The bottom longline fishery and its use as a source of benthic biodiversity information around South Georgia

Thesis

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The bottom longline fishery and its use as a source of benthic biodiversity information around South Georgia

by

Ramon Augusto Benedet

BSc. Oceanography
MSc. Biological Oceanography

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in partial fulfilment for the degree of

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To my beloved daughter, wife, and family

“Para minha amada filha, esposa e família”
Author's declaration

I, Ramon Benedet declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

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ABSTRACT

South Georgia is a large, old, and isolated oceanic archipelago in the Atlantic sector of the Southern Ocean. It is surrounded by a wide continental shelf which is highly productive, rich in biodiversity and one of the world’s largest Marine Protected Areas. Most of its ~1450 species live on the seabed, many are endemic or at the edge of their geographic ranges, but are still quite poorly known. This UK overseas territory is administered by the Government of South Georgia and South Sandwich Islands and its waters are designated Food & Agricultural Organisation (FAO) area 48.3. They form an important fishing ground for a well established fishery for the Patagonian toothfish Dissostichus eleginoides, a high value fish endemic to the Southern Hemisphere. There are many more fishing than scientific vessels visits to South Georgia and fishing boats, deploy lines at locations too steep or rough for most scientific sampling gear. This thesis investigates the potential for this fishery to be a source of much needed biodiversity information and evaluates how benthic invertebrate bycatch data is collected by fishing observers. After a general introduction, chapter 2 describes and compares the two longline systems (autoline and Spanish system) used around South Georgia. It also investigates how technical changes in the gear imposed through legislation was responsible for one of the best examples worldwide of successful management on reducing seabirds mortality from nearly 6000 birds yearly to almost zero in the recent years. Historical data was used to show how both gear types have evolved and new weighting regimes adopted. Chapter 3 investigated a method to potentially improve collection of benthic bycatch information by observers, by reducing routine workload. An electronic monitoring system (EM) was designed and installed on a longline vessel to record footage of fishing activity. Data
collected was compared to that from human observers, which could optimise that during settings by ~89% of the time spent by the observer. Hauling monitoring operations were reduced by ~56%. Species identification agreement across techniques was high for vertebrate, and for some groups of invertebrates, especially larger specimens. For detection of small benthic bycatch the video technique showed clear limitations but with the expected reduction in workload, more time will be available for observers identify through direct collection of VME taxa by the crew during hauling operations. Chapter 4 examines the composition of benthic bycatch particularly those constituting Vulnerable Marine Ecosystems (VME) from trials in well known fishing grounds. Bycatch composition collected did not differ with gear type but significantly varied with area and depth. In total 199 taxa were found in the study period, of which 28 represented new records for South Georgia and at least one species of Holothuroidea (Laetmogonidae) was previously undescribed. These new records are compared with previous distribution and maps showing the previous and new range are shown. Chapter 5 shows the spatial and bathymetric distribution of the most important VME groups using information collected by observers. The amount (CPUE) of bycatch of each fishing gear is compared and differed significantly with gear type system where invertebrate bycatch is higher on Spanish than autoline system. The quality of the data collected by these observers are then assessed and compared with longline trials in the same area. Two methods of observation used by observers are also evaluated showing significant differences in CPUE and numbers of VME groups identified. The general findings, implications and recommendations are then given in a general discussion.
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CHAPTER ONE
1. GENERAL INTRODUCTION

1.1. Study region

The study region was 800 miles east of Southern South America and the Falkland Islands. This area - the Scotia Sea - has amongst the highest wind speeds and wave heights recorded, partly because it is the only latitude at which winds can travel around the world without interruption by a continent. The seabed and isolated islands are mountainous. The mountains that form the Andes, which run the length of South America, link southwards, oceanically, to another range, the Antarctic Peninsula. Between those two considerable ranges along continents spans the Scotia Arc, which mainly comprises subsurface marine mountains. This arc is south of the Atlantic Ocean, in the cold Southern Ocean which surrounds Antarctica. Over the last few tens of millions of years the arc has spread eastwards, so comprises mountains of different ages. In a few locations, the Scotia Arc Mountains protrude above the surface, as the (old) South Orkney Islands, the young volcanic chain of the South Sandwich Islands, and the large, old archipelago of South Georgia (Mukasa and Dalziel, 1996; Livermore et al., 2007).

1.2. South Georgia

The archipelago comprises a few small islands, notably Bird Island (with a permanent UK scientific research station and the world’s largest population of the largest flying bird – the wandering albatross) and the large island of South Georgia. To the west lie Shag Rocks that are mainly subsurface mountains which just break the surface as very small, uninhabited islands. The fragment of micro-continental crust which forms the island of South Georgia, in the
Atlantic sector of the Southern Ocean, and lies between 53°58’ and 54°53’ S and 035°47’ and 038°01’ W.

Historically South Georgia has been a prominent location on several occasions. It was one of the most important centres of whaling with many stations in fjords along the north coast, one of which Shackleton’s ill-fated voyage had to sail across the Southern Ocean and scale the South Georgia mountains to reach. Since the abandonment of the last of whaling stations in the 1960s a biological research station was established but then in 1982 South Georgia became a location of conflict between the UK and Argentina. Since then it has become one of the most visited locations by tourism ships and tourists around Antarctica. In March 2015, this UK Overseas Territory administered by the Government of South Georgia and the South Sandwich Islands (GSGSSI), declared that the Convention on Biological Diversity (CBD) would extend to South Georgia and the South Sandwich Islands.

The area falls under the jurisdiction of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and it is situated within the FAO (Food and Agriculture Organization of the United Nations) statistical division 48.3. The area was divided in 3 sub managements areas (A, B and C) by CCAMLR (for the 2004/05 season) and Area A which is outside the SGSSI Maritime Zone now has a zero catch limit (Figure 1.1).

The fishery management regime is compatible with CCAMLR, but with additional conservation measures in place, such as closed fishing areas. Most recently the region has again been newsworthy because of attempts to remove non-indigenous mammals – first the reindeer and then rats. This is the biggest island in the world for which this has been attempted. In addition, a major
conservation effort has led to the establishment of a multizone, South Georgia and South Sandwich Islands Marine Protected Area (SGSSI MPA) (Figure 1.1). This was established in February 2012, as the world’s largest MPA, and the MPA Order updated in June 2013 (Trathan et al., 2014; Rogers et al., 2015).

Figure 1.1 - Map of South Georgia and South Sandwich Islands Marine Protected Area (GSGSSI, 2012).

1.3. The oceanographic setting of South Georgia

South Georgia is surrounded by a wide continental shelf, which is mostly ~200-300 m deep and lies in the path of the world’s largest current – the Antarctic Circumpolar Current (ACC). The strongest jet of this, the Polar Front (PF), is forced northwards to flow round the ‘obstacle’ of the South Georgia continental mass (Figure 1.2). Other important contributory factors making South Georgia remote include the distance to the nearest continent margin (1000 km) and lack of any continuous continental shelf with any other localities. Also important to the oceanographic context of South Georgia’s marine biodiversity is another
boundary, the Southern ACC Front (SACCF), which lies to the south of it has consistently stayed to the north of South Georgia (e.g. see Trathan et al., 1997) and thus its shelf can truly be regarded as Southern Ocean. Thus South Georgia, and Bouvetøya to the east, are the most northerly islands south of the PF (the oceanographic definition of the Southern Ocean).

Together with that around Kerguelen, South Georgia has the most northerly continental shelf in the Southern Ocean. On the shelf the waters are cold and nutrient rich, but may reach 4°C on the surface in summer (the warmest in the Southern Ocean). In contrast, the temperatures associated with the surrounding continental slope are rarely higher than 2°C (Holeton et al., 2005). The phytoplankton bloom, dominated by diatoms, is regular, predictable and intense (Borrione and Schlitzer, 2013). The bloom peak in December is easily visible from space (see NASA image http://visibleearth.nasa.gov/view.php?id=69773) and is sometimes followed by a second smaller phytoplankton peak in late summer. Most of this primary productivity sinks to the seabed and is broken down and recycled through the ‘microbial loop’, but most of what is eaten is done by the krill *Euphausia superba* (Thomas, 2004; Atkinson et al., 2012). The large blooms of diatoms and massive swarms of krill results in the waters surrounding the Island of South Georgia being one of the most productive in the Southern Ocean (Murphy et al., 2007). The huge secondary productivity of krill is consumed by considerable populations of baleen whales, seals and seabirds, the populations of which vary not just with natural cycles (such as bloom strength, timing and location) but also selective human harvesting (see e.g. Trathan et al., 2012).
1.4. The South Georgia benthic environment

Benthic investigation and sampling have been undertaken around South Georgia since the ‘heroic era’ of exploration (Fogg, 1992). It has long been clear that the shelf seabed has, in places, ‘forests’ of abundant corals, sponges and associated benthic species (Figure 1.3). Even a century ago it was apparent that many species resembled those further south in Antarctic waters, and were perhaps the same. Perhaps most strikingly were the presence of crushing predators, such as large stone crabs (Lithodidae), lobsters (Thymops), skates and rays (Rajidae), which are otherwise rare on Antarctic continental shelves.

Recently there have been renewed efforts by multiple groups including the Government of South Georgia and South Sandwich Islands (GSGSSI), British
Antarctic Survey, Shallow Marine Surveys Group, Alfred Wegner Institute and others to catalogue what is known and map and explore areas which are not. As with zooplankton and higher predator studies (see e.g. Murphy et al., 2007, Trathan et al., 2012) South Georgia is argued to be a key area for benthic research particularly because it seems to have a unique frontier fauna (Barnes et al., 2009b). For a considerable proportion of the species which have been recorded there, it is either the southern limit of temperate fauna or the northern limit of Antarctica fauna. As with other old, remote islands many species are endemic – most obviously in the shallows, the brittle star *Ophionotus hexactis*.

Records examined by Barnes et al. (2011) and Hogg et al. (2011) show that the diversity of the South Georgia benthos is as rich as the shelves of some tropical islands, e.g. Galapagos, and may be the most speciose area of its size measured within the Southern Ocean.

Antarctic sessile deep sea fauna are associated with high complexity benthic communities as they provided structural habitat for many different species. Many of these benthic communities have been considered as Vulnerable Marine Ecosystems (VME). CCAMLR VMEs are defined according to their ecological characteristics including areas containing high abundances of species that are endemic, habitat forming, vulnerable to fishing gears, or requiring decades for recovery from fishing impacts (see CCAMLR, 2009; Parker and Bowden, 2010)

Following these concerns, and based on studies conducted using observer bycatch data, the Government of South Georgia and the South Sandwich Islands (GSGSSI) introduced a series of measures to reduce fishing impacts
such as the introduction of depth limits and the implementation of Benthic Closed Areas (BCAs) (Agnew et al., 2007; Martin et al., 2012).

