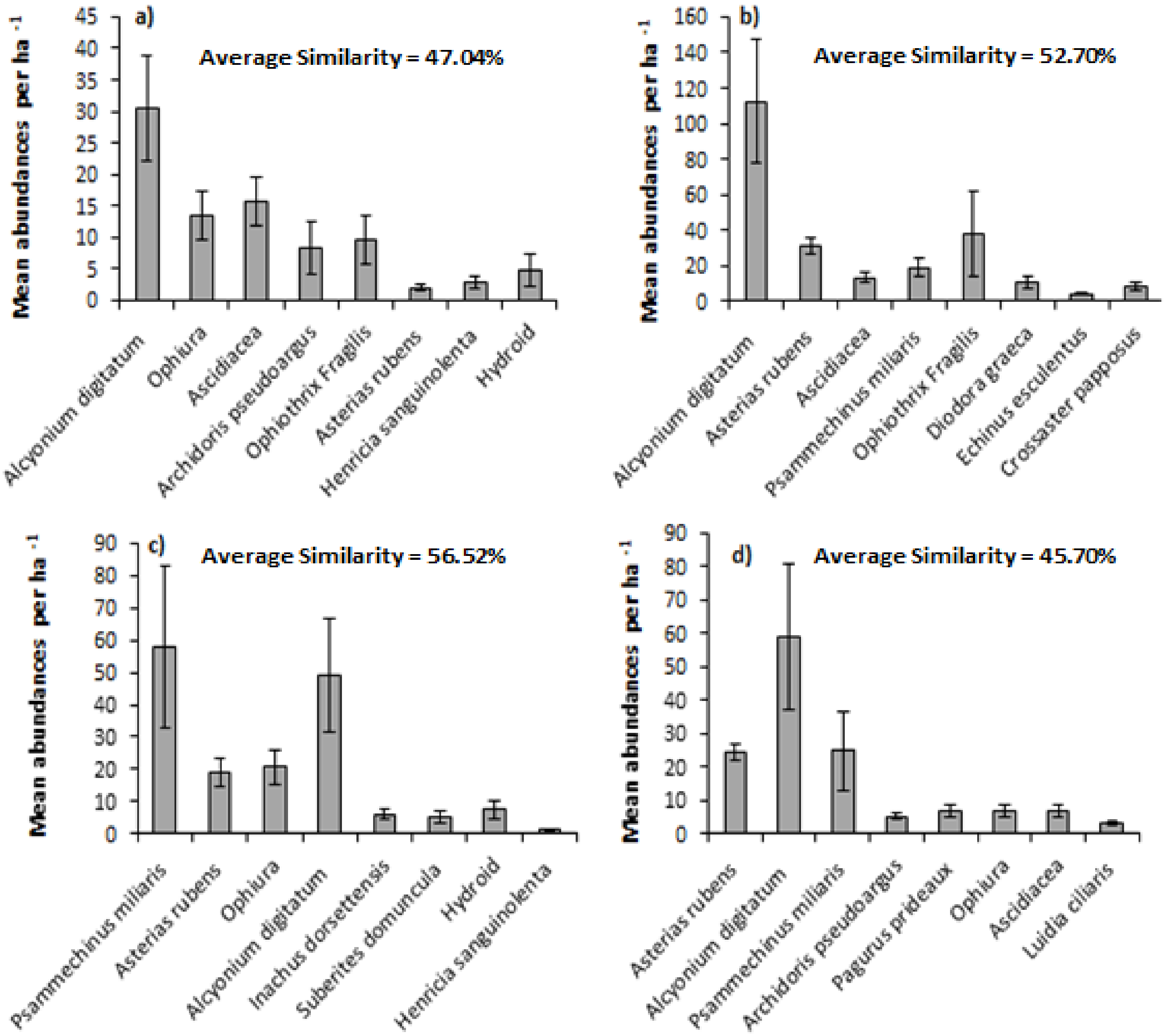

Figure 10: The mean abundance (± SE) of the invertebrate species that contribute most to the similarity among samples at each of the four fishing grounds a) Chickens, b) Douglas, c) Ramsey and d) Targets taken from the outcome of a SIMPER analysis. The average percentage similarity within each of the fishing grounds is also given.

Table 4 shows the results of univariate analysis of the species identified by SIMER as causing the biggest differences between fishing grounds. All species apart from *Alcyomium digitatum* showed a significant difference between fishing grounds. Although *A. digitatum* appears to have a higher abundance in Douglas (Table 5) there in no significant difference between grounds which may be due to the high variation associated with these abundance measures.

Table 4: ANOVA/Kruskal-Wallis tests performed on indicator invertebrate species identified from SIMPER analysis, also shown are the P values of post- hoc tests. All tests had 3, 53 degrees of freedom. Letters of post – hoc tests identify fishing grounds C = Chickens, D = Douglas, R = Ramsey and T = Targets.

		F/ χ^2	**P**	**Post-hoc C, D**	**C,R**	**C,T**	**D,R**	**D,T**	**R,T**
Alcyonium digitatum	Log(n + 1)	1.896	0.141	0.113	0.805	0.383	0.547	0.885	0.916
Ophiura	SQRT	6.969	**<0.001**	**0.043**	0.420	0.328	**0.001**	0.711	**0.010**
Ophiothrix fragilis	K-W	11.887	**0.008**	0.652	0.105	**0.015**	0.052	**0.009**	0.232
Psammechinus miliaris	K-W	18.237	**<0.001**	**0.016**	**<0.001**	**0.001**	0.254	0.953	0.075
Ascidiacea	SQRT	5.460	**0.002**	1.0	**0.008**	0.144	**0.008**	0.153	0.550
Archidoris pseudoargus	SQRT	7.895	**<0.001**	**0.005**	**0.007**	0.999	1.00	**0.005**	**0.007**
Diodora graeca	K-W	32.517	**<0.001**	<0.001	0.519	1.00	**0.002**	**<0.001**	0.503
Hydroid	K-W	8.562	**0.036**	0.085	0.488	0.411	**0.015**	0.338	0.132
Inachus dorsettensis	4RT	3.182	**0.031**	0.993	0.776	0.077	0.606	**0.035**	0.485
Suberites domuncula	K-W	16.714	**0.001**	**0.037**	**0.009**	0.951	0.294	**0.017**	**0.004**
Asterias rubens	SQRT	28.253	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.071	0.747	0.405
Crossaster Papposus	K-W	27.083	**<0.001**	**0.001**	0.325	0.759	**0.005**	**<0.001**	0.170
Buccinum undatum	K-W	23.952	**<0.001**	**0.005**	1.00	0.580	**0.006**	**0.011**	0.589

Table 5: Mean Abundances (± SE) per hectare of the invertebrate bycatch species that caused the highest dissimilarity between fishing ground taken from SIMPER analysis.

	Chickens	Douglas	Ramsey	Targets
Alcyonium digitatum	30.47 ± 8.39	112.52 ± 34.78	49.26 ± 17.64	59 ± 21.93
Ophiura	13.37 ± 3.92	3.30 ± 0.89	20.73 ± 5.23	6.97 ± 1.84
Ophiothrix fragilis	9.61 ± 3.75	37.78 ± 24.05	1.35 ± 0.44	0.69 ± 0.34
Psammechinus miliaris	1.21 ± 0.49	19.08 ± 5.14	57.87 ± 25.25	24.74 ± 11.86
Ascidiacea	15.70 ± 3.76	13.47 ± 2.74	3.19 ± 1.50	6.81 ± 1.97
Archidorispse udoargus	8.43 ± 4.21	0.82 ± 0.43	0.94 ± 0.53	5.24 ± 0.96
Diodora graeca	-	10.51 ± 3.28	0.35 ± 0.24	-
Hydroid	4.69 ± 2.51	0.56 ± 0.45	7.65 ± 2.77	3.61 ± 1.93
Inachus dorsettensis	3.95 ± 1.54	0.11 ± 0.11	6.18 ± 1.49	3.32 ± 1.14
Suberite domuncula	0.48 ± 0.34	2.58 ± 0.86	5.23 ± 1.74	0.29 ± 0.17
Asterias rubens	1.99 ± 0.43	31.38 ±4.49	19.12 ± 4.26	24.56 ± 2.47
Crossaster papposus	0.17 ± 0.17	8.09 ± 2.27	0.58 ± 0.28	-
Buccinum undatum	-	4.90 ± 1.47	-	0.32 ± 0.24

Table 6 shows the results of a BEST analysis which tries to use environmental variables to explain the variation in the invertebrate bycatch assemblages. The BEST showed that a combination of sea surface temperature and depth indicated the best fit for the environmental variables that accounted for the most similarity in the abundance data (Rho=0.285). Depth was the best fit of any single environmental variable (Rho=0.272). Although SST and depth are the best fit the correlation between these environmental variables and the abundance data is very low.

Table 6: BEST analysis results for environmental explanatory variables for invertebrate species assemblages.

Variables	Correlation
SST (°C), Depth (m)	0.285
Depth (m)	0.272
SST (°C), Depth (m), Habitat type	0.189
Chlorophyll a, SST (°C), Depth (m)	0.170
Chlorophyll a, Depth (m)	0.163

3.1.3 Fish and elasmobranch bycatch assemblages

The MDS plot shown in Figure 11 illustrates the similarity between samples. It is apparent from the MDS that there is a similarity in fish and elasmobranch bycatch assemblages within fishing grounds and a clear difference between fishing grounds which is confirmed by the result of an ANOSIM analysis of similarities which revealed significant differences in fish and elasmobranch bycatch assemblages between fishing grounds (ANOSIM, $R = 0.544$, $p = 0.001$). Multivariate pairwise ANOSIM tests showed significant differences between all fishing grounds (Table 7).

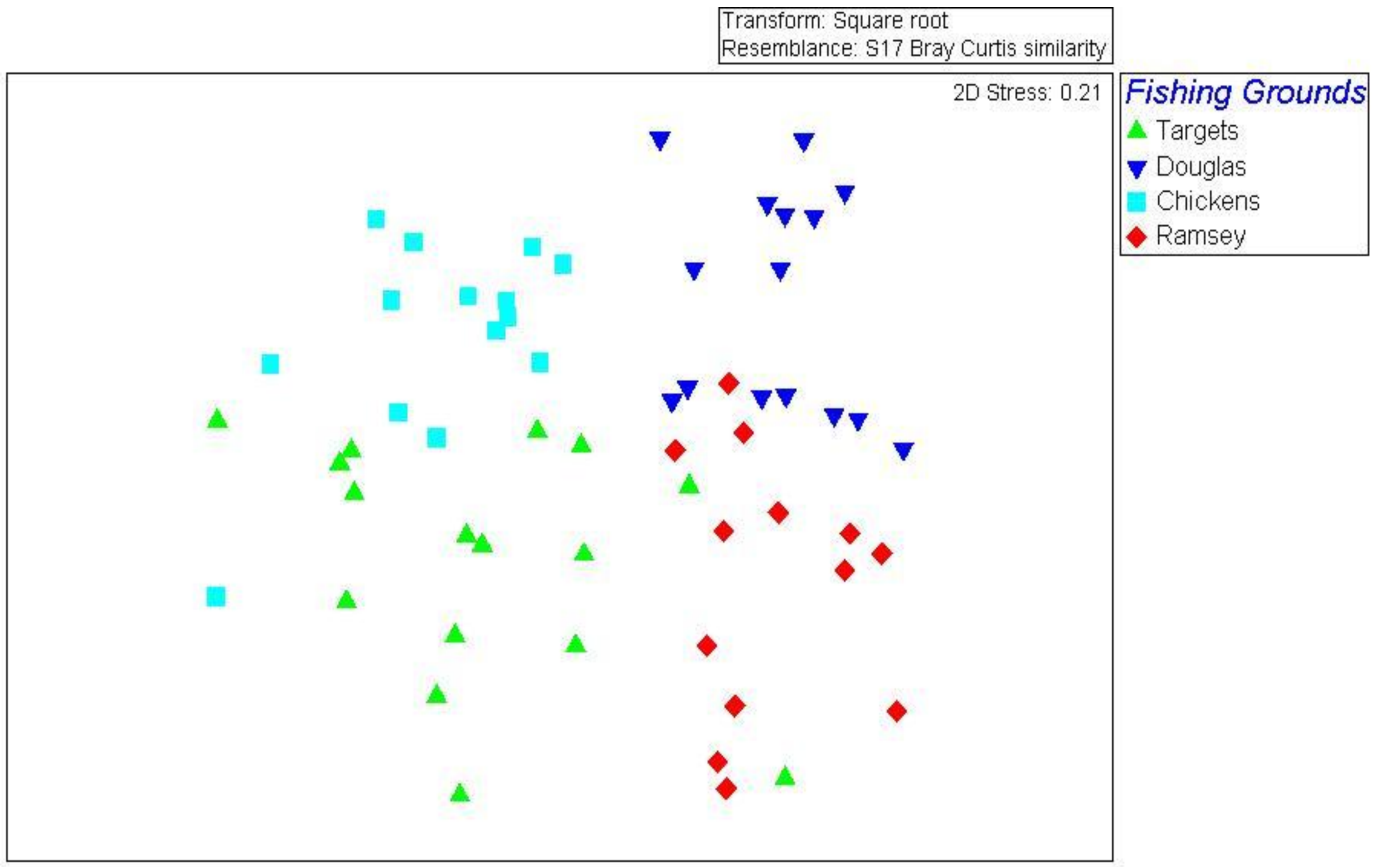

Figure 11: MDS plot of fish and elasmobranch bycatch assemblages, within the different fishing grounds based on Bray- Curtis similarity of square root transformed standardised (per ha per tow) abundance data from 58 tows conducted as part of this survey.

Table 7: ANOSIM pair-wise comparisons of fish and elasmobranch bycatch species composition between fishing grounds.

Fishing ground	R statistic	P Value
Targets v Douglas	0.62	0.001
Targets v Chickens	0.326	0.001
Targets v Ramsey	0.528	0.001
Douglas v Chickens	0.617	0.001
Douglas v Ramsey	0.353	0.001
Chickens v Ramsey	0.841	0.001

SIMPER analysis was used to examine similarities within and dissimilarities between fishing grounds. The species that contributed most to the similarity in fish and elasmobranch bycatch assemblages within fishing grounds and the average similarity of each of the grounds can be seen in Figure 12. The average similarity of each of the fishing grounds is very similar with Chickens having a slightly higher similarity (68.79%) than the other fishing grounds, followed by Ramsey (68.44%), then Douglas (65.69%) and finally by Targets (63.18%).