In addition to CCAMLR aims in reporting locations of and impacts to VMEs the Convention on Biological Diversity (CBD) has reiterated the urgency of mitigating threats to biodiversity, particularly for locations like South Georgia with rich and endemic biotas. The Darwin Initiative has supported the aims of GSGSSI to attempt to map the biodiversity on the South Georgia seabed, which is much more poorly known than that in the water column or on land. This does, however, have to ‘sit alongside’ ecosystem services of the region, the most important of which is the toothfish fishery.
Figure 1.3 – Example of benthic fauna found around South Georgia: (A) Stylasteridae (Hydrocoral); (B) Gorgonacea (Gorgonian); (C) Crinoidea (Stalked crinoids); (D) Bryozoa (Lace coral); (E) Actiniaria (Anemone); (F) Alcyonacea (Soft coral); (G) Euryalida (Snake star) on a Antipatharia (black coral) and (H) Porifera (Sponge). Yellow scale = 1 cm.

1.5. Patagonian toothfish fishery

The Patagonian toothfish *Dissostichus eleginoides* (Figure 1.4) is a large, long-lived demersal fish endemic to the Southern Hemisphere (Collins *et al.*, 2010).
It is the most valuable fishery around South Georgia, which the GSGSSI income is highly dependent on from the sale of fishing licenses. In 2013, around 75% of total revenues of the GSGSSI came from the fishery and toothfish fees were responsible for around 68% (≈ £3.86 million).

![Figure 1.4 - A hooked Patagonian toothfish D. eleginoides caught by an autoliner.](image)

The Patagonian toothfish started appearing in the catch statistics of South Georgia in the middle of the 1970s, as bycatch in the trawl fishery for marbled rock cod *Notothenia rossii* (Agnew, 2004). From the middle of the 1980s vessels from Soviet Union followed by Bulgarian and Ukrainian longliners started deploying fishing lines in deeper areas which were inaccessible to the traditional trawl fishery. These targeted large adult toothfish on new fishing grounds around the island (Agnew, 2004; Collins et al., 2010).

From 1989, catches were ≈7000 tonnes per annum and the high price paid (The fish was known as white gold) made the fishery very attractive for fishing companies. As a consequence, the number of vessels increased and lead to an illegal, unregulated and unreported (IUU) fishery (Agnew, 2004). The IUU
started to decline from 1995 as a result of better surveillance and arrests made by UK authorities (Agnew and Kirkwood, 2005) (Figure 1.5).

Figure 1.5 - Total catch per year of *D. eleginoides* from South Georgia. IUU: Illegal, unreported and unregulated. (CCAMLR, 2015).

There are current two methods employed to catch *D. eleginoides* around South Georgia. The traditional “Spanish” system (SP), sometimes referred to as ‘double line’ and the autoline (AU), also known as Mustad© system. Since 2004, both systems deployments are restricted, by GSGSSI regulations, in waters shallower than 500 m and then extended from 2011 to depths from 700 to 2250 m (continental slope) (see chapter 2).

The SP system is characterised by the presence of a main line with fishing lines attached on it by a series of connecting ropes. The hooks are attached to the fishing line through snoods and the baiting regime is manual. In the autoline system hooked snoods are attached directly to the single mainline. In this method, the bait is cut and hooked using an automatic bait machine (see chapter 2).

Every year during winter months licensed vessels (longliners) are awarded by the GSGSSI a pre set quota of *D. eleginoides*. They are required to carry on
board independent observers under the CCAMLR scientific observer scheme. Such observers monitor the catch of target species but also collect a growing variety of other scientific information (Sabourenkov and Appleyard, 2005).

1.6. Fishery impacts

Bottom fishing has been established to have negative effects on benthic community richness, diversity and abundance (Kaiser et al., 2002; 2006; Hiddink et al., 2006). Of special concern are taxa with slow growth rates, and rare or endemic species (Parker and Bowden, 2010). In other words, the benthos considered most vulnerable to fishing impacts are those for which the potential for recovery is low because of low (global or regional) population or lifestyle characteristics (such as delayed maturity, slow growth and/or development).

Historically most studies investigating bottom fishing are based on active fishing gear (see Bjordal and Løkkeborg, 1996) such as trawls or dredges because of their intuitively obvious destructive impact on seabed mega and macro-biota (Watling and Norse, 1998; Craven et al., 2013; Grabowski et al., 2014). In contrast, bottom longlining is classified as a passive fishing gear and has been thought or assumed to have less impact on benthic environments than active fishing gear (Chuenpagdee et al., 2003; Pham et al., 2014). Benthic impact is of particular importance at South Georgia which is considered to have an abundant but vulnerable benthos rich in endemic, rare and range edge species (Barnes, 2008; Barnes et al., 2009b; Hogg et al., 2011).

In the past few years there has been increasing scientific interest shown in bottom longline interactions with benthic biota (Orejas et al., 2009; Sharp et al.,
2009; Durán Muñoza et al., 2010; Welsford et al., 2014; Pham et al., 2014). To date however no consensus has been reached about the impacts of the gear on the seabed. Bo et al. (2014) brought up an additional and important impact; that of lost gear. Fragments of longline were found to cause major degradation to some species found on rocky habitats.

Other potential impact on benthic communities is the additional of bait (squid and small pelagic fish - see chapter 2). Every year during fishing operations thousands of ton of bait becomes available to the benthic community. Offal dumping overboard from fish processing at sea plus dead hooked fish (consumed during soak time) are also eaten by scavengers. The availability of this “free” food could potentially increase populations of scavengers and change locally the balance of the food chain. In the northern Spain fisheries the increase abundance of dogfish (Scyliorhinus canicula) and that of Raja radiata in Greenland shrimp fisheries have been associated with the increased of discards (FAO, 2003).

1.7. Aims and objectives of the research

The use of bottom longlines as a scientific tool for sampling invertebrate benthic fauna is recent (Braga-Henriques et al., 2013; Taylor et al., 2013b; Mytilineou et al., 2014). Bycatch data of invertebrate was also used before around South Georgia by Wakeford et al. (2006) and Martin et al. (2012). They used observer data from longlines deployments to characterise the benthic environmental.

Longlining, as a passive fishing method, can work in areas with sharply sloping and rough topography where traditional sampling gear is difficult to deploy or tow.
As consequence of this, these areas are rarely investigated and exploration is usually limited to underwater imagery by research vessels, which is a slow and costly process. This thesis aims to investigate if longline gear, and the longline fishery, can provide biodiversity information that would otherwise be scarce or absent. Do longlines catch invertebrate benthic fauna which are representative of the local bottom biodiversity? Initially investigation of the detail of fishing gear was necessary due to the paucity of information. Methods to improve collection of data were considered and comparative data analysed. Quality of observer data was also investigated. In brief, the chapter descriptions are:

**Chapter 2** – Describes and analyses the differences between the two bottom longline systems currently deployed around South Georgia; the autoline and Spanish system. It investigates how technical changes in the gear imposed through legislation was responsible for reducing seabirds mortality from nearly 6000 birds yearly to almost zero in the recent years.

**Chapter 3** – Investigates the use of camera systems to help reduce the workload of scientific observers on longline vessels and supplement the information they collect. An electronic monitoring system (EM) was designed and installed on a longline vessel to record footage of fishing activity. Here the quality of the data is compared with observers as well as time efficiency to collect it.

**Chapter 4** – Investigates the composition of benthic bycatch particularly those constituting Vulnerable Marine Ecosystems (VME) from trials around Shag Rocks, South Georgia. It shows what taxa are part of the bycatch composition from the two fishing gears currently deployed in the area. New records are
compared with previous distribution and maps showing the previous and new range are shown for 28 species.

**Chapter 5** – Shows the spatial and bathymetric distribution of the most important VME groups using information collected by observers. The amount (CPUE) of bycatch of each fishing gear is compared. The quality of the data collected by these observers is assessed.

**Chapter 6** – Final chapter containing general findings, implications and recommendations.
CHAPTER TWO
2. THE EVOLUTION AND DESCRIPTION OF THE SOUTH GEORGIA LONGLINE FISHERY: AN EXAMPLE OF HOW TECHNICAL MEASURES CAN REDUCE SEABIRD MORTALITY

2.1. ABSTRACT

The longline fishery targeting Patagonian toothfish (*Dissostichus eleginoides*), around South Georgia, started in the middle of the 1980s with vessels from the Soviet Union and Chile. It quickly caught the attention of many fishing companies due to the elevated catches. During the 1990s, a large scale illegal, unreported and unregulated (IUU) fishery was established in South Georgia waters. Currently no IUU fishery takes place around the Island and the fishery has been certified as sustainable by the MSC since 2004. Historically two bottom longline types have been deployed by the multinational fishing fleet targeting *D. eleginoides*: Spanish and autoline system. Both systems have evolved and changes in gear configuration and fishing strategies have been observed over time. The changes found in the systems configuration were driven by new fishing regulations such as the increase in line weights to reduce bird mortality or by new technologies such as the introduction of integrated weight lines. Longline fishing is a major threat for seabird populations if not well managed and at South Georgia concerns were raised by at-sea observers during the early stages of the fishery due to initially high mortality. CCAMLR has adopted measures including gear changes to reduce these mortality rates. After years of management it dropped from 0.23 birds per 1000 hooks in 1996 to nearly 0 in recent years. Characteristics of each gear and fishing strategy are here compared and described. Historical georeferenced fishing data were gathered and used to show spatial distribution of the fishing effort divided by
gear and areas around South Georgia. Current gear configuration diagrams of the Spanish and autoline system are also presented.
2.2. INTRODUCTION

Fishing activities are one of the oldest and principal factors that modify marine ecosystems (Jackson et al., 2001). These include changes in the composition of ecological communities that influence the diversity, biomass, and productivity of the associated biota (Jennings and Kaiser, 1998). Particular concerns are for the bottom deep-sea fisheries that normally target slow growing species and indirectly cause physical disturbance impacting the benthic deep sea ecosystems (Morato et al., 2006; FAO, 2009; Parker and Bowden, 2010).

The effect of fisheries on the marine ecosystems depends directly on the type of fishing gear and the scale of the activity. Active fishing gear such as bottom trawling is the most destructive form of deep sea fishery on benthic communities (Watling, 2013) and it is well recognised to be less selective fishing gear (Harrington et al., 2005; Kelleher, 2005). On the other hand, passive bottom longlining gear is considered to have low impact on benthic assemblages (Chuenpagdee et al., 2003; Auster et al., 2011; Pham et al., 2014) and be highly selective (Bjordal and Løkkeborg, 1996). The low benthic impact is of particular importance at South Georgia which is considered to have an abundant but vulnerable benthos rich in endemic, rare and range edge species (Hogg et al., 2011).

However, longlining has been recognised as a potentially major threat to certain seabird populations (Agnew et al., 2000; Robertson, 2000; Melvin et al., 2004; Poncet et al., 2006; Løkkeborg, 2011). Incidental mortality occurs mostly during the setting of the gear where foraging seabirds attack baited hooks, become hooked and drown as the line sinks (Ashford et al., 1995; Varty et al., 2008).
The problem of seabird mortality in the toothfish fishery around South Georgia was first reported by scientific observers working under the CCAMLR (Convention on the Conservation of Antarctic Marine Living Resources) international scientific observation scheme in 1994 (Ashford et al., 1994). Following the success of the pilot project in data collection, observers became mandatory in 1996 on all longliners targeting toothfish around South Georgia (Sabourenkov and Appleyard, 2005). The numbers of seabirds that were incidentally killed reported by those observers raised concerns and subsequently CCAMLR adopted conservation measures to reduce these mortality rates.

Following the adoption of mitigation measures that included gear modifications such as seasonal closures and settings practices, there has been a drastic reduction in seabird bycatch rates around South Georgia. For example, the rate of seabirds estimated caught in 1996 as bycatch was 0.23 per 1000 hooks and it dropped to nearly 0 in the last years (CCAMLR, 2007; 2015).

Bottom longlining for Patagonian toothfish began in Chile in the early 1980s and its use spread to new frontiers such as South Georgia where it has developed since the late 1980s. Vessels from the Soviet Union (USSR), Bulgaria, Ukraine and Chile started deploying longlines in areas which were inaccessible to the demersal multi-species trawl fishery (where toothfish was initially caught as bycatch), targeting large adult toothfish on new fishing grounds around the island (Agnew, 2004; Collins et al., 2010). Two different bottom longline methods have been consistently used in the South Georgia fishery: the traditional “Spanish” system (SP), sometimes referred to as ‘double line’ and the autoline (AU), also known as Mustad© system.
The current work aims to describe how the regulation of fishery has evolved over time, through the introduction of technical measures and how this has reduced the ecological impact of the fishery in terms of seabird by-catch. A plan and description of the current fishing gears deployed around South Georgia is also provided. The Spanish system has been briefly described for South Georgia (Agnew et al., 2000; Robertson, 2000; Robertson et al., 2008b) and both the autoline and Spanish system have been described in the grey literature from a similar fishery in the Ross Sea (Kokorin and Istomin, 2006; Fenaughty, 2008). However, these studies were based on descriptions of single vessels' gear used during trials and until now, they have not been compared technically or historically at South Georgia. Detailed knowledge of fishing gear is essential for better understanding and management of potential ecological impacts caused by the fishery.
2.3. MATERIAL AND METHODS

2.3.1. Study area

The study area around South Georgia has been previously described in detail in chapter 1.

2.3.2. Data sources

CCAMLR toothfish fishing data from South Georgia used in this study were extracted from different sources:

**CCAMLR C2 database**: Available from 1985 to 2014. The data gathered include type of fishing gear, vessels characteristics, fishing operation and effort.

**CCAMLR Observer database**: Since 1996 deployment of scientific observers became mandatory on all fishing vessels targeting toothfish around South Georgia and the quality and quantity of data collected increased (see Sabourenkov and Appleyard, 2005). Observers are required to collect detailed fishing information on each fishing vessel, such as detailed descriptions of fishing gear, vessel details, strategy and mitigation methods, fishing effort data, biological sampling, activity from each line deployed and accidental mortality including birds and marine mammals.

Vessel details include the country under which they are registered (flag), length overall (LOA), crew size and nationality, acoustic equipment, hold capacity and processing factory details. The gear description data comprise the type of line, hook spacing, weight system regime - including an accurate weight of anchors and weights deployed, and finally a general plan of the gear layout. Hooks are classified according to their shape, in “J” or circle type hooks (see Hannan et al., 2013). Fishing strategy methods and fishing data per set include types of
fishing gear deployed, details of how the gear was set, positions, depth, the total time the gear remained in the water (soak time), type of bait, total catch, number of hooks deployed, catch species composition and fleet structure. Data checks were conducted for all datasets and when discrepancies were found between the sets they were removed.

**GSGSSI data:** The Government of South Georgia and South Sandwich Islands (GSGSSI) provided information on licence conditions (Information for Applicants, published on the GSGSSI website for each licensing round).

**CCAMLR Conservation Measures (CMs):** Published annually since 1989, CMs are a list of rules and regulations to manage the marine ecosystems in the CCAMLR Convention Area alongside fishing activities. It is available on [https://www.ccamlr.org/en/publications/past-and-present-conservation-measures](https://www.ccamlr.org/en/publications/past-and-present-conservation-measures).

Data were also collected in the form of unstructured interviews conducted from 2008-2013. Eight experienced Fishing Masters and 16 crew members (first and second bosun) were questioned about the history and the methods used in this fishery. Direct field research involved participation in the voyages of three Spanish and four autoline longliners, totalling more than 420 days at sea viewing and recording methods first-hand, to obtain a better understanding of the fishing process and its actual state in South Georgia.

### 2.3.3. Underwater camera deployments

In order to investigate the position of fishing gear on the seabed, a customised Benthic Impacts Camera System (BICS, Figure 2.1) designed by the Australian Antarctic Division (Kilpatrick et al., 2011) was deployed during the trials. The
camera was specifically developed to be attached to the autoline gear system. Due to its technical characteristics, modifications were introduced to the BICS systems when the camera was deployed on the Spanish system. During autoline deployments, the camera successfully recorded fishing activity around the fishing line on the seabed. During Spanish system deployments, due to its technical changes, the system recorded only the seabed and the weights attached to the gear consequently positions of the hooks in relation to the seabed could not be observed. A hypothetical diagram is presented as an example of the gear position during soak time. The camera system was successfully deployed on 8 occasions (4 AU and 4 SP).

Figure 2.1 - Detailed diagram of the Benthic Impacts Camera System attached to the fishing gears during the trials around South Georgia (From Kilpatrick et al., 2011).

2.3.4. Data analysis

Configuration details of the fishing gear, fishing strategy and vessel characteristics were compared and statistical tests carried out when necessary. All statistical tests were performed using the software Minitab® 15 and significance was assessed at p = 0.05. Prior to statistical analysis, dependent
variables were tested for normality (Kolmogorov & Smirnov normality test) and homogeneity of variance (Levenes homogeneity of variance test). None of the data met the assumptions for parametric testing, therefore, in order to compare data between two groups, non-parametric tests were used. For possible differences between hauling speed the Kruskal-Wallis test was used. For all other comparison between AU and SP the Mann-Whitney test was used.

High resolution position data of where fishing gear was set were used to show spatial trends in fishing effort per fishing gear type. Using the software ArcGIS 13, the area was divided into square grids of 10 km². The number of sets deployed per season was plotted into these grids to map the effort used with each fishing gear. Historic depths of settings were also investigated. When the difference of start and end depth of the setting was greater than 200 m they were excluded from the analyses.
2.4. RESULTS

2.4.1. Management regimes

South Georgia was part of the Falkland Island Dependencies until 1985 when it became a separate territory. The Territorial Sea (12 nm) was established in 1989 and on May 1st 1993 the current 200 nautical miles (nm) South Georgia and the South Sandwich Islands Maritime Zone (SGSSIMZ) was adopted.

The 200 nm maritime zone (MZ) in South Georgia was adopted in order to regulate the fishery within its boundary. Most of the longline fishery was in deep waters beyond the previous 12 nm territorial waters - i.e., GSGSSI had no legal control over fishing activities outside of the 12 nm limit. Due to the high numbers of unregulated vessels fishing for toothfish in this area, the UK government realised that in order to ensure control of the fishery and deterring illegal fishing it would have to declare the current MZ (Agnew, 2004).

The South Georgia and the South Sandwich Islands Maritime Zone (SGSSIMZ) is entirely within the area covered by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), to which the United Kingdom is a contracting party. Fisheries currently are managed under the CCAMLR conservation measures plus a number of additional conditions ruled by the GSGSSI.

2.4.2. Fishing fleet composition and TACs

The longline fleet that has been operating in the Patagonian toothfish fishery is divided into autoliners and Spanish system vessels. There have been 23 licensed autoliners and 64 licensed vessels using the Spanish system and an unknown number of unlicensed fishing vessels involved in the longline toothfish
fishery around South Georgia since it began. The total number of vessels involved in the fishery has been reduced in recent years (Figure 2.2).

The vessels involved in the fishery are long range freezer vessels built of steel, which are able to stay at sea for 75-130 days or longer if resupplied. The fleet is heterogeneous in terms of construction types with a wide variety of designs formed by a mix of converted trawler vessels, typical bottom and converted pelagic longliners (Figure 2.3).

The number of vessels peaked in 1992 with 30 longliners, the year before the declaration of the maritime zone around South Georgia. After that, it dropped to around 14 longliners per year until 2005. From 2005-2009 another decline in the number of vessels occurred, with around 10 vessels per fishing season. Since 2010, following a reduction in the quota, the number of longliners in the fishery has been gradually reduced to a constant 6 vessels (Figure 2.2).
Figure 2.3 - Pictures showing typical licensed longliners around South Georgia (48.3) equipped with Spanish and autoline systems.

The first deployment of an autoline system at South Georgia is recorded in 1988 by a Soviet Union vessel. Until the introduction of the Spanish system by Chilean vessels in 1991, autolining with non integrated weight was used by all longliners targeting toothfish around South Georgia. The Spanish system was then widely used by the fleet operating in South Georgia, where this system strongly dominated the fleet from 1992 until 2005 after which autoliners started to appear more frequently. From 2005 autoliners started to form around half the fleet (Figure 2.2).
Fishing quotas for toothfish fishery around South Georgia were first introduced in 1991. Initially catches were well above the total allowable catch (TAC) due to the elevated number of illegal vessels fishing in the area. Two years after the MZ declaration, the total catches and TAC started equalising. This followed the UK gaining control of its 200 nm territorial waters and thus taking a series of measures to tackle illegal fishing activity. The peak of toothfish catch was in 2003 where almost 8000 tonnes (t) were fished from South Georgia. In recent years, the TAC in the South Georgia fishery has been stable at around 2000 t (Figure 2.4).

![Figure 2.4 - Total catch and toothfish quota (TAC) per year of D. eleginoides from South Georgia. IUU: Illegal, unreported and unregulated. (Source: CCAMLR and GSGSSI, 2014).](image)

### 2.4.3. Fishing gear

Two different types of bottom longline (Spanish system and autoline) are currently deployed in the Patagonian toothfish fishery around South Georgia on a variety of seafloor types and depths. They have been historically deployed most at slope depths around South Georgia (Figure 2.5).
Figure 2.5 - Spatial distribution of total fishing effort showing the number of sets deployed for Spanish system (top) and autoline (bottom) around South Georgia in management areas A, B and C. Effort aggregated to 10 km$^2$ cells from 1985 - 2014. 500 m and 1500 m are depth contours. Source: C2 CCAMLR and CCAMLR observer database, 2014).

The main components of a bottom longline are the mainline, snooods (branch) lines, weights and hooks. Both systems have similar principles and strategy however, the difference in its configuration makes them distinctive and each vessel generally has a unique configuration to be able to deploy and retrieve the gear.

Through the years, both types of gear went through technical and operational modifications, most of them caused by changes in the CCAMLR Conservation Measures and GSGSSI Licence Conditions (both of which are legally binding),
such as an increase in the weight regime, reduction of spacing used between weights and night settings.

2.4.4. Spanish system

The Spanish system (Figure 2.6) is well known for its rudimentary appearance and the high manpower needed for operation. Baiting and coiling of this type of fishing gear is done by hand. Since its debut in the South Georgia fishery, modifications have been introduced on the configuration of the gear, such as increasing the weight regime and the replacement of fibre and weight types.