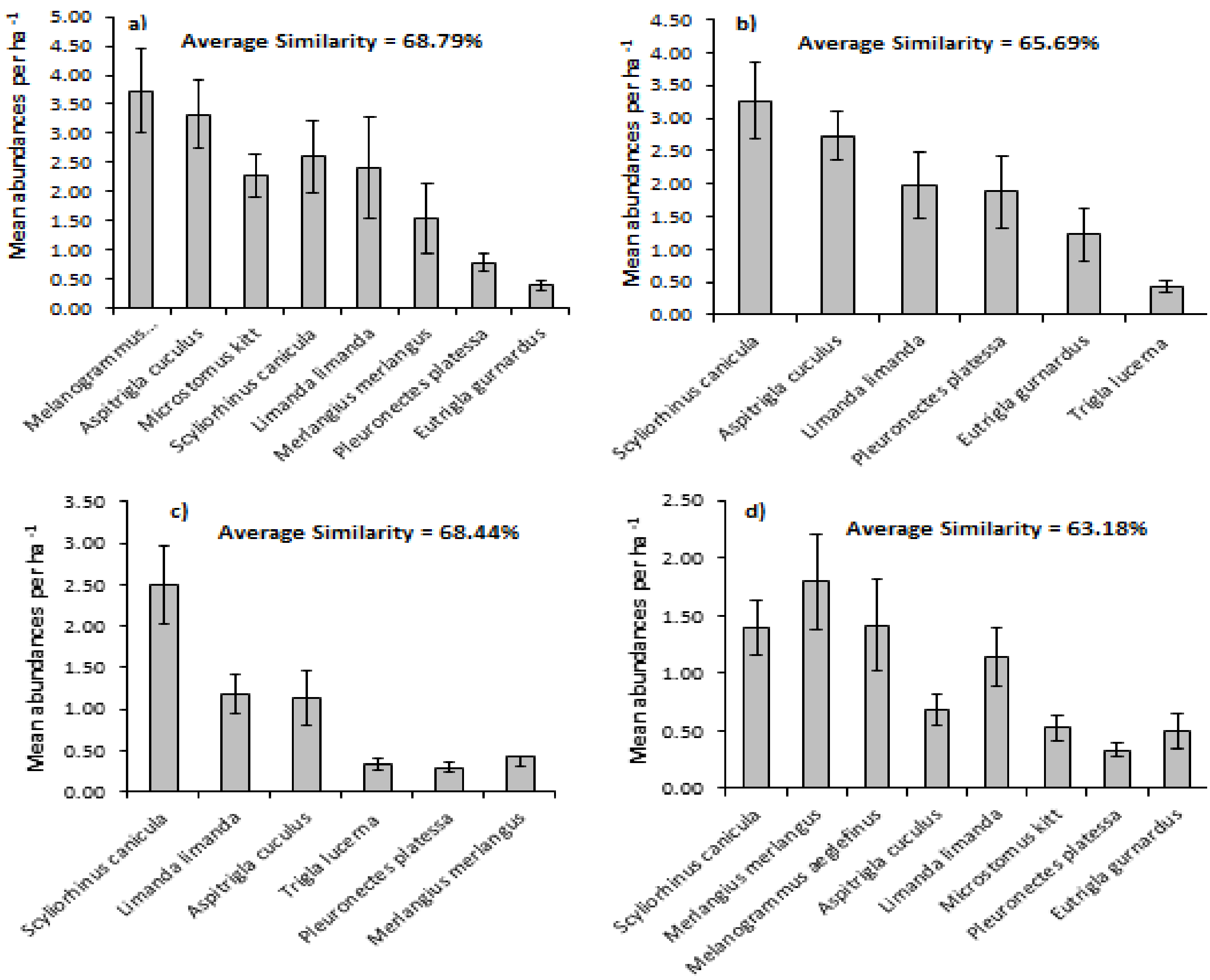

Figure 12: The mean (±SE) abundance of the fish and elasmobranch species that contribute most to the similarity among samples at each of the four fishing grounds a) Chickens, b) Douglas, c) Ramsey and d) Targets taken from the outcome of a SIMPER analysis. The average percentage similarity within each of the fishing grounds is also given.

Table 8 shows the results of univariate analysis of the fish and elsombranch species identified by SIMER as causing the biggest differences between fishing grounds. All but three species tested showed significant differences in abundance between fishing grounds. There was no significant difference in *Scyliorhinus canicula, L.limanda* and *Pleuronectes platessa* found between fishing grounds. However there are some slight differences in abundances between areas Table 9.

Table 8: ANOVA/Kruskal-Wallis tests performed on indicator invertebrate species identified from SIMPER analysis, also shown are the P values of post- hoc tests. All tests had 3, 53 degrees of freedom. Letters of post – hoc tests identify fishing grounds C = Chickens, D = Douglas, R = Ramsey and T = Targets.

		F/ χ^2	**P**	**Post-hoc C, D**	**C,R**	**C,T**	**D,R**	**D,T**	**R,T**
Scyliorhinus canicula	SQRT	2.469	0.072	0.764	0.996	0.410	0.884	0.049	0.285
Limanda limanda	K-W	0.785	0.508	0.992	0.700	0.583	0.828	0.723	0.999
Eutrigla gurnardus	4RT	3.670	**0.018**	0.728	0.177	0.991	**0.012**	0.867	0.084
Melanogramus aeglefinus	K-W	20.443	**<0.001**	0.050	**<0.001**	**<0.001**	0.101	0.086	0.928
Microstomus kitt	K-W	35.088	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.004	0.066	**<0.001**
Pleuronectes platessa	K-W	6.099	0.107	0.650	**0.029**	**0.041**	0.132	0.232	0.650
Aspitrigla cuculus	SQRT	14.015	**<0.001**	0.909	**0.001**	**<0.001**	0.004	**<0.001**	0.680
Trigla lucerna	SQRT	5.052	**0.004**	0.405	0.206	0.955	0.929	**0.008**	0.060
Merlangius merlangus	4RT	15.710	**<0.001**	**<0.001**	0.144	0.867	**0.021**	**<0.001**	**0.020**
Callionymus lyra	SQRT	3.116	**0.034**	0.263	0.984	0.179	0.130	0.994	0.083
Liophius piscatorius	K-W	20.443	**<0.001**	0.050	**<0.001**	**<0.001**	0.101	0.086	0.928
Trisopterus minutus	K-W	9.364	**0.025**	0.308	0.186	0.717	0.779	0.119	0.072

Table 9 : Mean Abundances (± SE) per hectare of the fish and elasmobranch bycatch species that caused the highest dissimilarity between fishing ground taken from SIMPER analysis.

	Chickens	**Douglas**	**Ramsey**	**Targets**
Scyliorhinus canicula	2.6 ± 0.62	3.26 ± 0.57	2.51 ± 0.47	1.39 ± 0.24
Limanda limanda	2.41 ± 0.88	1.98 ± 0.49	1.18 ± 0.23	1.14 ± 0.25
Eutrigla gurnardus	0.39 ± 0.09	1.22 ± 0.40	0.20 ± 0.09	0.5 ± 0.14
Melanogramus aeglefinus	3.73 ± 0.72	0.29 ± 0.29	-	1.42 ± 0.40
Microstomus kitt	2.28 ± 0.36	0.26 ± 0.08	-	0.53 ± 0.11
Pleuronectes platessa	0.77 ± 0.15	1.88 ± 0.55	0.30 ± 0.07	0.33 ± 0.06
Aspitrigla cuculus	3.32 ± 0.58	2.73 ± 0.37	1.13 ± 0.33	0.68 ± 0.13
Trigla lucerna	0.15 ± 0.04	0.42 ± 0.08	0.34 ± 0.07	0.13 ± 0.05
Merlangius merlangus	1.53 ± 0.59	0.08 ± 0.04	0.42 ± 0.11	1.80 ± 0.41
Callionymus lyra	0.09 ± 0.06	0.23 ± 0.06	0.07 ± 0.03	0.24 ± 0.08
Liophius piscatorius	0.20 ± 0.04	0.09 ± 0.03	0.02 ± 0.01	0.02 ± 0.01
Trisopterus minutus	0.14 ± 0.08	0.08 ± 0.08	-	0.37 ± 0.22

Table 10 shows the results of a BEST analysis of the fish and elasmobranch abundance data against a number of environmental variables. The BEST analysis showed that depth (m) indicated the best fit of a single environmental variable that accounted for the most similarity in the abundance data (Rho = 0.335). Although depth is the best fit, the correlation between depth and the abundance data is very low.

Table 10: BEST analysis results for environmental explanatory variables for fish and elasmobranch species assemblages.

Variables	**Correlation**
Depth (m)	0.355
Chlorophyll a, Depth (m)	0.338
Chlorophyll a, Depth(m), Habitat type	0.334
Depth, Habitat type	0.323
Chlorophyll a, Depth (m), Habitat type,SST(°C)	0.314

3.2 Bycatch fish stomach contents analysis

3.2.1 Dab

The stomach fullness of dab was found not to differ significantly between fishing grounds (χ^2_3 = 6.428, p = 0.093). However using multivariate analysis to compare percentage weighted resultant index for each prey item in each stomach, there was found to be a significant difference between fishing grounds within dab stomach contents (ANOSIM, R = 0.156, p = 0.004). Pairwise comparisons revealed that these differences lay between Chickens and Douglas, Chickens and Ramsey, and Chickens and Targets (Table 11). The average dissimilarity between each of these groups and the prey items contributing to this dissimilarity are shown in Table 12.

Table 11: ANOSIM pair-wise comparisons of the % weighted resultant index of prey items from Dab (*Limanda limanda*) stomach contents between fishing grounds.

Fishing grounds	R statistic	P value
Chickens v Douglas	0.346	0.001
Chickens v Ramsey	0.617	0.001
Chickens v Targets	0.477	0.001
Douglas v Ramsey	-0.096	100
Douglas v Targets	-0.08	85.8
Ramsey v Targets	0.049	7.7

The prey item that was identified most often as causing the dissimilarity between groups was *A. opercularis*. As can be seen from Table 13 this was the prey item which had the highest % weighted resultant index (*%* R_W) in Douglas, Ramsey and Targets but not Chickens. In Ramsey it accounted for 100% of the *%* R_W, thus is would appear that *A. opercularis* was the main controlling prey item for differences between areas in dab stomach contents.

Table 12: Indicator prey items derived from SIMPER analysis of dab (*Limanda limanda*) prey items by grounds. Shown are the grounds which identified by ANOSIM as having significant differences between them.

	Taxa	Diss/SD	% Contribution
Groups Chickens & Douglas	*Aepuipecten opercularis*	1.33	33.04
Average dissimilarity = 86.85	Bivalvia	0.82	18.91
	Aequipectan Spat	0.67	15.03
	Ophiura	0.59	12.18
	Caridea	0.39	6.40
	Pagurus bernhardus	0.42	6.26
Groups Chickens & Ramsey	*Aepuipecten opercularis*	2.26	44.53
Average dissimilarity = 86.83	Bivalvia	0.79	17.86
	Aequipectan Spat	0.67	15.17
	Ophiura	0.50	9.64
	Pagurus bernhardus	0.42	6.31
Groups Chickens & Targets	*Aepuipecten opercularis*	1.85	39.46
Average dissimilarity = 88.12	Bivalvia	0.79	17.32
	Aequipectan Spat	0.67	14.71
	Ophiura	0.50	9.35
	Pagurus bernhardus	0.42	6.13
	Amphipoda	0.35	4.87

Table 13: Diet composition of Dab (*Limanda limanda*) from the fishing grounds Chickens (n = 17), Douglas (n = 31) Ramsey (n = 15) and Targets (n = 18) .Values of percent of weight (%*W*), frequency of occurrence (%*O*), and weighted resultant index (%*R*w) for each food item are presented.

Prey Items	**Chickens**			**Douglas**		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Aepuipecten opercularis	9.68	28.65	16.58	61.30	90.92	87.51
Bivalvia	22.58	38.10	39.89	6.45	0.80	1.08
Pagurus bernhardus	9.68	13.43	7.40	-	-	-
Ophiura	16.13	4.29	7.31	12.90	1.33	1.80
Aequipectan Spat	22.58	5.15	8.75	-	-	-
Caridea	-	-	-	12.90	5.72	7.93
Asecidian	3.23	7.73	5.57	-	-	-
Pisces	6.45	1.33	2.25	3.23	1.22	1.68
Polychaete	6.45	1.25	2.12	-	-	-
Nemertesia	-	-	-	-	-	-
Amphipoda	3.23	0.08	0.13	3.23	0.002	0.002

Prey Items	Ramsey			Targets		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Aepuipecten opercularis	100	100	100	80	98.41	98.19
Bivalvia	-	-	-	-	-	-
Pagurus bernhardus	-	-	-	-	-	-
Ophiura	-	-	-	-	-	-
Aequipectan Spat	-	-	-	-	-	-
Caridea	-	-	-	-	-	-
Asecidian	-	-	-	-	-	-
Pisces	-	-	-	-	-	-
Polychaete	-	-	-	-	-	-
Nemertesia	-	-	-	6.67	1.33	1.51
Amphipoda	-	-	-	13.33	0.27	0.30

3.2.2 Red Gurnard

The stomach fullness of Red Gurnard was found not to differ significantly between fishing grounds (χ^2_2 = 2.850 , p = 0.241). Also when using multivariate analysis to compare *% R_W* for each prey items in each stomach, there was found to be no significant difference between fishing grounds (ANOSIM, R = 0.058, p = 0.094). However pairwise comparisons revealed that there was a significant difference between Chickens and Ramsey (Table 14).

Table 14: ANOSIM pair-wise comparisons of the % weighted resultant index of prey items from Red Gurnard (*Aspitrigla cuculus*) stomach contents between fishing grounds.

Fishing grounds	R statistic	P value
Chickens v Douglas	0.03	0.176
Chickens v Ramsey	0.338	0.024
Douglas v Ramsey	0.106	0.207

The prey item found to have the highest *% R_W* in stomachs from both Chickens and Douglas was Caridean shrimp. However, in Ramsey Caridea had the second lowest *% R_W*, the prey item with the highest *% R_W* in Ramsey was found to be *Liocarcinus* sp (Table 15).

Table 15 : Diet composition of Red Gurnard (*Aspitrigla cuculus*) from the fishing grounds Chickens (n = 30), Douglas (n = 50) and Ramsey (n = 4) .Values of percent of weight (%*W*), frequency of occurrence (%*O*), and weighted resultant index (%*R*w) for each food item are presented.

Prey Items	**Chickens**			**Douglas**		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Caridea	30.67	19.70	33.64	21.31	18.08	34.70
Liocarcinus sp.	5.33	5.53	9.53	3.28	6.75	5.99
Callionymus lyra	4.00	11.14	6.60	0.82	0.82	1.60
Macropodia sp.	12.00	39.46	19.68	3.28	2.37	4.47
Pagurus bernhardus	1.33	5.68	2.17	3.28	21.78	5.81
Pisces	5.33	2.95	4.97	15.57	7.82	14.32
Brachyura	10.67	2.26	3.68	11.48	3.41	6.11
Galatheoidea	8.00	5.61	9.66	13.11	2.71	4.81
Amphipoda	14.67	1.87	3.03	16.39	4.73	8.46
Carcinus maenas	-	-	-	3.28	3.47	6.38
Atelecyclus rotundatus	2.67	4.13	4.56	0.82	2.52	1.47
Upogebia deltaura	-	-	-	2.46	24.71	4.35
Aequipecten opercularis	1.33	1.59	2.34	-	-	-
Carcer Pagurus	-	-	-	0.82	0.57	1.08
Pisidia longicornis	-	-	-	0.82	0.15	0.26
Bivalvia	1.33	0.04	0.07	0.82	0.02	0.03
Hyas sp.	-	-	-	0.82	0.07	0.13
Aequipecten spat	2.67	0.04	0.07	-	-	-
Polychaete	-	-	-	1.64	0.02	0.04

Prey Items	**Ramsey**		
	% W	*% O*	*% R_W*
Caridea	13.33	0.49	1.18
Liocarcinus sp.	13.33	13.15	34.87
Callionymus lyra	13.33	50.84	32.24
Macropodia sp.	-	-	-
Pagurus bernhardus	6.67	29.00	16.08
Pisces	13.33	1.72	4.13
Brachyura	26.67	3.73	8.95
Galatheoidea	6.67	1.02	2.46
Amphipoda	-	-	-
Carcinus maenas	-	-	-
Atelecyclus rotundatus	-	-	-
Upogebia deltaura	-	-	-
Aequipecten opercularis	-	-	-
Carcer Pagurus	-	-	-
Pisidia longicornis	-	-	-
Bivalvia	6.67	0.04	0.10
Hyas sp.	-	-	-
Aequipecten spat	-	-	-
Polychaete	-	-	-

3.2.3 Whiting

When examining the stomach fullness of whiting a significant difference was found between fishing grounds (χ^2_3 = 15.087, p = 0.002). Using Mann Whitney U tests it was found that the stomach fullness differed significantly between Chickens and Targets, and also between Douglas and Targets (Figure 13). Stomach fullness was found to be significantly greater in whiting from Targets (4.79 ± 0.29 n = 34) compared with Chickens (2.0 ± 0.82, n = 7) and Douglas (3.0 ± 0.42, n = 10) grounds. Stomach fullness was not found to differ between Targets and Ramsey, or between Ramsey and other sites.

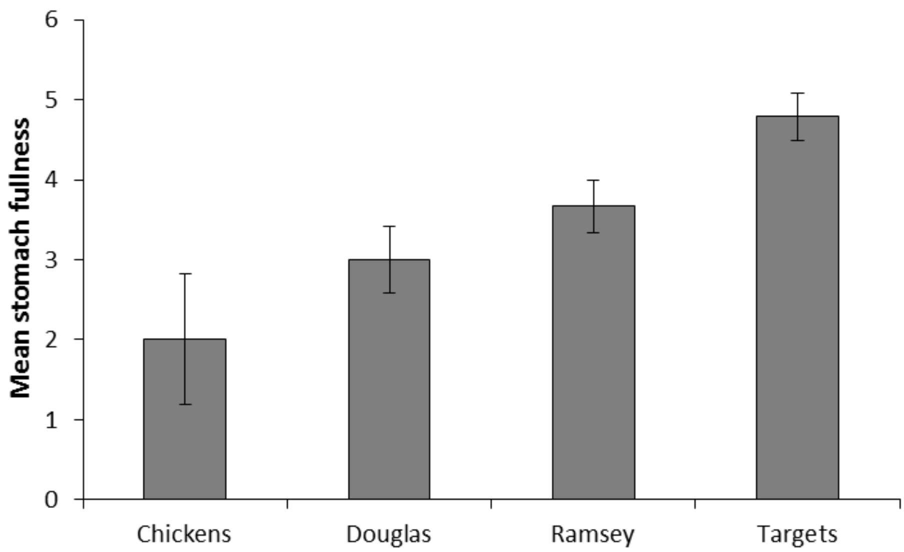

Figure 13: Mean (±SE) stomach fullness of whiting from each of the four fishing grounds.

Using multivariate analysis to compare *% R_W* for each prey items in each stomach, there was found to be a significant difference between fishing grounds when examining whiting stomach contents (ANOSIM, R = 0.39, p = 0.002). Pairwise comparisons revealed that these differences lay between Douglas and Targets and between Ramsey and Targets (Table 16). The average dissimilarity between each of these groups and the prey items contributing to this dissimilarity are shown in Table 17.

Table 16: ANOSIM pair-wise comparisons of the % weighted resultant index of prey items from whiting (*Merlangius merlangus*) stomach contents between fishing grounds.

Fishing Grounds	R statistic	P value
Chickens v Douglas	0.444	0.1
Chickens v Ramsey	0	1.0
Chickens v Targets	0.779	0.063
Douglas v Ramsey	-0.055	.609
Douglas v Targets	0.311	0.018
Ramsey v Targets	0.486	0.038

Table 17: Indicator prey items derived from SIMPER analysis of analysis of from whiting (*Merlangius merlangus*) prey items by grounds. grounds. Shown are the grounds which were identified by ANOSIM as having significant differences between them.

	Taxa	Diss/SD	% Contribution
Groups Douglas & Targets	*Aepuipecten opercularis*	1.10	34.18
Average dissimilarity = 58.69	Caridea	0.81	22.86
	Algae	0.35	7.74
	Pagurus bernhardus	0.47	6.68
	Ophiura	0.40	6.03
	Amphipoda	0.44	5.19
	Galatheoidea	0.35	4.46
	Mollusc	0.40	4.29
Groups Ramsey & Targets	*Aepuipecten opercularis*	1.33	37.51
Average dissimilarity = 70.80	Caridea	0.78	23.36
	Algae	0.70	17.24
	Amphipoda	0.69	5.75
	Polychaete	0.83	5.49
	Pisces	0.26	3.60

As with Dab it appears that *A. opercularis* was the prey item causing the highest dissimilarity between grounds. This was followed by Caridea and Algae. Table 18 shows that the *%Rw* of these three items differs between both Douglas and Targets, and Ramsey and Targets.

Table 18: Diet composition of Whiting (Merlangius merlangus) from the fishing grounds Chickens (n = 7), Douglas (n = 10), Ramsey (n = 3) and Targets (n = 34) .Values of percent of weight (%W), frequency of occurrence (%O), and weighted resultant index (%Rw) for each food item are presented.

Prey Items	**Chickens**			**Douglas**		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Aepuipecten opercularis	-	-	-	31.25	85.50	68.08
Pisces	100	100	100	-	-	-
Caridea	-	-	-	25.00	2.19	4.67
Algae	-	-	-	6.25	3.22	7.14
Pagurus bernhardus	-	-	-	6.25	4.37	9.94
Galatheoidea	-	-	-	6.25	1.96	4.24
Mollusc	-	-	-	6.25	1.27	2.72
Ophiura	-	-	-	6.25	1.27	2.72
Polychaete	-	-	-	6.25	0.12	0.25
Amphipoda	-	-	-	6.25	0.12	0.25
Nemertesia	-	-	-	-	-	-
Bivalvia	-	-	-	-	-	-
Brachyura	-	-	-	-	-	-

Prey Items	**Ramsey**			**Targets**		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Aepuipecten opercularis	16.67	40.11	35.60	53.85	89.88	87.12
Pisces	-	-	-	3.85	5.88	6.27
Caridea	16.67	46.80	35.37	9.62	1.85	2.87
Algae	16.67	12.26	27.30	-	-	-
Pagurus bernhardus	-	-	-	5.77	0.74	1.15
Galatheoidea	-	-	-	-	-	-
Mollusc	-	-	-	1.92	0.89	1.42
Ophiura	16.67	0.28	0.58	1.92	0.24	0.38
Polychaete	16.67	0.28	0.58	11.54	0.36	0.036
Amphipoda	16.67	0.28	0.58	5.77	0.02	0.03
Nemertesia	-	-	-	1.92	0.05	0.07
Bivalvia	-	-	-	1.92	0.01	0.01
Brachyura	-	-	-	1.92	0.01	0.01

3.2.4 Haddock

The stomach fullness of haddock was found not to differ significantly between Chickens and Targets (χ^2_1 = 3.129 , p = 0.077). There was found to be no significant difference between Chickens and Targets (ANOSIM, R = 0.022, p = 0.307) when examining the *% R_W* for each prey items in each stomach in haddock. In both Chickens and Targets the prey item with the highest *% R_W* was found to be Ophiura, followed by *A.opercularis* and then Bivalvia (Table 19).

Table 19: Diet composition of Haddock (*Melanogrammus aeglefinus*) from the fishing grounds Chickens (n = 12) and Targets (n = 21).Values of percent of weight (%W), frequency of occurrence (%O), and weighted resultant index (%Rw) for each food item are presented.

Prey Items	**Chickens**			**Targets**		
	% W	*% O*	*% R_W*	*% W*	*% O*	*% R_W*
Ophiura	16.67	23.98	30.09	25.00	18.29	32.97
Aepuipecten opercularis	13.89	23.11	24.76	16.07	45.92	27.60
Bivalvia	11.11	31.83	19.21	14.29	12.94	23.90
Polychaete	16.67	3.20	5.46	5.36	1.06	1.80
Pisces	-	-	-	3.57	17.28	6.06
Asecidin	2.78	8.87	4.79	-	-	-
Amphipoda	16.67	2.62	4.46	7.14	0.13	0.21
Echinoidea	8.33	2.33	3.99	5.36	0.15	0.25
Liocarcinussp	2.78	1.45	2.56	1.79	0.76	1.32
Hyas	2.78	2.03	3.69	-	-	-
Brachyura	-	-	-	7.14	1.97	3.36
Caridea	2.78	0.15	0.25	8.93	1.16	1.97
Aequiecten Spat	5.56	0.44	0.74	-	-	-
Galatheoidea	-	-	-	3.57	0.25	0.43
Doris pseudoargus	-	-	-	1.79	0.08	0.14

3.3 Dab feeding behaviour

A total of 106 dab were included in this section of the study, of which 96 were female and 10 were male. The mean total length of the individuals examined was 20.87 ± 0.22 cm with a mean weight of 102 ± 3 g. The mean length of dab did not differ significantly between tows ($F_{4,97}$ = 0.590, p = 0.671) nor did the mean weight ($F_{4,97}$ = 0.551, p = 0.699). The mean stomach fullness of dab was found to be significantly different between tows (χ^2_4 = 14.679, p = 0.005). The tow number counts the number of tows performed by a particular vessel on a particular day, such that the first tow of a fishing trip is always given the number 1. The mean stomach fullness was found to increase with increasing tow number as is shown in Figure 14.

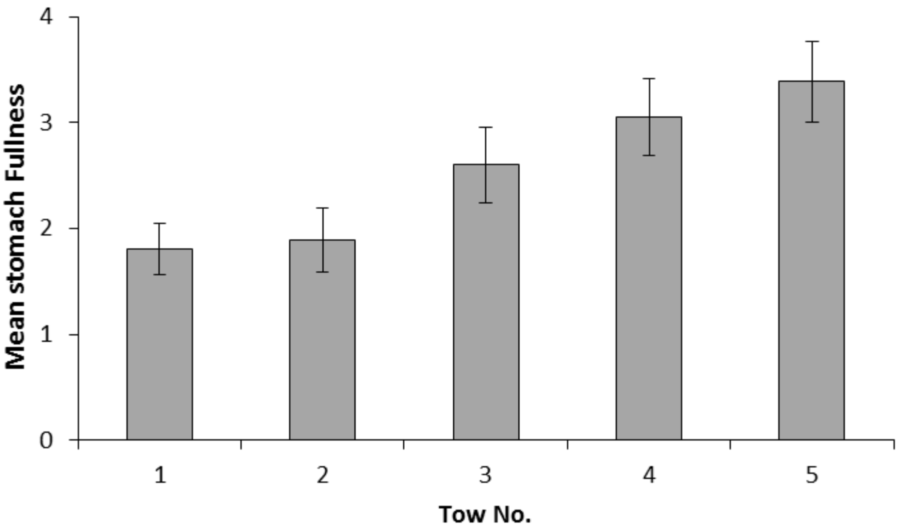

Figure 14: Mean (± SE) stomach fullness of dab (*L.limanda*) against the tow number.

Post hoc tests revealed that there were significant differences between tows 1 and 4, tows 1 and 5 and tows 2 and 4 and tows 2 and 5 (Table 20). This demonstrates a gradual increase in the stomach fullness as the tow number increases or as the day progressed.

Table 20: Mann Whitney U pairwise tests between mean stomach fullness of dab and the tow no.

Mann Whitney U Tow	P	U	Z
1,2	0.76	223	-0.306
1,3	0.09	243	-1.697
1,4	**0.007***	148	-2.675
1,5	**0.001***	69.5	-3.175
2,3	0.202	177	-1.276
2,4	**0.025***	107.5	-2.236
2,5	**0.007***	52.5	-2.713
3,4	0.344	210	-0.945
3,5	0.129	114.5	-1.52
4,5	0.596	116	-0.53

The mean abundance of dab per tow when standardised per hectare showed no significant differences ($F_{4,53}$= 0.111, p = 0.978), nor any obvious trends, indicating that dab numbers neither increased or decreased as the day progressed (Figure 15).