It is characterised by the deployment of two separate lines (main and fishing line) connected by the *barandillo* (second or connecting line). The main line is a thick braided polypropylene rope (16-18 mm diameter (Ø)) that gives the strength needed in the gear for deep fishing. It has positive buoyancy staying in the water column with no contact to the seabed.

The *barandillo* is also a braided line (8-10 mm Ø) that is attached at equal intervals (currently 80 m apart) along the main line. It connects the main line with the fishing line (*aparejo*) and holds a weight. The length has ranged from 14-25 m long and is normally attached to the main line during setting, by a clove hitch knot (*barandillo movel*). A few vessels deploy another version called “*barandillo fixo*” where the *barandillo* is fastened to the main line using splicing methods. In this case, the main line is stored with the *barandillo* attached ready for deployment.
Figure 2.6 - Plan showing a configuration of the Spanish system longline currently deployed at South Georgia.
An external line weight is placed in each barandillo at the end where the aparejo is connected. At present, vessels set weights of at least 8.5 kg (a stone or a concrete block) or a 5 kg solid steel weight every 40 m. To achieve this figure, the aparejo is divided and an extra weight is attached between barandillos (Figure 2.6).

Segments of the aparejo, snoods and hooks are kept coiled inside plastic boxes called “cajas”. The number of hooks per box varied from vessel to vessel depending on the hook spacing and the distance between weights. The size of the line deployed depends on how many boxes are set. Boxes became the unit of measurement of the gear, in which the total length and number of hooks deployed are found out by using the total number of boxes deployed (each box contains the same number of hooks and thus the same length of line).

The fishing line is formed by a junction of line segments of 3 mm Ø (monofilament nylon) or 5 mm Ø if constructed of braided polypropylene. Each segment has a maximum length of 40 m and the number of hooks attached will depend on the hook spacing.

Hooks are attached to braided (Ø 3 mm) or monofilament nylon (Ø 1 or 2 mm) snoods by a hook eye knot and then connected to the fishing line by swivels. A pair of knots are tied on the fishing line forming a stopper that holds the swivel, and consequently the snood, in the desired position.

An additional set of weights are attached to both ends of the gear to prevent gear drifting from the desired location. A set of chains or heavy stones weighing around 40 kg followed by an anchor (weighing 60-90 kg) are attached to the buoy line (Ø 16-20 mm) using a short piece of thinner rope as a ‘weak-
link’ breaking point. This is to prevent the breakage of the buoy line as anchors can get stuck on the seabed and in this case just the set of weights would be lost. The length of the buoy line depended on the depth to which the gear was deployed.

The connection of the mainline to the buoy line is called a ‘lazy line’ (200-300 m), which is actually a section of the mainline left free of barandillos, fishing line and attached hooks. A set of surface buoys were marked with the call sign and vessel’s name and had a strobe light and radio buoy (or a tracking device such as GPS). Buoys deployed were Norwegian types (windy buoys) with diameter ranging from 46 cm (A3 code) to 85 cm (A6 code).

The fishing process starts with the setting of the gear from the stern of the vessel. First, a set of buoys from one end of the gear are thrown overboard and this starts pulling the buoy line. The vessel’s speed during the deployments of the buoys is around 6 knots and once deployed, the speed is increased up to 9 knots. Nearing the end of the deployment of the buoy line, speed is then reduced to 6.5-8 knots, when the first set of weights are attached and deployed at the desired site, sinking the line quickly. The set of weights then starts pulling the mainline, which is kept in big boxes in the setting room or outside the vessel on the deck or stern of the vessel. After the deployment of the lazy line, crew start to connect the barandillos with the weights on (see diagram - Figure 2.6). Fishing lines are simultaneously attached to the other end of the barandillo/weight using a short rope with a slipknot.

Once the total required number of boxes are deployed, vessels reduce their speed and the mainline is stopped for less than a minute when the crew cuts and connects it to the buoy line. Once this process is finished, vessels start to
increase speed again until all the buoy line and floats are deployed. The process is a hazardous operation, and it is labour-intensive, in which up to 15 crew members are needed.

Hauling operations commence with the pickup of the buoys and the hauling of the buoy line by the main hauler. Once the weights and anchor arrive on board they are disconnected from the buoy line, then the lazy line starts to be hauled in until the first section of barandillo emerges bringing together the first section of the fishing line (aparejo). Hauling is then stopped, the fishing line is untied from the barandillo and the weight is then transferred to a second hauler called a “halador”, that is located at the side but separate to the main hauler. The reason for this is to keep the mainline separate from the fishing line during hauling. The “halador” hauls just the aparejos/fishing line and it is the main hauler that is responsible for lifting the gear, pulling the mainline from the bottom.

Once the mainline has passed through the hauler the barandillo is untied and removed. The mainline is then placed into the storage area where it is carefully arranged ready for the next deployment. The fishing line is collected into plastic baskets and repaired and arranged back into the boxes (cajas) for baiting then stored on shelves ready for the next deployment.

2.4.5. Autoline system

The current autoline (Figure 2.7) or Mustad® system deployed around South Georgia is a modern fishing technique. As its name suggests, the system is highly mechanised, in which the baiting and coiling process are carried out by machinery instead of by hand, thus it uses much less human effort. The gear is
characterised by the deployment of one strong single line on the seabed and it has evolved since its first use in South Georgia. This is especially the case in recent years with the addition of new type of fibre and different set up. The most recent and visible change was the development of integrated weighted lines (IWL), which uses lead filaments inside the mainline instead of conventional external weights attached to the main line.

The system consists of a braided main line of 11.5 mm Ø (mother line) made from a combination of polypropylene and polyethene. It has 4 strands, of which one is leaded with an integrated weight regime of 50 grammes per metre (Figure 2.7).

Hooks are attached to the mainline at equal intervals using a nylon braided line of 3 mm Ø called snoods or branch lines. A stainless steel swivel is attached to one end, connecting the snood to the main line where circle metal rings (stoppers) are placed.

The main line with hooks and snoods are stored in aluminium or stainless steel racks called magazines. They can hold different sizes and types of hooks and the number and size of magazines vary from vessel to vessel depending on the internal space of the setting room. Vessels involved in the South Georgia fishery carry 21-50 magazines onboard, each of which contains 810-1380 hooks.
Figure 2.7 - Plan showing a configuration of an autoline longline system deployed around South Georgia.
The length of each main line depends on how many magazines are attached. Magazines are widely used as the unit of measurement onboard. Each fishing vessel uses the same hook spacing on all its lines and the same number of hooks per magazine. The total length is easily determined by multiplying the number of hooks by the hook spacing.

The gear contains a grapnel type anchor and chain links on each end. A set of weights are deployed to hold the ends of the mainline in place to prevent them from drifting with currents. At one of the ends, two free lines with approximately 250 m each (12 or 14 mm Ø) are placed either side of the chains, following the first set of anchor and chains to minimise entanglements. At the other end, just one free line is placed. The weights of anchors range from 35-85 kg and chains from 30-60 kg.

Similarly to the Spanish system, a set of buoys and a tracking device are connected at one, or both, ends to the anchors using a buoy line of 12-14 mm Ø. The maximum size observed for the Norwegian buoys was 71 cm Ø, (A5 code) slightly smaller than the A6 size found in the Spanish system.

The setting arrangements of buoys and buoy line are equivalent to the Spanish system. Following the deployment of the anchor, chains and free line come the fishing line with the hooks attached to it. The hooks pass through the bait machine which cuts the bait to a preset size and baits the hooks. Once the fishing line is entirely deployed, another set of weights, buoy line and buoys are tied up and set at the other end of the gear.

Hauling begins with the buoys being picked up and buoy line passed into the line hauler that pulls all the gear over a rail roller. Fish species that have been
caught are manually gaffed and hooks removed at the automatic de-hooker. The line and hooks pass through a hook cleaner (hard brushes and a jet of water) to remove any residual bait. After that a hook separator pulls the line through the guide tubes into the setting room and separates the hooks from the main line, hanging the hooks with the fishing line on the storage magazine ready for the next setting.

2.4.6. Fishing strategy and technical comparison between SP and AU

Every fishing vessel targeting toothfish around South Georgia has its own strategy based mainly on the Fishing Master’s experience. Vessels normally deploy their lines on known fishing grounds that have produced good catches in the past, utilising previous data stored in the navigation plotters or logbooks. Fishing Masters also exchange information of positions and catch rates between them, occasionally, using encrypted codes.

Prior to setting gear on unfamiliar grounds, the fishing master checks the seabed mapping data for areas potentially suitable for fishing. Hardness and topography of the ground are taken into account to minimise breakage and gear loss. Fishing efforts are directed over a variety of topography, such as ridges, hills, valleys and plains. Environmental parameters such as weather conditions and currents are also verified prior to setting to determine the direction of the lines to be deployed. Lines are preferentially set in such a way that they can be hauled with the vessel’s bow facing the wind.

The fishing line is normally set in a straight line along a determined course however major changes in direction are also made when the Fishing Master wants to follow a particular patch or bathymetric feature. Once vessels arrive
on a fishing ground, lines are normally set at different depths trying to establish the best depth for catching fish. Once catches are considered reasonable, vessels tend to work with all fishing capacity optimising the soak time for each line. Lines are also preferentially set and hauled in an order to minimise time spent steaming between them, so they may not be hauled in the same order they were set.

The distance between sets and the way that lines are set and hauled can be affected by the presence of sperm whales *Physeter macrocephalus* and killer whales *Orcinus orca*. Those marine mammals interact with the gear and depredate the catch (Soeffker *et al.*, 2015). Vessels may set very short lines, spreading their effort across a bigger area, increasing the navigation time between them in an attempt to avoid depredation.

SP and AU longliners have deployed lines at depths ranging from 100 m to 2792 m, averaging 1159 m. Spanish system longliners typically targeted shallower water than those using the autoline, with 35.1% of lines set on depths less than 900 m compared with 17.2% on autoliners since 1995.

The average depth has increased with time as a result of new minimum depth limits introduced around South Georgia (Table 2.1).

Table 2.1 - Historical changes on minimum and maximum depths used in the South Georgia toothfish fishery. They were introduced by GSGSSI.

<table>
<thead>
<tr>
<th>Year</th>
<th>Minimum Depth (m)</th>
<th>Maximum Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Until 2004</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td>2004 to 2009</td>
<td>500</td>
<td>No limit</td>
</tr>
<tr>
<td>2010</td>
<td>550</td>
<td>No limit</td>
</tr>
<tr>
<td>2011 to 2014</td>
<td>700</td>
<td>2250</td>
</tr>
</tbody>
</table>
From the beginning of the fishery until 2004 fishing vessels operating with AU and SP deployed around 18.4% of total number of lines at depths shallower than 500 m. Over the following 4 years, both systems started to move their lines deeper with AU vessels setting 80.5% of the total number of lines deeper than 1100 m compared with 58.6 % using the SP system (Figure 2.8).