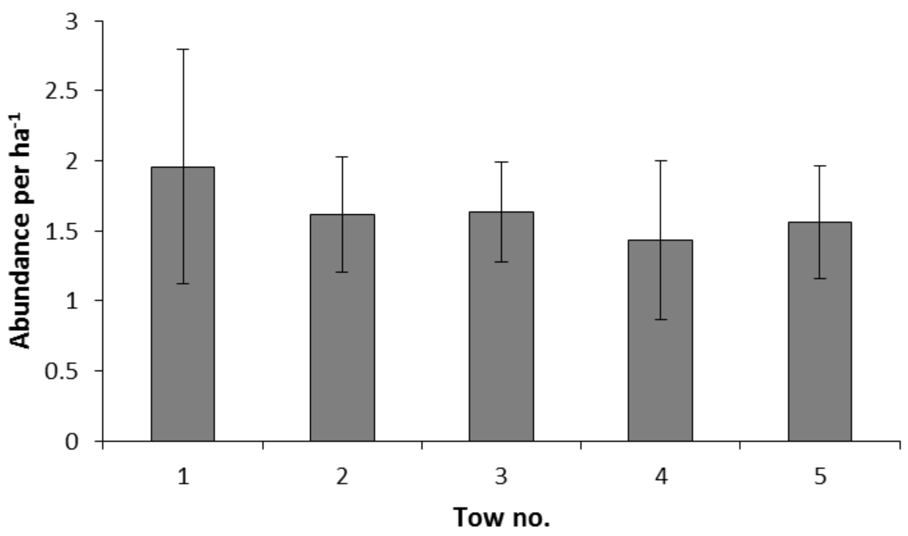

Figure 15: Mean abundance (SE) of dab by tow no from all 58 tows surveyed as part of this study.

There is a clear positive relationship between the amount of discarded (undersized) queen scallops and the mean stomach fullness of dab (Figure 16).

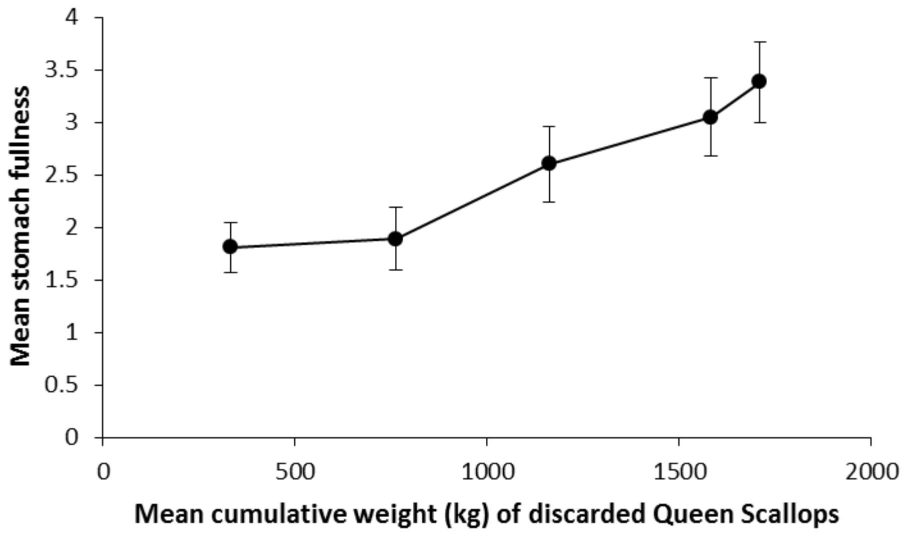

Figure 16: Mean (± SE) stomach fullness of dab against the mean cumulative weight (kg) of discarded queen scallops form the five days used for the dab stomach investigation, separated by tow number.

The prey item that accounts for the highest $\%R_W$ in the stomach contents of dab from all 5 of the tow groups is queen scallops (Table 21). The $\%R_W$ of Queen scallops can be seen to increase with increase in tow number (time since beginning of fishing day). A linear regression found that there was a significant positive relationship between stomach fullness of dab and the $\%R_W$ of Queen Scallops ($R^2 = 0.628$, $p < 0.001$) (Figure 17).

Table 21: Diet composition of dab divided by tow number. Values of percent weighted resultant index (%Rw) for each tow number and prey items are presented.

%Rw	Tow no.				
Prey Item	1	2	3	4	5
Aepuipecten opercularis	74.12772	80.17309	80.82604	97.437	95.91039
Amphipoda	0.408915	-	-	-	-
Polychaete	4.892288	9.290896	1.428447	1.240053	-
Pagurus bernhardus	12.04188	4.449603	14.8832	1.281831	-
Bivalvia	8.529197	-	0.492201	-	-
Galatheoidea	-	-	-	0.041121	0.668717
Ophiura	-	1.149935	2.37011	-	1.90944
Liocarcinus sp	-	-	-	-	1.511455
Suberites domuncula	-	4.936473	-	-	-

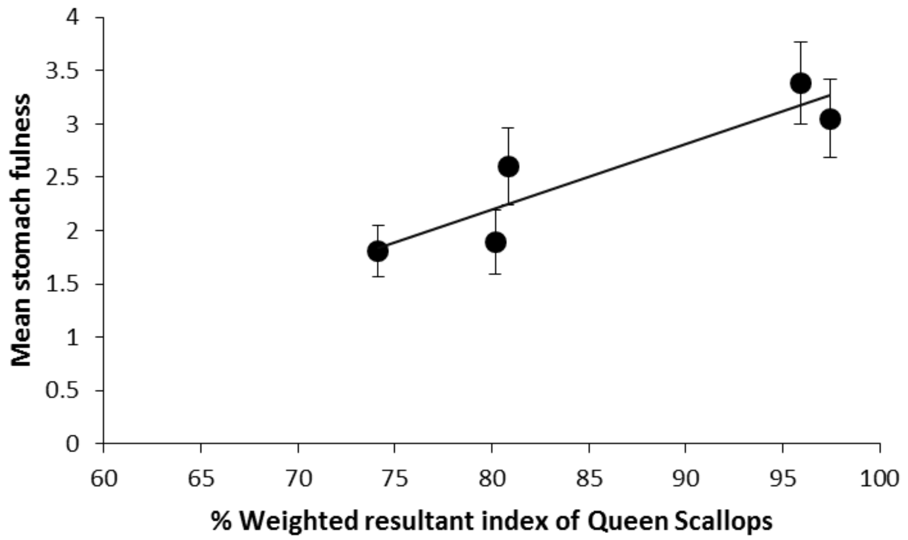

Figure 17: The mean (±SE) stomach fullness of dab from each tow against the %Rw of queen scallops for that tow.

3.4 Ecologically important species

3.4.1 Cod

The number of cod (*Gadus morhua)* encountered as bycatch of the Queen scallop fishery was 44 individuals with a total weight of 14.07kg. The mean abundance of cod per hectare was not found to be significantly different between fishing grounds ($F_{3,54}$ = 0.352, p = 0.788). Cod were found in all of the fishing grounds in similar quantities (Figure 18).

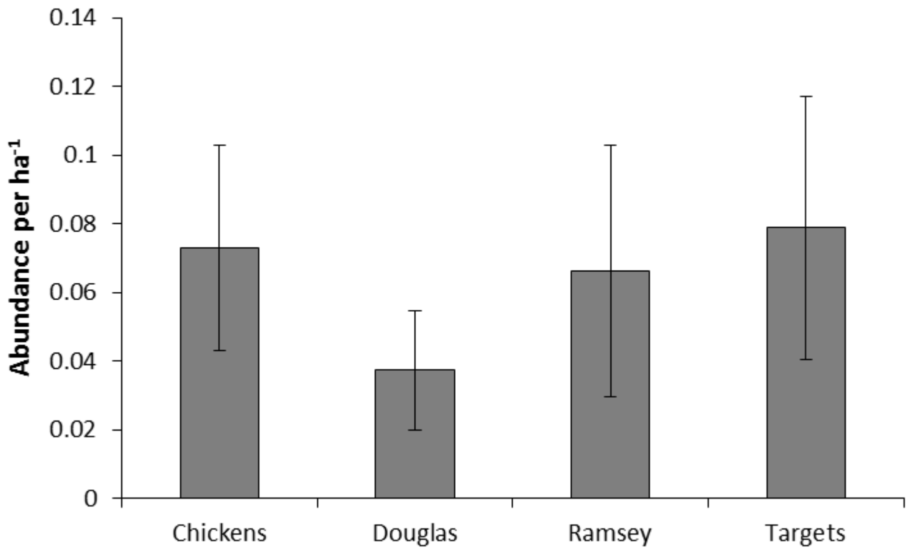

Figure 18: Mean (±SE) abundance per hectare of Cod (*Gadus morhua*) at each of the four fishing grounds.

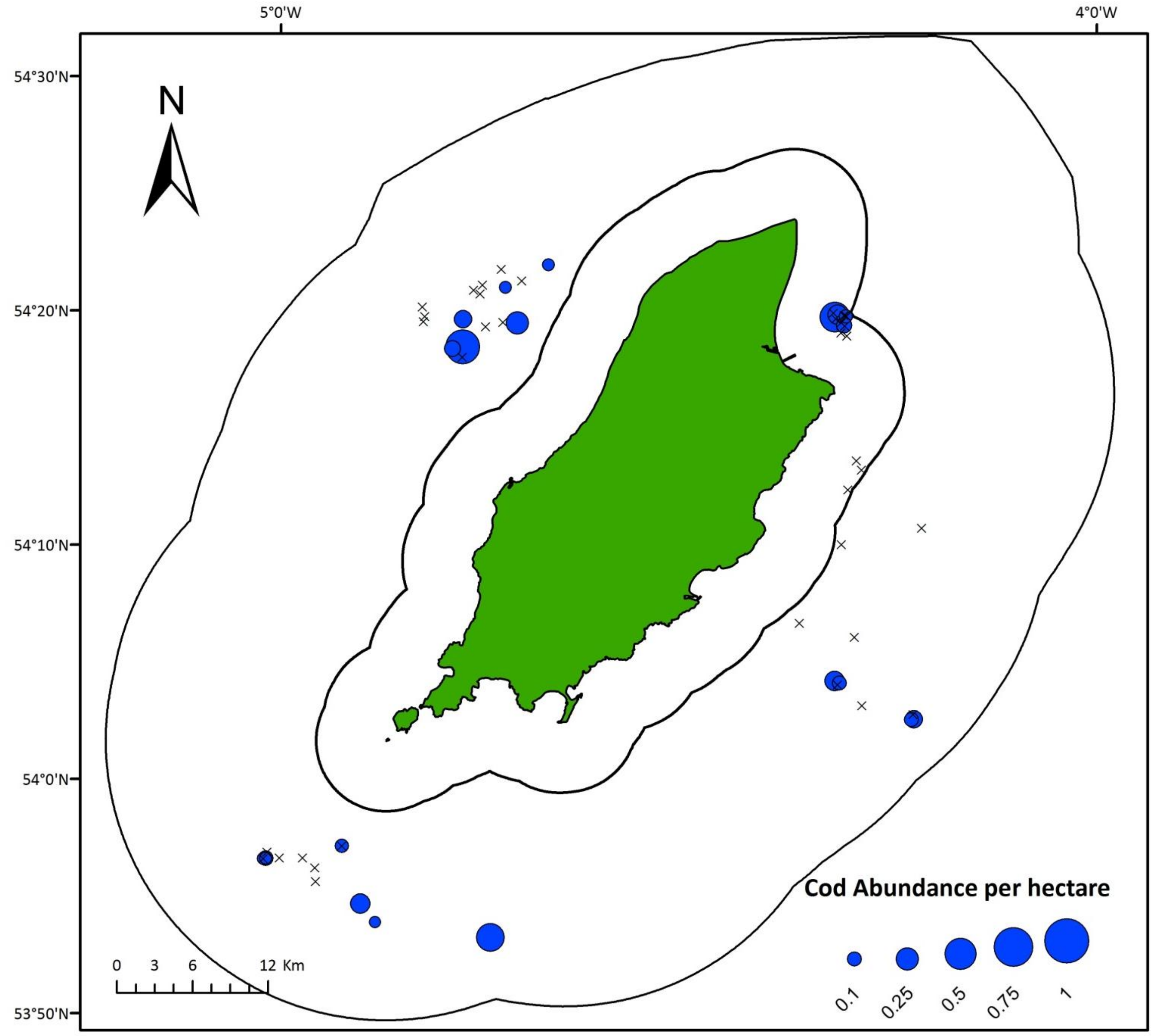

Figure 19: The Abundance of cod per tow per hectare swept at each of the 58 tow locations around the Isle of Man, zero values are marked with an x symbol. The 3 and 12 nautical mile limit are also shown.

The mean total length of Cod sampled was 29 ± 1 cm with a mean weight of 304 ± 30 g. The median length of cod sampled was also 29cm. The length frequency and length weight relationship of cod found as bycatch are shown in Figure 20 and Figure 21 respectively.

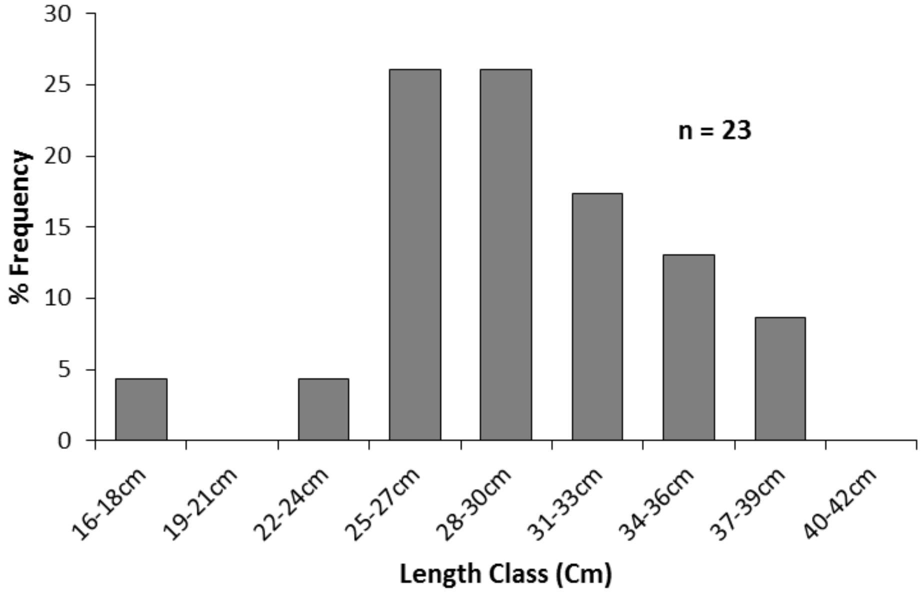

Figure 20: The length frequency of cod caught as bycatch of the Isle of Man Queen scallop fishery.

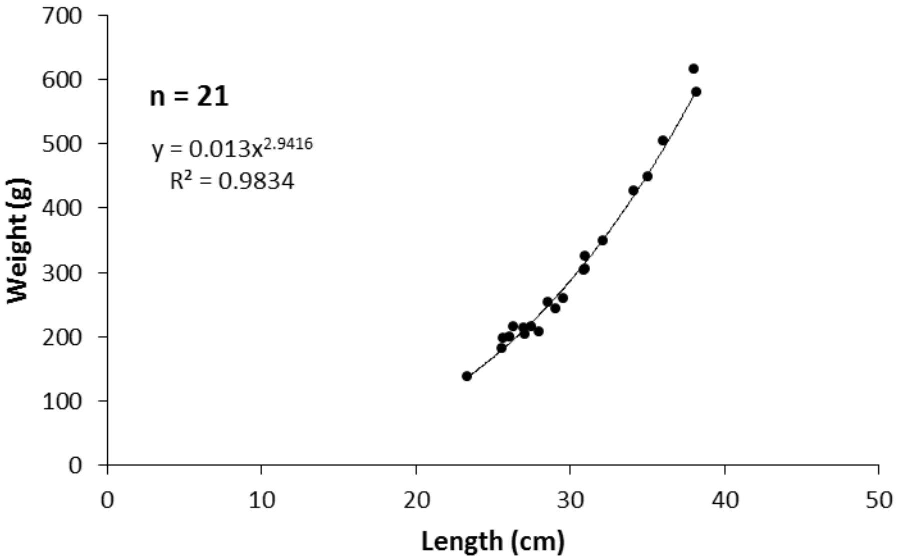

Figure 21: The length - weight relationship of cod caught as bycatch of the Isle of Man Queen Scallop fishery.

3.4.2 Streaked Gurnard

During this study a total of 25 streaked gurnards were found with a total weight of 3.81kg. The location of the tows in which streaked gurnard where found are shown in Figure 25. Streaked gurnard were only found to occur on the east side of the Isle of Man, not being found at either Targets or Chickens. The mean abundance of streaked gurnard at the four fishing grounds were found to be significantly different (χ^2_3 = 9.014, p = 0.029). Post hoc tests revealed that there were significant differences between Chicken and Ramsey, and between Ramsey and Targets (Figure 23).

Figure 22: Photo of a Streaked Gurnard found in the Douglas Fishing Ground

The mean length of streaked gurnard sampled was 25.59 ± 0.42 cm with a mean weight of 177 ± 9 g. The length-weight relationship for streaked gurnard is shown in Figure 24.

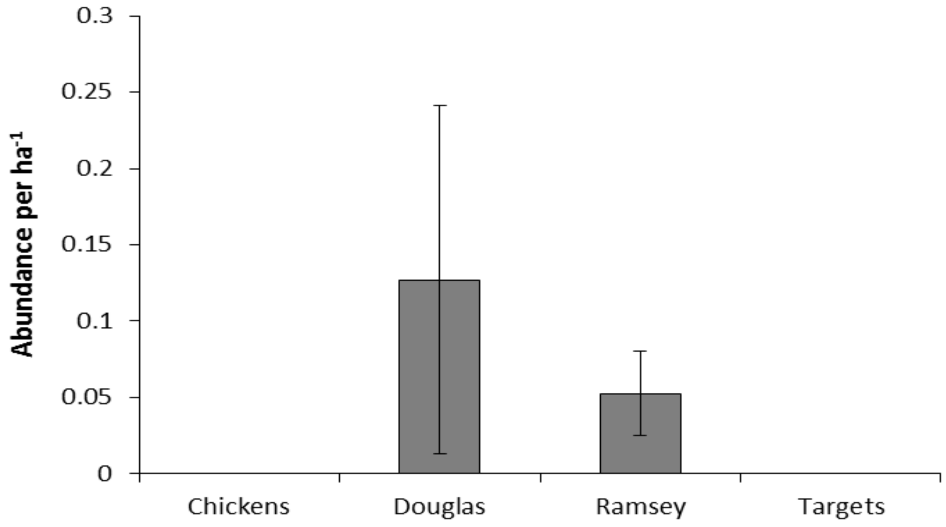

Figure 23: Mean abundance (±SE) per hectare of Streaked Gurnard (*Trigloporus lastoviza*) at each of the four fishing grounds.

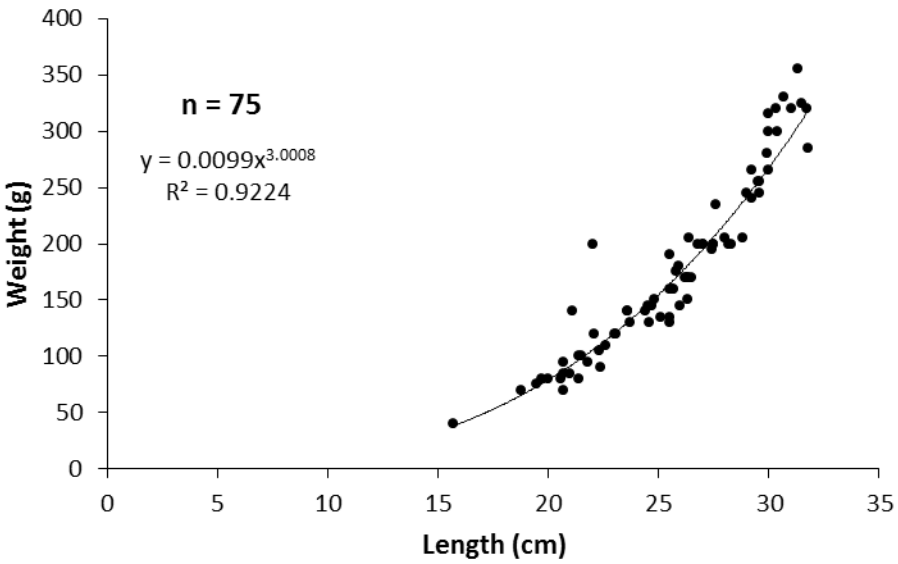

Figure 24: The length - weight relationship of streaked gurnard caught as bycatch of the Isle of Man Queen Scallop fishery. Shown are the fish sampled as part of this study combined with data from a study affiliated study from the same area and time.

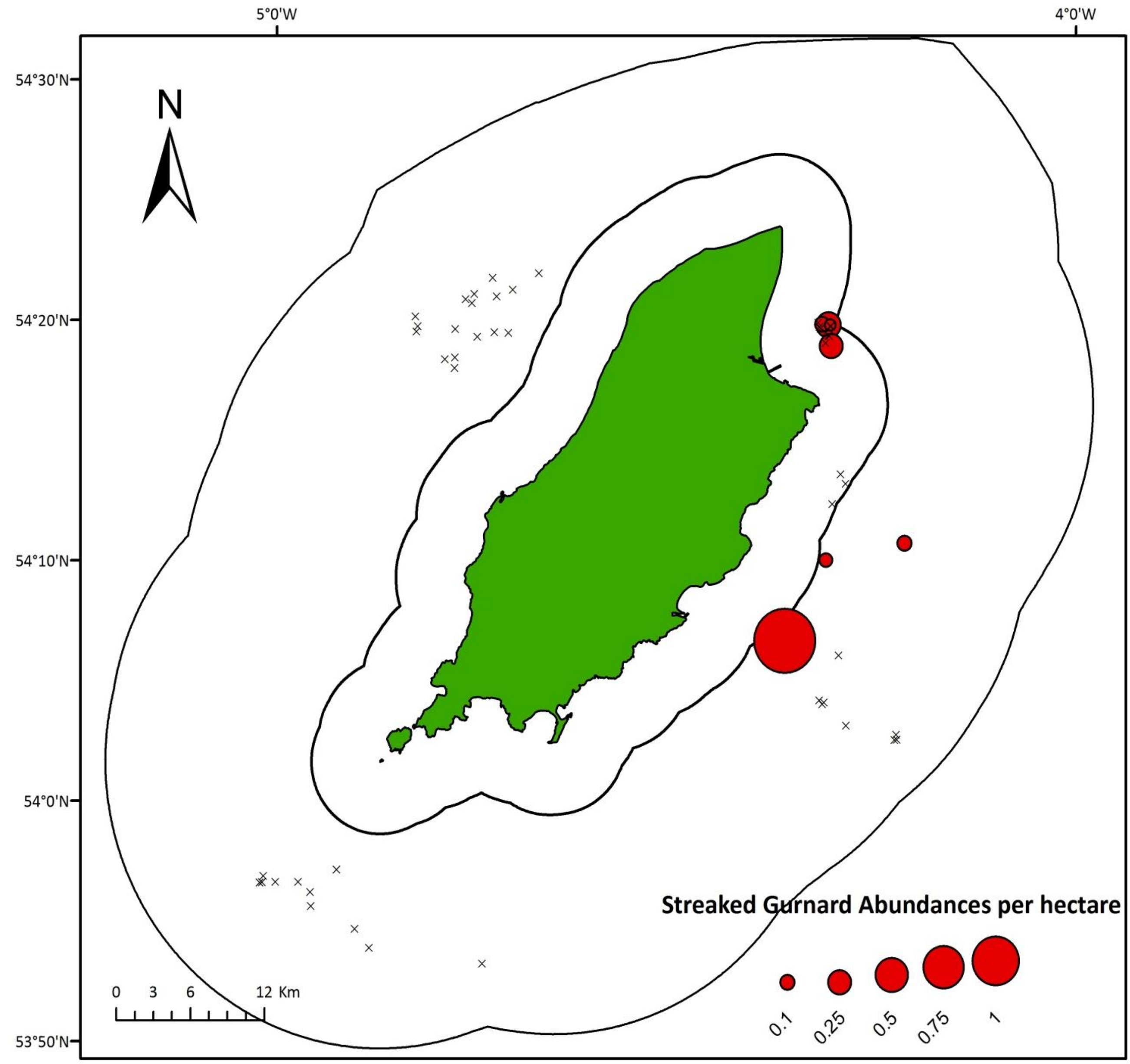

Figure 25: The Abundance of Streaked Gurnard (*Trigloporus lastoviza*) per hectare at each of the 58 tow locations around the Isle of Man, zero values are marked with an x symbol. The 3 and 12 nautical mile limit are also shown.

4.0 Discussion

4.1 Bycatch abundance and composition

During this study bycatch as a proportion of the total queen scallop fishery catch was found to be 7.42% ± 0.52, a considerable increase of bycatch over 3.36% from 2009 data by Duncan (2009). This increase in percentage proportions of bycatch between 2009 and 2012 could be indicative of increased bycatch rates, but is most likely due to differences in sampling methodology or large differences in the fishing grounds which were sampled. In Duncan (2009) the majority of sampling was conducted 10- miles south of the Isle of Man (57% of tows) and in areas NW of Peel (some in Targets and some further NW) (19% of tows), but no sampling was conducted in either Ramsey or Douglas. Considering Douglas was found to have the highest bycatch proportion, this may be the reason for such large differences in bycatch rates between the two studies. Also in the present study a subsampling method was used to estimate the invertebrate bycatch component of the catch whereas in the 2009 study the entire bycatch component of the catch was sampled. However when compared to other fisheries the level of bycatch found in this study is still relatively low. Borges *et al.*, (2005) estimated the rate of discards in the Irish Sea (ICES division VIIa) for the Irish beam trawl fleet to be 67% and the otter trawl fleet for *N. norvegicus* at 25%. While the *N. norvegicus* trawl fishery in the Clyde in the west of Scotland has a reported mean discard rate of 62%. The Patagonian scallop (*Zygochlamys patagonica)* fishery which operates in Argentine waters also uses otter trawls; the rate of bycatch by weight relative to the quantity of target species caught is not known, however the gear is considered to be relatively non- selective and the efficiency was estimated to range between 21-31%, which is low for scallop fisheries and would imply that the bycatch rate would be around 69 – 79% (Lasta & Iribarne, 1997). In the Canadian Georges Bank fishery dredge fishery for *Placopecten magellanicus* was estimated a bycatch at a level of 6% (DFO, 2007; DFO, 2008), while in the Queensland otter trawl fishery which includes Saucer Scallop (*Amusium balloti*) and Mud Scallop (*Amusium pleuronectes*) the bycatch was estimated at 25,000 tonnes annually with a catch rate of 10,000 tonnes making the discard rate approximately 250% (Robins & Courtney,1998).

A total of 94 species were recorded as bycatch in the present study this is very similar to the number of 97 species found by Duncan in 2009. In the Argentinian fishery a total of 82 species where recorded as incidental bycatch during a survey in 1995, prior to commencement of the fishery (Bremec, 2002), and 56 species recorded during a survey between 1998-2002 (Schejter *et al*., 2008). It should be noted that this reduction in species number is thought to be related to sampling effort of the studies rather than a reduction of species numbers due to the impacts of the fishery. In the Canadian Georges Bank fishery the recorded bycatch consisted of 150 taxa (DFO 2007; 2008), however the gear used in this fishery is a dredge which is known to catch more benthic species than otter trawls (Hinz *et al*.,2009). In the *Nephrops* fishery in the Clyde, 61 species of fish were recorded belonging to 28 families (Stratoudakis *et al.*, 2001b). In ICES subarea VII (which includes the Irish sea) Enever *et al*., (2007) found that 165 species where recorded in the composition of the discards from English and Welsh otter trawl boats, however is should be noted that this number includes all boats and trawl gear modifications. In this same study when all gear types were included a total of 182 species where reported in the area as incidental bycatch.

The catch composition between the four areas was found to be different, with tows from Douglas and Targets having on average the highest percentage of retained queen scallops

73.45% and 72.96% respectively. Despite this these two areas also had the highest percentage bycatch 8.41% and 8.10%, but the lowest percentage of unretained queen scallop 18.14% and 18.94%, by contrast Ramsey attained the lowest catch rate of retained queen scallops (57.14%), the highest rate of unretained queen scallops (36.57%) and the lowest bycatch rate (6.30%). This variation between areas is somewhat expected as it is often observed that catch rates vary both spatialy and temporaly (Hutchings, 1996; Walters, 2003; Poos & Rijnsdorp, 2007; Rijnsdorp *et al.*, 2011). However it is interesting to note that the areas with the highest catch rate of sizeable queen scallops also had the highest rate of bycatch; this may imply a relationship.

In terms of biomass per hectare all three components of the catch differed significantly between fishing grounds. Douglas had the highest mean weight per hectare of retained queen scallops which was significantly greater than the mean biomass in both Targets and Ramsey, but similar to that of Chickens. The highest biomass per hectare of unretained undersized queen scallops was found in Ramsey which differed significantly from that of Targets with the lowest biomass of unretained queen scallops. Targets also differed significantly from Chickens which had the second highest biomass of unretained queen scallops. The results here indicate that the catch composition varies considerably between fishing grounds, therefore where a vessel chooses to fish may have major impact on the efficiency of a fishing vessel and subsequently could have major implications for the amount of bycatch caught and the amount of seabed impacted upon by fishing activity. These results suggest Douglas to be the preferred fishing ground, a suggestion borne out by fishery preference during the surveyed season and can be seen from Figure 26 which shows the area referred to as Douglas in this study had the largest concentration of fishing effort.