Since the last increase in minimum depth in 2011, most of lines have been set from 1100-1700 m for both systems (73.24% AU; 63.45% SP system) (Figure 2.8).
The start depth of a set was not always similar to the end depth. Vessels can start to deploy a line in shallow waters but finish at deeper depths and vice versa. Figure 2.9 shows the percentage of lines set by the difference of depths from start and end position divided into bins of 100 m. Deployment of both
fishing gear types have shown similar strategies with 61.2 % of lines from AU and 63.7 % of SP system deployed with a 200 m interval between start and end depth.

![Histogram of the frequency distribution (% of lines (AU and SP) by depth range bins (100 meters) according to the difference in depth between the start and end position of each set deployed from 1995-2013. Source: CCAMLR observer database, 2014.](image)

Spanish system and autoline differ technically from each other. The line length, the hooks average per line, hook spacing and snood length are statistically different and greater in the SP than AU. On the other hand, hauling speed of SP is slower than AU. The length overall (LOA) of vessels using AU and SP are not statistically different but the number of crew per vessel is with SP vessels deploying much more crew than autoliners (Table 2.2).
Table 2.2 - Comparison between the Spanish (SP) and autoline (AU) gear. **LOA**: Vessel length overall; **St Dev**: Standard deviation; **Range**: Minimum and maximum values; *: Statistic different

<table>
<thead>
<tr>
<th>Gear</th>
<th>Mean</th>
<th>St Dev</th>
<th>Range</th>
<th>Mann-Whitney</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line length (m)*</td>
<td>SP</td>
<td>12816</td>
<td>5649</td>
<td>1440 - 50000</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>8869</td>
<td>3327</td>
<td>1120 - 45000</td>
</tr>
<tr>
<td>Number of hooks/line*</td>
<td>SP</td>
<td>7422.2</td>
<td>3457</td>
<td>1050 - 36000</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>6293.3</td>
<td>2281.2</td>
<td>810 - 30000</td>
</tr>
<tr>
<td>Hook spacing (m)*</td>
<td>SP</td>
<td>1.68</td>
<td>0.22</td>
<td>1.1 - 2.1</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>1.4</td>
<td>0.08</td>
<td>1 - 1.6</td>
</tr>
<tr>
<td>Snood length (m)*</td>
<td>SP</td>
<td>1.02</td>
<td>0.15</td>
<td>0.6 - 1.2</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>0.43</td>
<td>0.09</td>
<td>0.4 - 0.55</td>
</tr>
<tr>
<td>Hauling speed (hooks/minute)*</td>
<td>SP</td>
<td>20.01</td>
<td>1.48</td>
<td>17.34 - 23.58</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>23.67</td>
<td>2.34</td>
<td>18.79 - 26.72</td>
</tr>
<tr>
<td>LOA (m)</td>
<td>SP</td>
<td>51.22</td>
<td>6.41</td>
<td>36 - 63.15</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>50.97</td>
<td>5.38</td>
<td>40.93 - 70.97</td>
</tr>
<tr>
<td>Crew number*</td>
<td>SP</td>
<td>39.28</td>
<td>4.59</td>
<td>30 - 44</td>
</tr>
<tr>
<td></td>
<td>AU</td>
<td>23.87</td>
<td>1.34</td>
<td>22 - 26</td>
</tr>
</tbody>
</table>

Hooks used were straight, ringed eye containing a barb and all were made of alloy or stainless steel. Data available from 60 fishing trips (n SP = 29; n AU = 31) showed that circle hooks were used exclusively on autoline vessels 9 times. “J” hooks were deployed in both systems with 29 trips on SP and 22 on AU. Examples of hooks and snoods used in the fishery are shown in the Figure 2.10. Total length data was available for one fishing season (2014) and hook “J” ranged from 60-78 cm on SP and 78-88 cm on AU. Circle hooks from 59-62 cm on AU.
2.4.7. Bait regime

On autoliners bait machines are used, in which bait is cut automatically by a strong blade, preventing the use of bait species with soft flesh such as sardine-like-species as they would easily fall from hooks reducing the bait ratio success (Figure 2.11).

Therefore autoliners use species with harder flesh such as squid or mackerel as bait. This includes horse mackerels (*Trachurus* spp.), true mackerels (*Scomber* spp.) and squid (e.g. *Illex* spp., *Nototodarus* spp.) and more recently the use of the humboldt squid (*Dosidicus gigas*).
Figure 2.11 - Bating process on autoline system. (a) Shortfin squid (*Illex argentinus*) ready to be used on the (b) bait machine. (c) Hook baited with a piece of squid during setting and (d) line, snoods and hooks on the magazines before to pass the bait machine.

By contrast hooks on the SP system are baited manually making the process of baiting run smoothly for baits with soft flesh such sardines species. They include sardines (*Sardinella* spp.), pilchards (*Sardinops* spp. and *Sardina* sp.) and the same mackerel species listed for autoliners. The use of squid is also popular and some vessels mixed them with fish species (Figure 2.12).
Lines are set using one type or a combination of different baits. For AU, the great majority of lines (12188; 93.14%) were set using just one type of bait (fish or squid), against 897 lines in which two different types were mixed (Figure 2.13). Squid has been the major bait used by autoliners totalling 84.55% (11064 lines) compared with 8.59% (1124 lines) for the SP system. Mixed bait (squid and fish) was used on just 6.86% of the lines set (897).
SP system vessels deployed 22288 lines (84.15%) using one type of bait compared to 15.85% (4196) using two different types on the same line. The most abundant groups of bait were fish, mostly sardines and pilchards (70.86%, 18767 lines) followed by mixed bait (fish and squid on 13.89%, 3678 lines). Squid was only used on 13.29% (3521) of the sets and finally mixed fish were deployed on 1.96% of the lines (518) (Figure 2.13).

The amount of bait used by each fishing vessel varied according to the number of hooks set during the season, their cut size (AU and SP) or the grade of the fish when whole fish is used (SP). When the mantle of the squid *Dosidicus gigas* is used in the SP, they have to be cut but *Illex* spp. is normally used whole. Data available from 2014 fishing season for 5 vessels (2 SP; 3 AU) showed that the amount of bait used by the two SP vessels was 90,500 and 105,100 kg of sardine. Autoliners varied from 68,000 to 92,000 kg of *Dosidicus gigas*. 

Figure 2.13 - Histograms showing the number of lines deployed, by the type of bait used. Data available from 1989-2014 (Fish – Fish = vessel deployed the line with 2 different species of fish). Source: C2 CCAMLR and CCAMLR observer database, 2014).
2.4.8. Changes on gear configuration and its practices

Through the years, Spanish and autoline system gear went through technical and operational changes in the South Georgia toothfish fishery. Such modifications were driven by compulsory enforcement to protect the marine environment (mostly to tackle the high seabird mortality) or voluntary changes such technologic improvements on the fishing gear adopted by fishing vessels to improve catches or reduce operational costs.

Operational changes in the fishery around South Georgia were all compulsorily enforced and include seasonal closures, use of bird deterrents, night setting, offal management and closed areas for fishing. Technical changes include change on the weighting regime system including the net ban around the weights (compulsorily enforced) and the development of integrated weighted lines (IWL) for autoline system (voluntarily introduced).

Compulsory enforcement was introduced through CCAMLR Conservation Measures and GSGSSI Licence Conditions (both of which are legally binding). During the early stages of the longline fishery, GSGSSI simply enforced the CCAMLR regulations. Additional measures started to be added by the South Georgia government during the MSC process of certification in 2004.

Operational changes introduced by CCAMLR conservation measures

Over time a series of conservations measures were introduced by CCAMLR in subarea 48.3 to address the problem of seabird mortality. The first measure was implemented in 1993 (Conservation Measure (CM) 29/XI-1992). It stated that lights should be kept at minimum level during night operations, offal should not be dumped, a streamer line should be deployed and vessels should make
an effort to sink baited hooks as soon as possible. However, a clear specification on best protocol was not given. After the unsuccessful results from the first measure, CCAMLR decided to change the advisory status of its first measure to directly compulsory measures as shown on Table 2.3.

**Night setting:** Introduced in 1995, longlines must be set at night time only when total darkness is observed (between the times of nautical twilight). On the following year, vessels were advised when possible complete setting operations at least three hours before sunrise. These measures were implemented to reduce the ability of seabirds in see baited hooks in the water.

**No line tension:** Introduced in 1996 for Spanish system vessels. Line weights during setting had to be released before fishing line get tension and consequently pulled by the vessel. It was implemented to reduce time of hooks exposure on the surface and to avoid that the part of line already away from bird gets re-exposed once line tension occurs were the line could be pulled by the vessel.

**Season dates:**

In 1995 CCAMLR began contracting the season to avoid fishing activities during the summer months when seabirds are more abundant and susceptible to capture. In 1995, the toothfish season started on 1st of March around 80 days later than previous years. In 1998 it was changed to April 1st and in 1999 to 15th of April. In 2000, it started on 1st May and this remained the start date until 2014. The start date of the season was experimentally and conditionally brought forward in 2003 (to April 16th) and again in 2010. The 2003 early start was unsuccessful (three birds killed by the one vessel), but from 2010 the
season was brought forward in five day increments and from 2014 the official start date was changed to April 16\textsuperscript{th}. Further extensions were trialled, but when the season started on April 6\textsuperscript{th}, a large number of white-chinned petrels were killed (Collins \textit{et al.}, 2014).

**Offal discharge:** In 1998, the current offal discharge policy came into effect and stated that vessels are not allowed to discharge any offal during settings. Offal dumping during settings can attract birds and this measure was placed to avoid it. Most of the engagements with birds occur during settings.

Other operational measures implemented included the removal of all hooks from offal prior to discharge in 2003 and the use of bird exclusion device (Brickle curtain) in 2004 during hauling. The first one is to avoid birds consuming hooks when eating offal and the Brickle curtain is to reduce the number of birds around the hauling area where baited hooks are potentially accessible to them (Table 2.3)
Table 2.3 - Summary of changes introduce by CCAMLR and adopted by GSGSSI in the management of Patagonian toothfish fisheries around South Georgia (48.3). (x) no enforcement (√) enforced. **Streamer line**: Streamer line should be deployed during settings; **Lights off**: during night time vessel should keep minimum of lights; **Offal**: (√1) Offal discharge shall be avoided during longline operations and (√2): Offal discharge is prohibited during settings; **Night**: Settings only permitted at night; **Thawed**: Bait should be thawed before used in order to sink faster; **3 hrs sunrise**: Vessels are recommended to finish setting 3 hours before sunrise; **No line tension**: weights should be released before line tension occurred; **Hooks rem**: Hooks should be removed from offal before dumping; **BED**: Bird exclusion device should be deployed during hauling.