However, there is evidence that suggests that relative abundances of queen scallops in the different fishing grounds in Manx waters varies considerably from year to year (Murray & Kaiser, 2011), and therefore the preferred fishing ground may change with each fishing season. As a largely recruitment- dependant fishery, it would be expected that the focus of the fleet effort would move depending on where the last good settlement occurred. This change will clearly influence the bycatch, as the bycatch quantity and composition are dependent on area, this shows the importance of long term sampling as a true picture of the bycatch of the fishery will only become apparent after several years of sampling.

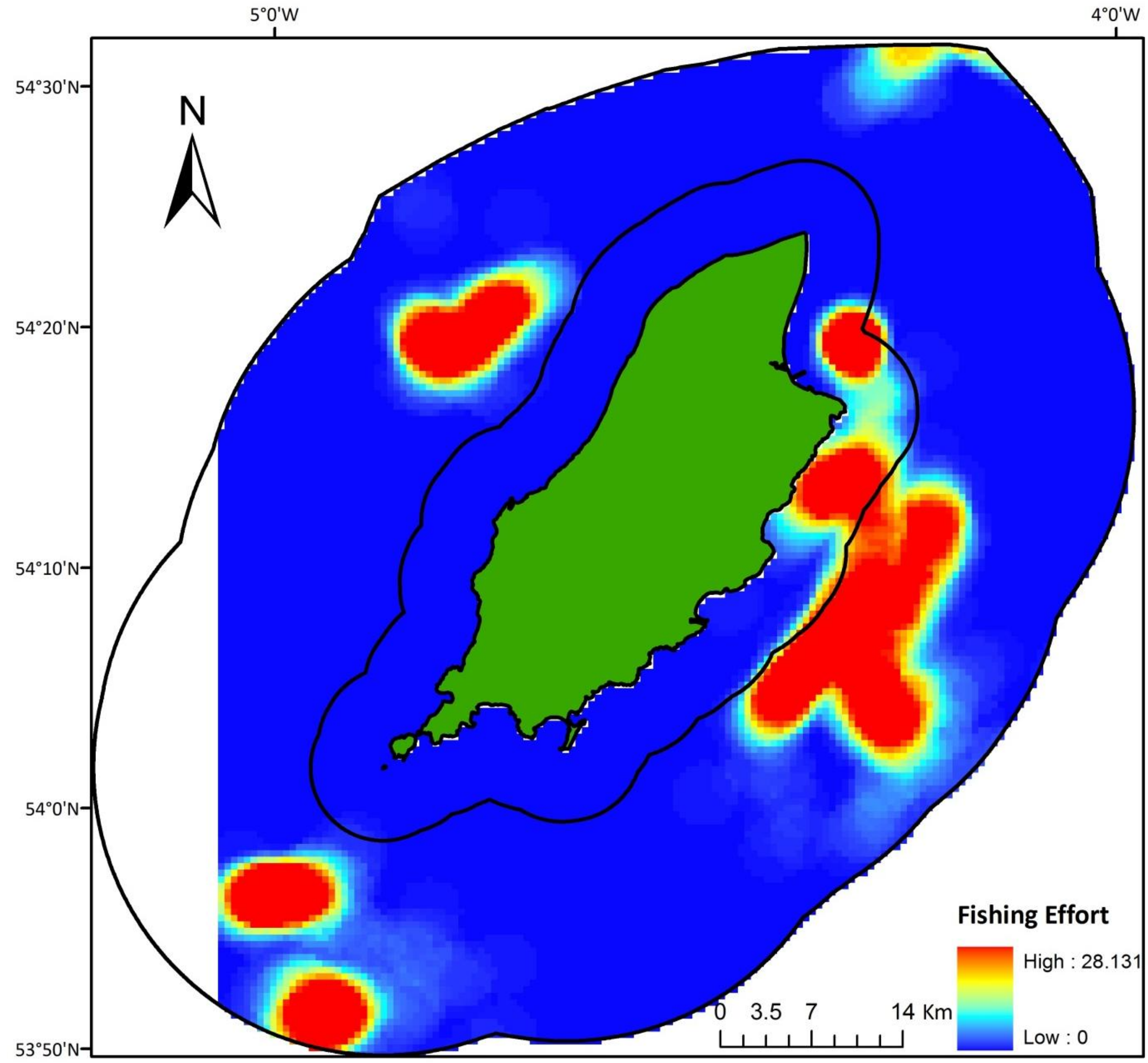

Figure 26: Heat map of the Isle of Man showing the fishing effort (hrs) of queen scallop boats from June to October 2012. 3 and 12 mile limits are also shown. Data provided by Murray.

Figure 5 shows the mean biomass of bycatch was significantly higher in Douglas than that of Targets but not of the other two fishing grounds. Differing trends in bycatch rates between areas within a single fishery have been observed elsewhere. In the Nephrops fishery in the Clyde Sea area of Scotland Bergmann *et al.*, (2002) found a significant different in the biomass of bycatch between the north and south of the area. However despite there being a significant difference in bycatch biomass between areas in this study there was no observable difference in abundance or diversity between the four fishing grounds.

4.1.1 Bycatch Composition

Not only was the overall catch composition different between areas, the makeup of the bycatch was also different between areas. The bycatch in Chickens by weight was predominantly fish (45%), with the second and third largest components being elasmobranchs and Invertebrates at 28% and 27% respectively. While in all three other fishing grounds the dominate component was invertebrates, in both Douglas and Ramsey the second largest component by weight was elasmobranchs followed by fish. In Targets the second largest component was fish followed by elasmobranchs. This indicates a spatial influence on the makeup of the bycatch, with Douglas and Ramsey located on the east side of the island having similar patterns of bycatch.

4.1.2 Invertebrate Bycatch assemblages

The Invertebrate by-catch obtained in tows differed according to the location of the tow. MDS analysis revealed clear patterns in invertebrate bycatch assemblages, with distinct pattern in community composition between fishing grounds. ANOSIM analysis further revealed that these patterns were significantly different, with each fishing ground showing a distinct community composition, all with high levels of similarity within fishing grounds and dissimilarity between fishing grounds. Some species identified as causing similarity within fishing grounds such as *Alycyonium digitatum*, hydroids, ascidiacea and *Diodora gracea* are known to be associated with or attached to queen scallops in the Isle of Man (Bradshaw *et al*., 2003). Similarly scallop spat have been reported to settle on Hydroids and bryozoans and are considered important for recruitment (Eggleston, 1962; Brand & Hoogesteger, 1980; Dare & Bannister, 1987), so their common presence on queen scallop fishing grounds is also not suprising. During this study *Alycyonium digitatum* and *Diodora gracea* were commonly observed attached to the shells of queen scallops, however none of the individuals counted in the samples were attached, implying they may have been detached by the trawling and sorting processes.

Despite the clear differences observed in invertebrate bycatch abundances between fishing grounds, none of the environmental variables investigated as part of this study showed a high level of correlation. Due to the nature of sampling on commercial fishing boats it was not possible to record parameters such as temperature, chlorophyll-a and habitat type *in situ*, with water depth being the only environmental variable recorded at the time of sampling. The inherent inaccuracies arising from the use of remotely sensed data may have masked any potential environmental relationship.

It was expected that habitat type would influence invertebrate abundance assemblages. However, habitat type was assigned according to data taken from a prior study (White, 2011) , which assigned habitat types to $0.25km^2$ cells corresponding to community group identified from the nearest survey station, which were located on a 5km grid throughout the Manx Territorial Sea. The habitat type categorisation was therefore at a relatively coarse resolution compared to the samples collected during this study. Furthermore the high level of fishing activity (both trawling and dredging) in Manx water may have significantly altered habitats since the sampling was conducted in 2008. This may explain the lack of observed relationship between habitat type and invertebrate abundance assemblages.

Figure 9 shows slight overlap of samples from Targets, Douglas and Ramsey but there is a clear division of the samples from Chickens. This may be due to the location of Chickens in much deeper waters than the other three fishing grounds. Depth was indicated by the BEST analysis as being the single factor that caused the best fit for similarities within fishing grounds although the correlation is very low. These results imply that depth has somewhat of an influence on the invertebrate assemblages. It is well known that depth influences species assemblages and a number of studies have found that depth influences invertebrate bycatch assemblages (Probert *et al*., 1997; Bergmann *et al.*, 2002).

4.1.3 Fish and elasmobranch bycatch assemblages

Fish and elasmobranch species assemblages showed similar patterns to that of invertebrate species assemblages. There were clear distinctions between fishing grounds, with no two fishing grounds being the same. In addition each fishing ground showed a distinct community composition, with high levels of within group similarity.

Furthermore there appears to be a clear separation between samples from Douglas and Ramsey, Chickens and Targets (Figure 11). The average dissimilarity was lowest between Douglas and Ramsey at 40.41% and Chickens and Targets at 40.83%, which demonstrates some similarity between these pairs of grounds. Douglas and Ramsey had a similar set of species that contributed most to the makeup, with spotted catshark (*Scyliorhinus canicula),* red gurnard (*Aspitrigla cuculus*) and dab (*Limanda limanda*) being the highest contributing species in both fishing grounds. The top four contributing species on Chickens were haddock (*Melanogrammus aeglefinus*), red gurnard, lemon sole (*Microstomus kitt*) and spotted catshark, while on Targets they were spotted catshark, whiting (*Merlangius merlangus*), haddock and red gurnard. Despite significant differences between all fishing groups it would appear that there is some grouping of the fishing grounds. These results indicate that geographic location is the biggest factor influencing fish and elasmobranch assemblages as Douglas and Ramsey are on the east coast of the Island and Chickens south- west and

Targets west. Depth was identified as the environmental variable that best fit similarities in species assemblages, this would appear to be a reasonable explanation as the MDS suggests that Chickens and Targets are more similar and these are the two deeper areas surveys, while Douglas and Targets are the shallower areas. However this correlation is relatively weak and would suggest that geographic area has a greater influence than depth. Depth has been found to drive patterns in dermersal fish assemblages (Jacob *et al.*, 1998; Hyndes *et al.*, 1999). These patterns in fish bycatch assemblage have been seen in other studies Bergmann *et al.*,(2002) found significant differences between the north and south of the Clyde sea area in Scotland, in this study the differences were also attributed to differences in depth.

4.2 Bycatch fish stomach contents analysis

Prey availability is considered to be an important component of habitat quality and is thought to a major factor influencing small and regional scale distributions of fish (Hinz *et al.*, 2003). Therefore when trying to understand distributions of bycatch fish species diet is a component that should not be overlooked and may yield valuable information on the influences on abundance and distribution.

The mean stomach fullness was found to be similar in dab between all four fishing grounds, indicating that dab may not gain any benefit from being located in one area over others, however they do seem to be gaining a benefit from fishing activity, and dab abundances also showed no difference between fishing grounds. Although stomach fullness did not differ between fishing grounds, stomach content composition was significantly different. The cause of these differences appeared to be due to the composition of prey items in the stomachs sampled from Chickens. Furthermore dab from Chickens had a higher number of prey items than the three other fishing grounds with queen scallops constituting the highest % R_W in Douglas, Ramsey and Targets but not Chickens. Queen scallops were identified as the prey item causing the biggest dissimilarity between these grounds and Chickens. Therefore these results would indicate that queen scallops play an important role in the diet of dab where available. Previous analysis of dab stomach contents conducted in waters around the Isle of Man from April 1977 to May 1979 of 4,329 dab did not identify queen scallops in any of the stomachs (Ortega-Salas, 1988). Dab appear to be benefiting from increased food availability produced as a result of fishing activity which will be discussed in more detail later in this section.

There were no differences found in red gurnard stomach contents between fishing grounds either by fullness or prey items, although the diet of red gurnard was more varied than that of any other fish investigated with 19 different prey taxa. Red gurnard was also the only species than did not appear to scavenge on queen scallops to any great extent, although red gurnard are known to exhibit scavenging behaviour in areas recently trawled (Kaiser & Spencer, 1994). The lack of any difference between areas may have been influenced by the fact all samples of red gurnard were taken from the last tow of the day and trawling activity had been taking place for a number of hours, which may have increased the general prey availability. The diet of red gurnard was typically small crustaceans, which corresponds to results from elsewhere in the Irish Sea (O'Brien & Fives, 1994). Caridean shrimp displayed the highest % in R_W Douglas and Chickens but not Ramsey, this may be due to the low sample size in Ramsey of just 4 fish.

The stomachs of whiting were found to be different both in terms of fullness and contents. Whiting from Targets had the highest mean stomach fullness, the highest number of prey items and the contents were significantly different from those of both Douglas and Ramsey. Targets also had the highest abundance of whiting of the four sampled fishing grounds which was significantly higher for whiting at both Douglas and Ramsey.

These results may imply that prey availability is a direct controlling factor of predator abundance, however due to the uneven sample size this cannot be conclusively demonstrated. Queen scallops were found to be a considerable component of whiting diet which implies that they may also scavenge on discarded queen scallops. This agrees with previous work that showed that whiting feed on damaged queen scallops after experimental trawling (Kaiser & Spencer, 1994). Haddock showed no significant difference in stomach contents between the two fishing grounds tested but again queen scallops did constitute a considerable proportion of haddock diet.

4.3 Dab scavenging behaviour

The results of this study suggest that dab scavenge on discarded queen scallops, it has been shown in other studies that dab are one of the first scavengers to aggregate in areas recently disturbed by trawling (Kaiser & Spencer, 1996), and have shown an increase in their intake of prey in trawled areas compared to that of undisturbed areas (Kaiser & Ramsay, 1997a). The results from this study show that there is a significant increase in the intake of prey and in particular queen scallops as the number of tows in an area increases. However these results may be influenced by the fact that dab are day feeders (De Groot, 1964) and the fishing activity in an area increased as the day progressed.

There is a clear increase in the stomach fullness of dab as the availability of discarded queen scallops increases. These results would indicate that survivability of discarded queen scallops could be largely impacted by abundances of predators in the area.

A combination of the stress induced by the trawling process, on deck sorting and air exposure pose a significant challenge to the survivorship of queen scallops and may make them more susceptible to predators once returned to the sea bed. A previous study on the effect of on-deck sorting processes has on the survival of undersized queen scallops found that post- capture queen scallops took up to 79 minutes to show any signs of response to predators (Montgomery 2008). Both damaged and undamaged queen scallops have been shown to attract up to seven times more scavengers than are present under normal conditions (Veale *et al*., 2000), suggesting that the survivability of discarded undersize queen scallops may be affected to some extent.

4.4 Ecologically important species

4.4.1 Cod

Cod have historically been a very important target species of commercial fisheries in the North Atlantic (Armstrong *et al.*, 2004). However increasing rates of fishing activity have caused serious declines in abundances in many Northeast Atlantic cod stocks including Irish Sea (ICES Area VIIa) cod stocks (ICES, 2003). As of February 2000 the European Commission established a number of measures to aid cod recovery which included a number of closed areas in the Irish Sea. The Isle of Man queen scallop fishery has been granted derogation from the Cod recovery plan provided the fishery does not impact upon cod stocks (*pers comms* Andy Reid 2012), therefore it is a vital part of this study to demonstrate the levels of cod which are caught as bycatch of this fishery. The numbers of cod caught as bycatch of this fishery were low, with a total of 44 individuals and a total weight of 14.07kg encountered in 58 tows surveyed, with a mean of 0.79 ± 0.24 cod per tow. This is slightly higher than the 0.42 cod per tow found by Duncan (2009), however as mentioned previously there was a considerable difference in sampling methodology and different areas sampled between the two studies.

There was also a reduction in the mean length of cod between the 2009 study and this study from 35cm to 29cm. There was no significant different in the number of cod caught per fishing ground. These results would indicate the queen scallop fishery has negligible impacts on cod stock in the Irish Sea.

4.4.2 Streaked Gurnard

Data obtained from bycatch observer programmes may be useful as a proxy for species abundances and distributions, particularly for non-commercial species and may provide valuable information in areas not covered by scientific surveys (Borges *et al*., 2005). Streaked gurnard is a species not known to commonly occur in waters surrounding the Isle of Man, with only one recorded occurrence in a trawl since 1955 (Bruce *et al*., 1963), and was not observed in recent work conducted on bycatch of the queen scallop fishery (Duncan,2009). In this study however, total of 25 streaked gurnards were encountered, with its distribution restricted to the east side of the island. Streaked gurnards are known to prefer shallower waters (Hayward & Ryland, 1995) and the fishing grounds of both Targets and Chickens are located in deeper waters. The presence of streaked gurnard in this survey potentially indicate an expansion of the range of this species as previously it has only been reported in the south and the south west of the UK (Hayward & Ryland, 1995).

5.0 Conclusions

This study has confirmed that bycatch levels in the Isle of Man queen scallop otter trawl fishery are relatively low, although slightly higher than the previous equivalent study. Differences in sampling area distributions may account for much of this difference, emphasising the importance of long-term data collection. Indeed, this study showed that there are clear differences in catch and bycatch rates between geographically locations and it would appear that the greater the distance between fishing grounds the bigger the difference in bycatch species assemblages, this may be due to a combination of factors relating to the locations such as depth, sediment type, habitat type and difference in currents. Although there were a number of explanatory environmental factors indicated as having possible influence on the species assemblages due to the nature of the sampling method this could not be conclusively proven. This study has shown that the discards from the queen scallop fishery have a major impact of the diet of bycatch fish species, and indicated that the survivability of undersized discarded queen scallops may be of a lower level than previously thought when on-bottom fish-predation is taken into account. An investigation into the extent of this scavenging behaviour may be an avenue for further study.

6.0 References

Allain, V., Biseau, A. & Kergoat, B. (2003) Preliminary estimates of french deepwater fishery discards in the northeast atlantic ocean. *Fisheries Research,* **60**, 185-192.

Almany, G.R. (2004) Does increased habitat complexity reduce predation and competition in coral reef fish assemblages? *Oikos,* **106**, 275-284.

Alverson, D.L. (1994) *A Global Assessment of Fisheries Bycatch and Discards,* Food & Agriculture Org.

Alverson, D.L. & Hughes, S.E. (1996) Bycatch: From emotion to effective natural resource management. *Reviews in Fish Biology and Fisheries,* **6**, 443-462.

Andrews, J.W., Brand, A.R. and Holt, T.J. (2010) MSC assessment report for isle of man queen scallop trawl and dredge fishery. client: Isle of man government. version: 1 client draft. moody marine ltd, derby. pp147.

Angel, A. & Ojeda, F.P. (2001) Structure and trophic organization of subtidal fish assemblages on the northern Chilean coast: The effect of habitat complexity. *Marine Ecology Progress Series,* **217**, 81-91.

Anon. (2007) A policy to reduce unwanted by-catches and eliminate discards inEuropean fisheries. communication from the commission to the council andthe european parliament. SEC (2007) 380. Brussels, Belgium: Commission ofthe European communities.

Armstrong, M., Gerritsen, H., Allen, M., McCurdy, W. & Peel, J. (2004) Variability in maturity and growth in a heavily exploited stock: Cod (gadus morhua L.) in the Irish sea. *ICES Journal of Marine Science: Journal Du Conseil,* **61**, 98-112.

Bergman, M. & Hup, M. (1992) Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern north sea. *ICES Journal of Marine Science: Journal Du Conseil,* **49**, 5-11.

Bergmann, M., Wieczorek, S., Moore, P. & Atkinson, R. (2002) Discard composition of the Nephrops fishery in the clyde sea area, Scotland. *Fisheries Research,* **57**, 169-183.

Blasdale, T. & Newton, A. (1998) Estimates of discards from two deepwater fleets in the rockall trough. *CM-International Council for the Exploration of the Sea,* **900**.

Borges, L., Rogan, E. & Officer, R. (2005) Discarding by the demersal fishery in the waters around ireland. *Fisheries Research,* **76**, 1-13.

Botsford, L.W., Castilla, J.C. & Peterson, C.H. (1997) The management of fisheries and marine ecosystems. *Science,* **277**, 509-515.

Bradshaw C, Veale LO, Hill AS, Brand AR. (2000) The effects of scallop dredging on gravelly sea-bed communities. in: Kaiser MJ, de groot SJ (eds) effects of fishing on non-target species and habitats. gray publishing, tunbridge wells, p 83-104. .

Bradshaw, C., Collins, P. & Brand, A. (2003) To what extent does upright sessile epifauna affect benthic biodiversity and community composition? *Marine Biology,* **143**, 783-791.

Brand, A. R. & Wilson, U.A.W. (1996) Seismic surveys and scallop fisheries. report to a consortium of oil companies by port erin marine laboratory, university of Liverpool, February 1996. 68 pp.

Brand, A., Paul, J. & Hoogesteger, J. (1980) Spat settlement of the scallops chlamys opercularis (L.) and pecten maximus (L.) on artificial collectors. *J.Mar.Biol.Assoc.UK,* **60**, 379-390.

Bremec, C.&.L.,M. (2002) Epibenthic assemblage associated with scallop (zygochlamys patagonica) beds in argentina. bulletin of marine sciences, 70: 89-106. .

Bruce, J.R., Colmann, J. & Jones, N.S. (1963) Marine fauna of the isle of man and its surrounding seas. *LMBC Memoirs on Typical British Marine Plants and Animals,* **36**.

Castriota, L., Campagnuolo, S. & Andaloro, F. (2001) Shrimp trawl fishery by-catch in the straits of sicily (central mediterranean sea). .

Catchpole, T.L. & Gray, T.S. (2010) Reducing discards of fish at sea: A review of european pilot projects. *Journal of Environmental Management,* **91**, 717-723.

Catchpole, T., Frid, C. & Gray, T. (2005a) Discards in north sea fisheries: Causes, consequences and solutions. *Marine Policy,* **29**, 421-430.

Catchpole, T., Frid, C. & Gray, T. (2005b) Discarding in the english north-east coast *nephrops norvegicus* fishery: The role of social and environmental factors. *Fisheries Research,* **72**, 45-54.

Clucas, I. (1997) The utilisation of bycatch/discards. *FAO Fisheries Report.*

Courtney A. J., J. A. Haddy, M. J. Campbell, D. P. Roy, M. L. Tonks, S. W. Gaddes, K. E. Chilcott, M. F. O'Neill, I. W. Brown, M. McLennan, E. J. Jebreen, C. van der Geest, C. Rose, S. Kistle, C. T. Turnbull, P. M. Kyne, M. B. Bennett, J. Taylor. (2007) Bycatch weight, composition and preliminary estimates of the impact of bycatch reduction devices in queensland's trawl fishery. final report for FRDC project no. 2000/170. brisbane. 323pp.

Crowder, L.B. & Murawski, S.A. (1998) Fisheries bycatch: Implications for management. *Fisheries,* **23**, 8-17.

D onghia, G., Carlucci, R., Maiorano, P. & Panza, M. (2003) Discards from deep-water bottom trawling in the eastern-central mediterranean sea and effects of mesh size changes. *Journal of Northwest Atlantic Fishery Science,* **31**, 245.

Dare, P. & Bannister, R. (1987) Settlement of scallop, pecten maximus, spat on natural substrates off south west england: The hydroid connection. , 9-14.

Davies, R., Cripps, S., Nickson, A. & Porter, G. (2009) Defining and estimating global marine fisheries bycatch. *Marine Policy,* **33**, 661-672.

De Groot, S. (1964) Diurnal activity and feeding habits of plaice. *Rapp PV.Réun Cons Int Explor Mer,* **155**, 48-51.

DFO. (2008) Assessment of georges bank scallops (placopecten magellanicus). Canadian science advisory secretariat science advisory report 2008/045.

DFO. (2007) Scallop fishery area/time closure to reduce yellowtail flounder bycatch on georges bank in 2007. Canadian science advisory secretariat science response 2007/001.

Duncan, P.F. (2009) An assessment of bycatch in the isle of man queen scallop trawl fishery A report prepared for the isle of man government department of agriculture, fisheries and forestry. nov 2009.

Eggleston, D. (1962) Spat of the scallop (pecten maximus (L.)) from off Port Erin, Isle of Man. *Annual Report,* **74**, 29-32.

Eleftheriou, A. & Robertson, M. (1992) The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. *Netherlands Journal of Sea Research,* **30**, 289-299.

Enever, R., Revill, A. & Grant, A. (2007) Discarding in the English channel, western approaches, celtic and irish seas (ICES subarea VII). *Fisheries Research,* **86**, 143-152.

Evans, S., Hunter, J. & Wahju, R. (1994) Composition and fate of the catch and bycatch in the farne deep (north sea) nephrops fishery. *ICES Journal of Marine Science: Journal Du Conseil,* **51**, 155-168.

FAO. (2011) Review of the state of world marine fishery resources, FAO fisheries and aquacultue technical paper 569 **ISSN 2070-7010**.

Garcia, S. M., Zerbi, A., Aliaume, C., Do Chi, T.,and Lasserre, G. (2003) The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook.*FAO fisheries technical paper*, **443**. 71 pp.

Genner, M.J., Sims, D.W., Wearmouth, V.J., Southall, E.J., Southward, A.J., Henderson, P.A. & Hawkins, S.J. (2004) Regional climatic warming drives long–term community changes of british marine fish. *Proceedings of the Royal Society of London.Series B: Biological Sciences,* **271**, 655-661.

Gilinsky, E. (1984) The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology,***65**, 455-468.

Groenewold, S. & Fonds, M. (2000) Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern north sea. *ICES Journal of Marine Science: Journal Du Conseil,* **57**, 1395-1406.

Gutiérrez, N.L., Valencia, S.R., Branch, T.A., Agnew, D.J., Baum, J.K., Bianchi, P.L., Cornejo-Donoso, J., Costello, C., Defeo, O. & Essington, T.E. (2012) Eco-label conveys reliable information on fish stock health to seafood consumers. *PloS One,* **7**, e43765.

Hayward, P. & Ryland, J.S. (1995) *Handbook of the Marine Fauna of North-West Europe,* Oxford University Press, USA.

Hinz, H., Kröncke, I. & Ehrich, S. (2005) The feeding strategy of dab limanda limanda in the southern north sea: Linking stomach contents to prey availability in the environment. *Journal of Fish Biology,* **67**, 125-145.

Hinz, H., Kaiser, M., Bergmann, M., Rogers, S. & Armstrong, M. (2003) Ecological relevance of temporal stability in regional fish catches. *Journal of Fish Biology,* **63**, 1219-1234.

Hinz, H., Murray, L.G. & Kaiser, M.J. (2009) Efficiency and environmental impacts of three different queen scallop fishing gears. fisheries & conservation report no. 8, bangor university. pp.23.

Hixon, M.A. & Jones, G.P. (2005) Competition, predation, and density-dependent mortality in demersal marine fishes. *Ecology,* **86**, 2847-2859.

Hixon, M.A. & Carr, M.H. (1997) Synergistic predation, density dependence, and population regulation in marine fish. *Science,* **277**, 946-949.

Hutchings, J.A. (1996) Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. *Canadian Journal of Fisheries and Aquatic Sciences,* **53**, 943-962.

Hyndes, G., Platell, M., Potter, I. & Lenanton, R. (1999) Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? *Marine Biology,* **134**, 335-352.

ICES. (2004) Report of the ICES advisory committee on FisheryManagement and the ICES advisory committee on ecosystems.ICES advice 1 (2), 1520 pp.

ICES. (2003) Report of the ICES advisory committee on Fisheries Management, October 2002. ICES cooperative ResearchReport: 255.

Jacob, W., McClatchie, S., Probert, P.K. & Hurst, R.J. (1998) Demersal fish assemblages off southern new zealand in relation to depth and temperature. *Deep Sea Research Part I: Oceanographic Research Papers,* **45**, 2119-2155.

Jennings, S. & Kaiser, M.J. (1998) The effects of fishing on marine ecosystems. *Advances in Marine Biology,* **34**, 201-352.

Johnson, A.F., Valls, M., Moranta, J., Jenkins, S.R., Hiddink, J.G., Hinz, H. & Rochet, M.J. (2012) Effect of prey abundance and size on the distribution of demersal fishes. *Canadian Journal of Fisheries and Aquatic Sciences,* **69**, 191-200.

Kaiser, M.J. & Hiddink, J.G. (2007) Food subsidies from fisheries to continental shelf benthic scavengers. *Marine Ecology Progress Series,* **350**,267-276.

Kaiser, M.J. & Spencer, B.E. (1996) The effects of beam-trawl disturbance on infaunal communities in different habitats. *Journal of Animal Ecology,***65** , 348-358.

Kaiser, M. & Ramsay, K. (1997a) Opportunistic feeding by dabs within areas of trawl disturbance: Possible implications for increased survival. *Marine Ecology Progress Series,* **152**, 307-310.

Kaiser, M. & Ramsay, K. (1997b) Opportunistic feeding by dabs within areas of trawl disturbance: Possible implications for increased survival. *Marine Ecology Progress Series,* **152**, 307-310.