<table>
<thead>
<tr>
<th>Year</th>
<th>Streamer line</th>
<th>Lights off</th>
<th>Offal</th>
<th>Night</th>
<th>Thawed</th>
<th>3 hrs sunrise</th>
<th>No line tension</th>
<th>Fishing season start</th>
<th>Fishing season end</th>
<th>Hooks removed</th>
<th>BED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>Not available</td>
<td>06th Nov 1992</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>1993</td>
<td>✔</td>
<td>✔</td>
<td>✔1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>06th Dec 1992</td>
<td>05th Nov 1993</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
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<td>✔</td>
<td>✔</td>
<td>✔1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>15th Dec 1993</td>
<td>15th Sep</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
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<td>✔</td>
<td>✔</td>
<td>✔1</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>X</td>
<td>1st Mar</td>
<td>31st Aug</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>1996</td>
<td>✔</td>
<td>✔</td>
<td>✔1</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>1st Mar</td>
<td>31st Aug</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>1998</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>1st Apr</td>
<td>31st Aug</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>1999</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>15th Apr</td>
<td>31st Aug</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2000</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>1st May</td>
<td>31st Aug</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2003</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>1st May</td>
<td>31st Aug</td>
<td>✔</td>
<td>x</td>
</tr>
<tr>
<td>2004</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>1st May</td>
<td>31st Aug</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2010</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>26th Apr</td>
<td>31st Aug</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>16th Apr</td>
<td>31st Aug</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2014</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>06th Apr</td>
<td>31st Aug</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2015</td>
<td>✔</td>
<td>✔</td>
<td>✔2</td>
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<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>16th Apr</td>
<td>31st Aug</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
2.4.8.1. Operational changes by GSGSSI regulations

A series of operational changes introduced by the government of South Georgia are currently in place in the toothfish fishery. The first measure was the declaration of a minimum depth (500 m) in 2004 in order to protect benthic habitats and juvenile toothfish. In 2010 and 2011 the minimum depth limit was further increased by the GSGSSI to 550 and 700 m respectively. The GSGSSI has also started a new approach and created a series of closed areas (now established as Benthic Closed Areas) for bottom fishing. This mitigation aims to protect areas with high concentration of benthic sessile invertebrate, especially cold water corals and a stock of large adults toothfish. In total 7 BCAs are currently in place (Table 2.4)

Table 2.4 - Summary of operational changes introduce by GSGSSI for the management of Patagonian toothfish fisheries around South Georgia to protect marine life. (x) no enforcement (√) enforced. Minimum depth: Minimum depth for setting a line; RIAs: number of Reduced Impact Areas implemented around South Georgia; Market hooks: each vessel should have a unique mark stamped on all hooks; Net ban: Vessels should not use nets around the weights

<table>
<thead>
<tr>
<th>Year</th>
<th>Minimum depth</th>
<th>RIAs</th>
<th>Marked hooks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>✔ (500 m)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2010</td>
<td>✔ (550 m)</td>
<td>3</td>
<td>x</td>
</tr>
<tr>
<td>2011</td>
<td>✔ (700 m)</td>
<td>4</td>
<td>x</td>
</tr>
<tr>
<td>2012</td>
<td>✔ (700 m)</td>
<td>5</td>
<td>✔</td>
</tr>
<tr>
<td>2013</td>
<td>✔ (700 m)</td>
<td>7</td>
<td>✔</td>
</tr>
</tbody>
</table>

In 2012, the GSGSSI introduced the policy of marked hooks. Vessels must deploy only hooks stamped with a unique mark (Figure 2.14) allowing the GSGSSI to identify any hook discarded, or to determine if any recovered gear was from a particular licensed vessel. The net ban rule states that vessels should not use nets around the fishing weights as lost nets are potential hazards to marine life through entanglement (Table 2.5).
2.4.8.2. Technical changes on the gear

The introduction of the first technical measure in the toothfish fishery by CCAMLR was to regulate the weight regime in 1996. The main objective was to aid hook sink rate reducing the exposure time of baited hooks to seabirds. Prior that, weighting was unregulated and vessels using the Spanish system set their lines using netted pebble/stones or concrete weights around 3.5 kg every 35-40 m (Figure 2.15C). For the AU, the distance between weights was 50 to 90 m and weight used was solid steel around 5.5 kg (Figure 2.15A).
The new policy stated the lines should be set using 6 kg every 20 m. In 2001, following new research, the weight regime was updated and vessels could choose from 8.5 kg (Figure 2.15D – E) every 40 m or keep the same previous regime (6 kg / 20 m). In 2008, the use of solid steel weights was revised and its use included in the normative allowing vessels use 5 kg weights every 40 m (Table 2.5). Weights could be set in a bunch using individual weights of 1-2 kg each or single bell shaped weights of 5-6 kg (Figure 2.15A - B).

The increase of weight use in the Spanish system forced the use of a thicker main line (from previous Ø 14 to 16/18 mm) to cooperate with the extra weight on the system.
The use of modern integrated weight lines and adoption of new fibre lines (more resilient) by autoliners are examples of technical changes introduced by the fleet. These changes were introduced to increase economic gains in the fishery. The use of integrated weight lines (in the autoline system) was regulated by CCAMLR in 2004. Since 2007, all vessels deploying autoline have been using just IWL with 50 grammes/m (Table 2.5).

Table 2.5 - Summary of changes in the fishing gears configuration deployed around South Georgia. SP: Spanish system; AU: Autoline; IW: integrated weight; Net ban: Vessels should not use nets around the weights. * CCAMLR and +GSGSSI regulations.

<table>
<thead>
<tr>
<th>Year</th>
<th>Concrete/pebble*</th>
<th>Steel*</th>
<th>IW (lead)*</th>
<th>Non IW (Steel)*</th>
<th>SP/AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>No minimum weight</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>x</td>
</tr>
<tr>
<td>1996</td>
<td>6kg, 20 m</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>x</td>
</tr>
<tr>
<td>2001</td>
<td>8.5 kg @40 m or 6 @ 20 m</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>x</td>
</tr>
<tr>
<td>2004</td>
<td>8.5 kg @40 m or 6 @ 20 m</td>
<td>50 g/m</td>
<td>5 kg @50 to 60 m</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>8.5 kg @40 m or 6 @ 20 m</td>
<td>5 kg @40 m</td>
<td>5 kg @50 to 60 m</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>8.5 kg @40 m or 6 @ 20 m</td>
<td>50 g/m</td>
<td>5 kg @50 to 60 m</td>
<td>✔️</td>
<td></td>
</tr>
</tbody>
</table>

2.4.9. Bycatch and catch rates from SP and AU

Although the longline fishery targets toothfish other vertebrate species are caught as bycatch or non-target species. These include grenadier (Macrouridae), *Antimora rostrata* (Moridae), skates (Rajidae) and seabirds.

Data collected by fisheries observers and vessels showed that macrourids were the most abundant fish bycatch species followed by skates and antimoras for both longline systems during the two periods studied (Table 2.6).

Bycatch data was divided into two different periods (2006-2010; 2011-2015) according to changes in the minimum depth changes.
When fishing systems were compared, Spanish system caught less fish bycatch than autoliners did, however bird mortality was higher on vessels deploying SP. For the first period (2006 to 2010), 4 birds were caught as bycatch; all of them on SP. During the second period (2011 to 2015), the total number of seabirds killed by AU and SP was 3 and 80 respectively totalling 83. This difference was most extreme during 2014 when 76 birds were killed by SP (74 White-chinned petrels caught on a single line) and only one on AU.

Different catch rates were observed for both systems between the two periods. All fish bycatch species dropped in the last period when compared to the first period. Observers and vessels catch rates were also different. On general observers reported more fish bycatch than vessels (Table 2.6).

Table 2.6 - Catch effort data from observer database and vessel figures (C2) of toothfish and bycatch from the Spanish and autoline system around South Georgia. Temporal data divided into two blocks (2006-10; 2011-15) due the increase of depth limits. CPUE: catch per unit effort.  
Skate data: total number of skates observed on the line (Skates release alive plus retained dead). Data from CCAMLR C2 and Observer database 2015.

<table>
<thead>
<tr>
<th>CPUE/Observer</th>
<th>Spanish system</th>
<th>Autoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrourids (n/1000 hooks)</td>
<td>4.42</td>
<td>3.08</td>
</tr>
<tr>
<td>Skate (n/1000 hooks)</td>
<td>0.94</td>
<td>0.71</td>
</tr>
<tr>
<td>Antimora (n/1000 hooks)</td>
<td>1.02</td>
<td>0.84</td>
</tr>
<tr>
<td>Birds (n'/100000 hooks)*</td>
<td>0.009</td>
<td>0.442</td>
</tr>
<tr>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CPUE C2</th>
<th>Spanish system</th>
<th>Autoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrourids (n/1000 hooks)</td>
<td>2.78</td>
<td>2.38</td>
</tr>
<tr>
<td>Skate (n/1000 hooks)</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Antimora (n/1000 hooks)</td>
<td>0.61</td>
<td>0.68</td>
</tr>
<tr>
<td>Toothfish (grams/hook)**</td>
<td>222.32</td>
<td>240.523</td>
</tr>
</tbody>
</table>

*Total number of birds dead divided by total number of hooks hauled (*100000). Figures of dead birds were collected by observers.

**Toothfish (grammes/hook): Figures of the target specie were provided by vessel.

As a result of most of these technical and operational changes in the Patagonian toothfish fishery around South Georgia, the bird mortality has
declined drastically in recent years. The biggest drop on rates was observed between 1997 and 1998 season (Figure 2.16).

The decline from an estimated 5755 to 640 birds (0.23 to 0.032 birds/1000 hooks) observed in 1998 coincided with the change of the open season from 1st March 1997 to 1st April 1998. Further declines in numbers were also observed in 1999 with 210 (0.013) and 2000 with just 21 seabirds (0.002) killed, which were years when the season also started later (15 of April 1999 and 1st May 2000). Due an increase in the bird mortally from 1 to 77 in 2014 (0.0001 to 0.01 birds/1000 hooks), the early extension was cancelled and in 2015, the season started on 16th April.

Figure 2.16 - Estimation of total seabird mortality showing the date of start of the longline toothfish fishery season around South Georgia from 1997 to 2015 (Data from CCAMLR, 2006; South Georgia Government, 2015.)
2.5. DISCUSSION

Longline fishing gear and techniques which use it have evolved worldwide in recent years (Bjordal and Løkkeborg, 1996), along with other fishing apparatus (Valdemarsen, 2001). Typically gear and fishing techniques in the pelagic longline fleet have progressively been changed by law/enforcement to minimise ecological impacts or for economic reasons in order to increase profit by reducing costs, improving catches or both (Ward and Hindmarsh, 2007).

Bottom longlining has proved a successful fishing gear for catching toothfish around South Georgia since the early stages of the fishery. During this time, other passive fishing gears have been tested such pots and trotline (Collins et al., 2010). However the use of other gear types showed poor catch rates in comparison (Agnew et al., 2000; Collins et al., 2010).

In the Patagonian toothfish fishery, the two longlining configurations (SP and AU) have evolved. At South Georgia, most of the changes were driven by implementation of new fishing policies in order to achieve more environmentally friendly fishing practises. The GSGSSI and CCAMLR have consistently tried to adopt best practice implementing a series of conservation measures and regulations minimising the impacts of fisheries on the ecosystem.

It was clear from the current study that differences in the Spanish system and autolining go beyond mere gear configuration but extend into the method of fishing. Little variation was observed between vessels using the same gear type, contrasting with other longline fisheries elsewhere, where important differences between fisheries using the same type of fishing gear targeting the same resource have been observed (Ward and Hindmarsh, 2007; Vega and
Licandeo, 2009). Furthermore, it has also been found that when vessels involved in a particular fishery are from the same country or region such differences seem to be reduced.