Kaiser, M. & Spencer, B. (1994) Fish scavenging behaviour in recently trawled areas. *Marine Ecology Progress Series.Oldendorf,* **112**, 41-49.

Kelleher, K. (2005) *Discards in the World's Marine Fisheries: An Update,* FAO.

Kumar, A.B. & Deepthi, G. (2006) Trawling and by-catch: Implications on marine ecosystem. *Current Science,* **90**, 922-931.

Lasta, M.L. & Iribarne, O.O. (1997) Southwestern atlantic scallop (zygochlamys patagonica) fishery: Assessment of gear efficiency through a depletion experiment. *Journal of Shellfish Research,* **16**, 59-62.

Liggins, G. & Kennelly, S. (1996) By-catch from prawn trawling in the clarence river estuary, new south wales, australia. *Fisheries Research,* **25**, 347-367.

Link, J.S. & Almeida, F.P. (2002) Opportunistic feeding of longhorn sculpin (myoxocephalus octodecemspinosus): Are scallop fishery discards an important food subsidy for scavengers on georges bank? *Fishery bulletin - national oceanic and atmospheric administration*, **100**, 381-385.

Machias, A., Vassilopoulou, V., Vatsos, D., Bekas, P., Kallianiotis, A., Papaconstantinou, C. & Tsimenides, N. (2001) Bottom trawl discards in the northeastern mediterranean sea. *Fisheries Research,* **53**, 181-195.

Marie-Joelle, R. & Trenkel, V.M. (2005) Factors for the variability of discards: Assumptions and field evidence. *Canadian Journal of Fisheries and Aquatic Sciences,* **62**, 224-235.

Mohan, M.V., Sankaran, T.M. (1988) Two new indices for stomach content analysis of fishes. Journal of fish biology, **33**, 289–292.

Montgomery, J. (2008) Discarding in the Isle of Man queen scallop, Aequipecten opercularis, fishery. The effect of on-deck sorting processes upon survival potential of undersized queen scallops. M.Sc. thesis, Bangor university 61pp.

Moranta, J., Massutí, E. & Morales-Nin, B. (2000) Fish catch composition of the deep-sea decapod crustacean fisheries in the balearic islands (western mediterranean). *Fisheries Research,* **45**, 253-264.

Moranta, J., Stefanescu, C., Massutí, E., Morales, B. & Lloris, D. (1998) Fish community structure and depth-related trends on the continental slope of the balearic islands (algerian basin, western mediterranean).*Marine ecology progress series*, **171**,247-259.

MSC. (2010) MSC fishery standard: Principles & criteria and criteria for sustainable fishing page 2 of 8.

Murawski, S. (1996) Factors influencing by-catch and discard rates: Analyses from multispecies/multifishery sea sampling. *Journal of Northwest Atlantic Fishery Science,* **19**, 31-40.

Murray, L. & Kaiser, M. (2011) The isle of man aequipecten opercularis fishery: Research update 2011.

O'Brien, K. & Fives, J. M. (1994) The feeding relationships of a small demersal fish community in the western irish sea, irish fisheries investigations, department of the marine 1994.

Ortega-Salas, A. (1988) Diet, food consumption and growth of the dab limanda limanda (linnaeus) in isle of man waters, UK. **15**, 31-40.

Pascoe, S. (1997) *Bycatch Management and the Economics of Discarding,* Food & Agriculture Org.

Perkins, P. & Edwards, E. (1996) A mixture model for estimating discarded bycatch from data with many zero observations: Tuna discards in the eastern tropical pacific ocean. *Fishery bulletin - national oceanic and atmospheric administration,* **94**, 330-340.

Petter Johnsen, J. & Eliasen, S. (2011) Solving complex fisheries management problems: What the EU can learn from the nordic experiences of reduction of discards. *Marine Policy,* **35**, 130-139.

Pinnegar, J., Trenkel, V., Tidd, A. & Dawson, W. (2003) Does diet in celtic sea fishes reflect prey availability? *Journal of Fish Biology,* **63**, 197-212.

Polis, G.A. & Strong, D.R. (1996) Food web complexity and community dynamics. *American Naturalist,***147** , 813-846.

Poos, J. & Rijnsdorp, A.D. (2007) The dynamics of small-scale patchiness of plaice and sole as reflected in the catch rates of the dutch beam trawl fleet and its implications for the fleet dynamics. *Journal of Sea Research,* **58**, 100-112.

Probert, P.K., McKnight, D. & Grove, S.L. (1997) Benthic invertebrate bycatch from a deep-water trawl fishery, chatham rise, New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **7**, 27-40.

Rijnsdorp, A.D., Poos, J.J., Quirijns, F.J. & Grant, J. (2011) Spatial dimension and exploitation dynamics of local fishing grounds by fishers targeting several flatfish species. *Canadian Journal of Fisheries and Aquatic Sciences,* **68**, 1064-1076.

Robins, J., Courtney, A. (1998) Status report on bycatch within the Queensland trawl fishery. in: Buxton, C., eayrs, S., (ed.), establishing meaningful targets for bycatch reduction in australian fisheries. Australian society for fish biology, sydney, hobart 24-25 september 1998, pp. 24-45.

Rochet, M.J., Péronnet, I. & Trenkel, V.M. (2002) An analysis of discards from the french trawler fleet in the celtic sea. *ICES Journal of Marine Science: Journal Du Conseil,* **59**, 538-552.

Roheim, C.A., Asche, F. & Santos, J.I. (2011) The elusive price premium for ecolabelled products: Evidence from seafood in the UK market. *Journal of Agricultural Economics,* **62**, 655-668.

Rumohr, H. & Krost, P. (1991) Experimental evidence of damage to benthos by bottom trawling with special reference to arctica islandica. *Meeresforschung Reports on Marine Research,* **33**, 340-345.

Sánchez, P., Demestre, M. & Martın, P. (2004) Characterisation of the discards generated by bottom trawling in the northwestern mediterranean. *Fisheries Research,* **67**, 71-80.

Schejter, L., Bremec, C.S. & Hernández, D. (2008) Comparison between disturbed and undisturbed areas of the patagonian scallop (zygochlamys patagonica) fishing ground “Reclutas” in the argentine sea. *Journal of Sea Research,* **60**, 193-200.

Sterling, D.J. (2005) Modelling the physics of prawn trawling for fisheries management. school of applied physics. curtin university of technology, western australia, perth, p. 236.

Stratoudakis, Y., Fryer, R.J. & Cook, R.M. (1998) Discarding practices for commercial gadoids in the north sea. *Canadian Journal of Fisheries and Aquatic Sciences,* **55**, 1632-1644.

Stratoudakis, Y., Fryer, R.J., Cook, R.M., Pierce, G.J. & Coull, K.A. (2001a) Fish bycatch and discarding in Nephrops trawlers in the firth of Clyde (west of Scotland). *Aquatic Living Resources,* **14**, 283-291.

Stratoudakis, Y., Fryer, R.J., Cook, R.M., Pierce, G.J. & Coull, K.A. (2001b) Fish bycatch and discarding in nephrops trawlers in the firth of clyde (west of scotland). *Aquatic Living Resources,* **14**, 283-291.

Trujillo, V. & Pereda, P. (1997) Factors affecting discards by coastal spanish north atlantic trawlers. ICES. CM DD,**03**, 1-19.

Van der Veer, H., Bergman, M. & Beukema, J. (1985) Dredging activities in the dutch wadden sea: Effects on macrobenthic infauna. *Netherlands Journal of Sea Research,* **19**, 183-190.

Van Dolah, R.F., Wendt, P.H. & Levisen, M.V. (1991) A study of the effects of shrimp trawling on benthic communities in two south carolina sounds. *Fisheries Research,* **12**, 139-156.

Van Dolah, R.F., Wendt, P.H. & Nicholson, N. (1987) Effects of a research trawl on a hard-bottom assemblage of sponges and corals. *Fisheries Research,* **5**, 39-54.

Veale, L.O., Hill, A.S. & Brand, A.R. (2000) An in situ study of predator aggregations on scallop (pecten maximus (L.)) dredge discards using a static time-lapse camera system. *Journal of Experimental Marine Biology and Ecology,* **255**, 111-129.

Votier, S.C., Bearhop, S., Witt, M.J., Inger, R., Thompson, D. & Newton, J. (2010) Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *Journal of Applied Ecology,* **47**, 487-497.

Votier, S.C., Furness, R.W., Bearhop, S., Crane, J.E., Caldow, R.W.G., Catry, P., Ensor, K., Hamer, K.C., Hudson, A.V. & Kalmbach, E. (2004) Changes in fisheries discard rates and seabird communities. *Nature,* **427**, 727-730.

Walters, C. (2003) Folly and fantasy in the analysis of spatial catch rate data. *Canadian Journal of Fisheries and Aquatic Sciences,* **60**, 1433-1436.

Wassenberg, T. & Hill, B. (1987) Feeding by the sand crab portunus pelagicus on material discarded from prawn trawlers in moreton bay, australia. *Marine Biology,* **95**, 387-393.

Werner, E.E. & Hall, D.J. (1979) Foraging efficiency and habitat switching in competiting sunfishes. *Ecology,***60** , 256-264.

Werner, E.E., Gilliam, J.F., Hall, D.J. & Mittelbach, G.G. (1983) An experimental test of the effects of predation risk on habitat use in fish. *Ecology,* **64**, 1540-1548.

White, S. (2011) An investigation of biotope distribution and susceptibility to fishing pressure in Manx territorial waters for the development of management recommendations for conservation. M.Sc. thesis, Bangor university 61pp.

URL reference list (accessed 2012-11-20)

1. http://www.defra.gov.uk/environment/marine/cfp/
2. http://ec.europa.eu/fisheries/reform/docs/regionalisation_en.pdf
3. http://ec.europa.eu/fisheries/reform/docs/msy_en.pdf
4. http://ec.europa.eu/fisheries/reform/docs/tfc_en.pdf
5. http://ec.europa.eu/fisheries/reform/docs/discards_en.pdf

7.0 Appendices

Appendix 1

TAXA
ECHINODERMATA **Asteroidea (seastars)**
7-armed starfish (*Luidia ciliaris*)
Bloody Henry (*Henricia sanguinolenta*)
Common Starfish (*Asterias rubens*)
Cushion star (*Porania pulvillus*)
Goose foot starfish (*Anseropoda placenta*)
Sand star (*Astropecten irregularis*)
Spiny starfish (*Marthasterias glacialis*)
Rosy starfish *(Stichastrella rosea)*
Sunstar (*Crossaster papposus*)
Ophiuroidea (brittle stars)
Ophiura
Ophiothrix fragilis
Echinoidea (urchins)
Edible sea urchin (*Echinus esculentus*)
Green sea urchin *(Psammechinus miliaris*)
Purple heart urchin (*Spatangus purpureus*)
CRUSTACEA
Decapoda
Hermit crab 1 (*Pagurus bernhardus*)
Hermit crab 2 (*Pagurus prideaux*)
Hermit crab 3 (sponge (*Suberites domuncula*) crab)
Spider crab 1 (*Inachus dorsettensis*)

Spider crab 2 (*Inachus phalangium*)
Masked crab (*Corystes cassivelaunus*)
Lobster (*Homarus gammarus*)
Edible crab (*Cancer pagurus*)
Swimming crab (*Liocarcinus depurator*)
Langoustine (*Nephrops norvegicus*)
Velvet swimming crab (*Necora puber*)
Pink Shrimp (*Pandalus montagui*)
Galatheid
Spider Crab (Maia squinado)
Round Crab (Atelecyclus rotundatus)
Macropodia sp
MOLLUSCA
Gastropoda
Common whelk (*Buccinum undatum*)
Red whelk (*Neptunia antiqua*)
Scaphander lignarius
Nudibranch (*Archidoris pseudoargus)*
Top shell (*Calliostoma granulata*)
Top shell (*Calliostoma zizyphinum*)
Saddle oyster (*Anomia ephippium)*
Colus gracilis
Keyhole limpet *(Diodora graeca)*
Pelican's foot (*Aporrhais pespelecani*)
Bivalvia
Scallop (*Pecten maximus*)
Horse mussel (*Modiolus modiolus*)
Dog Cockle (*Glycymeris glycymeris*)
Cephalopoda
Curled octopus (*Eledone cirrhosa*)
Squid (common squid) (*Loligo forbesi*)
Squid (pointy squid) (*Alloteuthis subulata*)
Cuttlefish (*Sepiola atlantica*)
Chondrichthyes (sharks, skates, rays)
Bull Huss (*Scyliorhinus stellaris*)
Cuckoo ray (*Raja naevus*)
Smooth hound (*Mustelus mustelus*)
Spiny dogfish (*Squalus acanthias*)
Spotted catshark (*Scyliorhinus canicula)*
Stellate smooth hound (*Mustelus asterias*)
Thornback ray (*Raja clavata*)
Tope (*Galeorhinus galeus*)

Blonde Ray (*Raja brachyura)*
Spotted Ray (*Raja montagui*)
Osteichthyes (bony fish)
Angler fish (*Lophius piscatorius*)
Cod *(Gadus morhua*)
Dab (*Limanda limanda*)
Dover sole (*Solea solea*)
Dragonet (*Callionymus lyra*)
Grey Gurnard (*Eutrigla gurnardus*)
Haddock (*Melanogrammus aeglefinus*)
Hake (*Merluccius merluccius*)
Herring (*Clupea harengus*)
John Dory (*Zeus faber*)
Lemon Sole (*Microstomus kitt*)
Plaice (*Pleuronectes platessa*)
Pogge (*Agonus cataphractus*)
Poor cod (*Trisopterus minutus*)
Pouting (*Trisopterus luscus*)
Red Gurnard (*Aspitrigla cuculus*)
SS Sea Scorpion (*Myoxocephalus scorpius*)
Streaked Gurnard (*Trigloporus lastoviza*)
Solenette (*Buglossidium luteum*)
Thick back sole (*Microchirus variegatus*)
Tub Gurnard (*Trigla lucerna)*
Whiting (*Merlangius merlangus*)
Atherina presbyter (sand smelt)
Topknot (*Zeugopterus punctatus*)
Norwegian topknot *(Phrynorhombus norvegicus)*
Solenette (*Buglossidium luteum*)
Witch (*Gyptocephalus cynoglossus*)
Ling (*Molva molva*)
Brill (*Scophthalmus rhombus*)
Mackerel (*Scomber scombrus*)
Five bearded rockling (*Ciliata mustela*)
ANNELIDA
Polychaeta
Sea mouse (*Aphrodite aculeata*)
CNIDARIA
Alcyonium digitatum
Plumose anemone (*Metridium senile*)
Nemertesia antennina