SP deployments are highly labour intensive as most of the process is undertaken by hand. As such there is a non-trivial difference in the number of crew per vessel between these two contrasting fishing systems. SP Vessels had almost double the crew compared with autoliners. Despite this crewing inequality, no statistical difference was found between the length of vessels (LOA) using SP versus AU. The explanation seems to be that autoliners are normally custom made vessels, typically Norwegian style longliners fitted with Mustad® gear, in which the crew is allocated double and single cabins. In contrast SP vessels are converted trawlers or pelagic longliners ‘Japanese style’ where as many as 8 crew share cabins.

The South Georgia toothfish fishery is a multinational fishery (i.e. different countries are involved) and different configurations of the same type of gear might be expected. However, observations in the current study suggest that this is not the case. All observed gear deployed in the toothfish fishery around South Georgia followed a strict configuration – one which is mandated CCAMLR and GSGSSI and because of this, variations were minor. Previous studies (Kokorin and Istomin, 2006; Fenaughty, 2008) in other regions managed by CCAMLR reported that weight regime, distance between weights and setting procedures were very similar to the South Georgia fishery. Similarities were even more apparent across vessels using the AU system where it seems that the nature of the method has little scope for variance.
Before the gradual adoption and implementation of a sequence of fishing gear technical and methodological requirements (started in 1996 by CCAMLR), each vessel was unrestricted in configuration, and thus they varied considerably according to their own regional and national fishing traditions.

Some parts of the fishing gear remain unregulated by CCAMLR, which include the type and size of hook, hook spacing, the dimensions (size) of weights, diameter and the type of material constituting the ropes. Consequently most current variation found between the gear types is restricted to these items.

Statistical differences were found between components and methods of fishing from SP and AU (Table 2.2). Hook spacing, snood size and length of lines are greater on SP when compared with AU. They are important factors when physical impacts are assessed. It is now well recognised that bottom longlines impact the seabed (Orejas et al., 2009; Sharp et al., 2009; Durán Muñoz et al., 2010; Welsford et al., 2014; Pham et al., 2014). A study on impacts from autoline fishery by the Australian Antarctic Division (AAD) in the Heard Island and the McDonald Islands found that lines move in both longitudinal and lateral directions (Welsford et al., 2014). It disaggregated all gear into components to estimate the swept area of each of one in order to quantify interactions between fishing gear and benthic habitats. It should be noticed that SP and AU have a very distinct weight system and dragging during hauling are expect to be different.

Due to the different configurations between autoline and Spanish system, different fishing behaviour would be expected between gear types. Autoline fishing is based on a single strong line with baited hooks attached to it and this
entire gear (which has negative buoyancy) being directly in contact with the seabed (see Figure 2.17).

Figure 2.17 - Still images from video footage showing two possible scenarios of a deployment of a line from autoline system. (A) Line is stretched on the seabed and (B) line is in coil arrangement.

In contrast the strong line of the Spanish system floats away from the seabed due the use of a thick rope with positive buoyancy. The line with baited hooks is thin and attached to the main line as a fishing line. It remains unclear what the behaviour and position of this fishing line is in relation to the seabed, but it seems that baited hooks stay in contact with seabed throughout the soak time whilst the fishing line and snood stayed in the water column (as shown in Figure 2.18).
Hauling speed between gears was also statistically different. SP vessels haul fewer hooks than AU (20.01 and 23.67 hooks per minute respectively). This is mostly because crew on SP needs stop the line to remove by hands the weights from the line different from AU where there are not weights connected to the line. A range of different speeds were found on the same gear (Table 2.2) as hauling speed could be affected by the amount and size of the fish on the line, weather conditions, pressure on the mainline and finally the ability of the crew.

This difference on line hauling speed could affect directly the catches of lines in presence of marine mammals. Soeffker et al. (2015) studying marine mammal depredation in South Georgia found a difference in CPUE for lines hauled in the presence of killer and sperm whales, compared to lines when they were absent. However no distinction of the gear was made. It is expected that marine mammals feeding on lines will have more time to do on SP compared with AU. In contrast Spanish system deployed two lines (fishing and mother line) instead one on autoline that may make it harder for the cetacean to remove the fish.
Longline fishing is classified as a selective fishing gear compared to other fishing practices like trawling (Bjordal and Løkkeborg, 1996; Mathai, 2009) however the catches of non-target species in the South Georgia longline fishery are of concern due the nature of their species live history.

Grenadiers and skates are the major part of the bycatch and both of them have late maturation, low fecundity and are slow growing (Lorance et al., 2008; Shibanov and Vinnichenko, 2008) thus they are very susceptible for fishing pressure. Also longlines could have a negative effect on seabird populations if the fishery is not well managed (Poncet et al., 2006; Løkkeborg, 2011).

The seabird mortal was very high in the early days of the longline fishery around South Georgia. The subsequent drastic reduction in seabird bycatch has been one of the most notable achievements in the management of the fishery. Many measures were implemented including the seasonal closures, the increased weight regime together with night setting, the use of bird deterrent devices and the prohibition of offal dumping during settings. These measures reduced the mortality from an estimated of 5755 seabirds in 1997 to almost none in recent years (Collins et al., 2010; CCAMLR, 2000; 2013; 2015). The biggest rate drops observed have been coincident with season closures which protect seasonal and breeding species of been caught by the fishing gear during the summer. During the summer season breeding birds are constrained to forage near the island and hence more susceptible to mortality. Outside the breeding season birds like black-browed albatross and white-chinned petrels forage much further afield.

Reduction in bird mortality was also observed in other fisheries where similar operational and technical changes were implemented (Melvin et al., 2001;
Sanchez and Belda, 2003; Reid et al., 2004; Anderson et al., 2011; Croxall et al., 2012). These results show that responsible management and the application of correct measures can drastically reduce the mortality of seabirds associated with longline fishery.

Other measures implemented by the GSGSSI are trying to minimise other fishing impacts. The Marine Protected Area Management Plan (GSGSSI, 2012) introduced benthic closed areas (BCAs) to move fishing activity away from specific areas to protect benthic communities, at sites considered to have a high bycatch of vulnerable invertebrates.

Minimum depth limits aimed to reduce the catch of juvenile toothfish by banning fishing effort from areas shallower than 700 m. These changes shifted fishing effort for both gear types to deeper waters and sets are now restricted to depths from 700 to 2250 m (Figure 2.19). Juvenile toothfish are typically abundant in shallow water where they seem to stay until they reach 50 to 70 cm in length, then move into deeper water (>500 m) (Collins et al., 2007; Collins et al., 2010). However this leads to trade offs of potential increases in impacts at continental slope depths.
Endicott and Agnew (2004) studying skate survivorship during hauling, found a strong correlation between skate mortality and increased depths from which they were caught. Thus moving fishing activity onto deeper grounds could be having a negative impact on skate survivorship. Fishing activity occurs on different grounds around South Georgia and the positions of AU and SP deployments showed similar patterns.

A relatively elevated proportion of lines were set with more than 200 m (Figure 2.9) from the start to the end point (39.8% AU; 36.3% SP) showing a high frequency of vessels targeting different depths at same line. Settings with a high range of depths are normally used by vessels to test the best operational depth of catch.

This needs be addressed with care when catch and fauna distribution and composition are analysed. In addition at South Georgia there is an ongoing tag study where toothfish (Agnew et al., 2006) and skates (Endicott, 2010) are
routinely tagged. This could potentially minimise in particular survivorship of skates if they are caught at one depth and released later deeper from the initial catch depth. Endicott (2010) found that at least on species of skate caught in South Georgia have restrict depth distribution on depths up to 800m.

Previous studies have indicated significant differences in the catch rate of skates in South Georgia and grenadiers in the Ross Sea between the two systems (Ballara and Driscoll, 2005; Laptikhovsky et al., 2014). They found that SP gear catches less skates and grenadiers than AU. Similar results were found in the present study where a relatively higher capture rate of fish bycatch was observed on vessels deploying AU however hook and bait type were not investigated in all of these studies.

South Georgia skates are bottom feeder and have its mouth located on ventral side. On AU the position of baited hooks and the entire fishing gear straight on the seabed (Figure 2.16) may contribute for an easier access to the bait. On the Spanish system, only baited hooks and weights are laid on the seabed and the rest of the gear is in the water column. Hooks are “hanged” through snoods from the fishing line (Figure 2.17) which could potentially form a barrier for the skate access the bait.

On the other hand, bird mortality is less frequently in AU than SP showing that incidental mortality of seabirds are more likely to happen on Spanish system deployments. In total, from 2006 to 2015 87 birds were killed in the longline fishery with 84 of them on SP. Each longline system used in South Georgia has different characteristics and different bycatch rates are expected. Based on this, South Georgia government introduced in 2010 a policy to balance the numbers of autoliners and Spanish system vessels fishing in South Georgia.
All three fish bycatch species studied here showed a reduction from the first to the second period. This could be as result of the restriction of depth limits and the implementation of BCAs around the island during the second period. According to Martin et al. (2012), BCAs were implemented in areas known to have a high bycatch rate of fish and bycatch rates are also greater in shallow waters, thus reduction on average bycatch in the fishery is expected from protecting these areas from fishing activity.

Catches were also different from observer and vessel data. Grenadier catch figures were higher during first period (2006-2010) when compared with the second. For the first period, observers reported 4.42 and 9.84 fish per 1000 hooks for SP and AU respectively compared with against 2.78 and 8.89 reported by the vessel operators. In the second period (2011-2015) SP observer data showed 3.08 against 5.56 on AU and vessels data showed 2.38 against 5.93 grenadiers per 1000 hooks. Observers are required to observe at least of 25% of the hooks hauled and the vessels figures are the catch of the entire line. This could affect the rates showed here and could be used to explain these differences. However observations made onboard showed that vessels misreporting bycatch for lack of time of the crew to weight the bycatch, difficult in count fish from the bridge by the skipper or lack of interest in make reliable counts.

The highest proportional difference in bycatch rates was found on skates. Skates should be reported by the vessel if they were released or discarded however the data showed that some vessels reported just the discarded ones and these figures should be analysed with precaution due the amount of errors found.
On the Spanish system weights are connected manually during setting, compared to the integrated weights of the AU system. Setting on SP vessels is a complex and hazardous operation; it is more susceptible to errors in weighting than the IW autoline system, where all the weight is integrated in the line. Any such errors will decrease the sink rate of part of the gear exposing baited hooks longer on the surface for seabirds increasing the chances of accidental mortality.

Interviews with masters of vessels targeting toothfish around South Georgia make it apparent that vessel operators have put in consistent effort to try to improve catches of the target species and minimise bycatch. There has been considerable competition between fishing companies for the limited number of fishing licences available. This has made the South Georgia toothfish fleet more receptive to changes imposed by the GSGSSI and even progressive in them, looking for best fishing practices. As such there have been considerable shifts in fishing gear configuration and methods utilised by the fleet around South Georgia. Once new materials and techniques became available, they are often quickly incorporated by this fleet.

New studies need to address if differences in bycatch levels has been caused by gear type factors, i.e., the way that fishing gear fishes or whether it is based on differences in hook type and bait (which normally differ between AU and SP vessels). Mitchell et al. (2007) found difference in catch levels of grenadiers by AU vessels using different hook and bait types. Bait is an important factor which affects directly the catch rates on longline gear (Lokkeborg and Bjordal, 1992) and is highly expected to have a direct influence on bycatch rates between SP and AU.
A more complete knowledge of how each gear type works, using for example underwater cameras and standardising hooks and bait types in future trials, should aid understating of the fishing process and help develop mitigation measures to reduce potential environmental impacts.
CHAPTER THREE
3. THE USE OF AN ELECTRONIC MONITORING CAMERA SYSTEM FOR THE TOOTHFISH FISHERY IN CCAMLR SUBAREA 48.3: A STUDY CASE TO HELP CCAMLR SCIENTIFIC OBSERVERS

3.1. ABSTRACT

To date, sampling methods to determine the composition and nature of the catch of the longlining fishery in CCAMLR Subarea 48.3 have been limited to in situ line observations, conducted by CCAMLR observers deployed in the fishing fleet. The collection of this data is important for the assessment and management of the fishery. This independent estimation of the total catch in the fishery requires considerable effort and cost. A video recording system was installed on a longliner targeting toothfish in CCAMLR Subarea 48.3. This system provided 100% coverage of all setting and hauling activities on this vessel. It proved to be reliable, easy to set up by the observer/crew and does not require structural modifications on the vessel. Fishing events were divided into setting and hauling operations in which at-sea observations were matched with video footage recorded, then divided into sessions termed ‘slots’. During settings, 284,800 hooks distributed in 31 slots totalling ~32 hours were observed and recorded. For hauling, a total of 53,403 hooks were randomly selected and observed at sea. The video footage recorded during these observations was 40 hours and 42 minutes, divided into 62 slots. Data gathered from at-sea observations conducted by a scientific observer was compared with recorded video footage recorded by 3 different video reviewers watching the video footage. No significant differences were found in the number of vertebrate species counted in situ and in the video footage by different video reviewers. However catch composition for invertebrates showed high discrepancy between in situ and video observations.
3.2. INTRODUCTION

Management of marine resources, mainly fisheries, is widely seen as one of the great challenges facing society both now and in the immediate future (Jackson et al., 2001). The responsible and sustainable management of fisheries resources is a major task for international, national, and regional governments (Ames, 2005).

Very few fisheries are currently operating at what is a scientifically regarded as ‘sustainable’ (see Agnew et al., 2014). In the waters around South Georgia (sub-Area 48.3) in the Atlantic Sector of the Southern Ocean, a strong emphasis has been placed on knowledge-based fishery management. The stocks assessment follows an ecosystem approach adopted by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) (Constable et al., 2000; Agnew, 2004). The combination of tight regulation, effective enforcement and strong dialogue between fishing industry, scientists and managers has helped to maintain a sustainable toothfish longline fishery (Agnew, 2004). This fishery has been certified as sustainable by the Marine Stewardship Council (MSC) since 2004.

The Patagonian toothfish (*Dissostichus eleginoides*) is a key resource in the CCAMLR Subarea 48.3. Worldwide wholesale prices can reach more than US$25/ kg (Grilly et al., 2015) making the fishery very attractive for the fishing industry. In the last 3 years, six vessels have fished in 48.3, with a catch limit of between 1800 and 2200 tonnes.

Collection of reliable scientific fishing data in South Georgia has been essential for assessment of (amongst other things) sustainability, but this has proved
difficult and challenging. In recent years there has been a significant improvement in the quantity and quality of data collected in Subarea 48.3. For example, a number of field and modelling studies based on ecosystem studies, biology, fisheries and stock assessment have been published (see Collins et al., 2010).

One of the most important methods aiding acquisition of scientific data in the Southern Ocean has been the CCAMLR scientific observer program. All licensed longliners vessels are required to carry onboard independent scientific observers under the CCAMLR scheme (Sabourenkov and Appleyard, 2005). Scientific observers are considered the most valuable sources of collecting data at sea on fishing vessels (Benoit and Allard, 2009). They collect a wide range of data, such as catch composition of target and bycatch species, characteristics of the fishing fleet, compliance data, and frequency of entanglement and incidental mortality of marine mammals and birds. On longline vessels in CCAMLR fisheries independent at-sea observers are required to observe all sets (at least part of each set) and at least 25% of hooks recovered. These tasks are labour intensive and generate a considerable workload for the observers. The observation of hooks is particularly important in ensuring that mortality of seabirds is recorded and minimised.

In fisheries, typical methods for gathering data are dockside monitoring, fishing logbooks, at-sea observers and tracking systems (e.g. VMS). Currently there are a great variety of electronic technologies to help with data collection and monitoring fishing activities, such as remote video recording.

The conception of using electronic methods to monitor fishing activities at sea dates back to the 1980s (Pitcher and Hart, 1982). Recent advances in
technology such as digital video encoding, increases in media storage capacity and miniaturisation have resulted in a reduction of costs for electronic monitoring (EM) video systems to be developed for the marine environment (e.g. Kilpatrick et al., 2011). Such systems have been used successfully in association with a wide variety of fishing activities including longlining and trawling (McElderry et al., 2003; Stanley et al., 2009; Cahalan et al., 2010; Stanley et al., 2011; Kindt-Larsen et al., 2011; Ruiz et al., 2014; van Helmond et al., 2015, Ulrich et al., 2015).

Data collected by EM systems include measures of fishing effort, effectiveness of deterrent devices such as streamer lines and number of target and non-target species caught. The correspondence between at-sea observer and video footage for counting of fish species on longlines has been documented (McElderry, 2008; Pria et al., 2008) although its potential use for collection of additional invertebrate benthic biodiversity data (bycatch) had not been tested prior to the current work.

The purpose of the current study is to examine the utility of video cameras on longliners targeting toothfish. EM systems have been seen as a potential method to replace onboard scientific observers worldwide. Here we try a new approach using the system to complement the tasks of the at-sea observers to maximise data collected. The key aims are to evaluate the capability of the EM system in monitoring setting and hauling operations. Time spent undertaking at-sea observations of vertebrate and invertebrate species were compared with time spent on video observations for the same period.
3.3. MATERIAL AND METHODS

3.3.1. Study area and fishing details

The study was conducted in the CCAMLR Subarea 48.3, around the island of South Georgia (Figure 3.1). It is located in the Atlantic sector of the Southern Ocean between 035°47′ to 038°01′ W and 53°58′ to 54°53′ S.

![Map of the Southern Ocean showing the CCAMLR Subarea 48.3.](image)

The Patagonian toothfish is a large demersal species endemic to the Southern Hemisphere (Collins et al., 2010). It occupies a broad bathymetric range, with juveniles normally found in shallow waters moving to deep waters (>500 m) when matured to adults (Collins et al., 2007). The fishery in CCAMLR Subarea 48.3 takes place annually from the middle of April to the end of August on fishing grounds deeper than 700 m.

An EM system was installed on one vessel during the 2012 season. All footage recorded was on the fishing vessel Tronio, from April to July. The vessel was built in 2005 and deploys a typical “Spanish” bottom longline system (see Chapter 2). The gross registered tonnage (GRT) is 1058 tonnes (t) and it is 55 m long (LOA), carrying up to 345 t of processed fish in four holds.
3.3.2. The Electronic monitoring system (EM)

The EM system aims to collect and store video footage of fishing events. The EM utilised in this study consisted of a set of analogue closed circuit TV cameras (CCTV) and a digital video recorder with storage facility able to record information continuously during the fishing trip.

3.3.3. Analogue CCTV cameras and housing

A total of five cameras (Table 3.1) were installed and tested in this study. Two cameras were placed in the stern of the vessel for monitoring line setting deployments and a third camera was in the factory of the vessel monitoring discard of offal during setting events. For hauling operations, two cameras were placed on the bird scaring device (see Reid et al., 2010) to monitor the retrieval of the fishing line (Figure 3.2). Positioning of the cameras on the vessel took into account the need to operate them safely without disturbing normal fishing operations, whilst giving an optimal view of the gear.

![Figure 3.2 - Bird scaring device plan in the hauling area showing the position of two CCTV cameras.](image)

All cameras were 12-Volt DC, PAL system devices that were weatherproof with an Ingress Protection (IP) rating of 68. To maximise protection against
environmental hazards, customised stainless steel housings were built onboard for each camera. To facilitate replacement, in case of failure of the devices, the housings were made using components normally found on fishing vessels such as steel, acrylic and sealing compound. In addition, stainless steel mounts with quick releases were built to fasten the cameras onto the vessel. All connectors of video and power signals were protected using a thick layer of self-amalgamating tape and placed inside a junction box (IP 65) on the upper deck.

Table 3.1 - Technical details of the five cameras used on the trial. (IR) – Infrared and (PCS) - Number of IR LEDs; (R) – Resolution TV lines.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Location</th>
<th>IR PCS</th>
<th>Colour</th>
<th>Lens</th>
<th>Image sensor</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zoom A</td>
<td>Upper deck - Hauling</td>
<td>24</td>
<td>Yes</td>
<td>2.8 - 12</td>
<td>1/3&quot; Exview HAD</td>
<td>650</td>
</tr>
<tr>
<td>Wide angle B</td>
<td>Upper deck - Hauling</td>
<td>No</td>
<td>Yes</td>
<td>3.6</td>
<td>1/3&quot; Sony Super</td>
<td>600</td>
</tr>
<tr>
<td>Zoom C</td>
<td>Stern – Setting room</td>
<td>32</td>
<td>Yes</td>
<td>2.8 - 6</td>
<td>1/3&quot; Sony DS</td>
<td>520</td>
</tr>
<tr>
<td>Wide angle D</td>
<td>Stern - Setting</td>
<td>No</td>
<td>No</td>
<td>3.6</td>
<td>1/3&quot; Sony</td>
<td>520</td>
</tr>
<tr>
<td>Wide angle E</td>
<td>Factory</td>
<td>24</td>
<td>Yes</td>
<td>2.8 - 12</td>
<td>1/3&quot; Exview HAD</td>
<td>650</td>
</tr>
</tbody>
</table>

3.3.4. Digital video recorder and data storage

The DVR Avtech® 8 was used to record video signal from the 5 cameras. The digital video recorder (DVR) operates using NTSC or PAL video systems and has a VGA video output to connect to an external monitor where footage can be viewed. A 2 Terabyte SATA hard drive was installed into the digital video recorder.

Backup of data was done via USB interface or Ethernet cable to an external hard drive. The system was password protected with two different levels of control: administrator (full control) or operator (restricted control). Time, date, camera name and vessel call sign were displayed on the footage. The system
could store recorded footage continuously from all five cameras 24 hours per
day with maximum resolution (25 frames per second) for up to 58 days.

3.3.5. Study design and analyses

During the first 48 hours of the trial, the system was tested to establish an
optimum set up of the cameras including the position and zoom extent of the
lenses. During this time no footage data was used for analysis. Through the
period of the trial, the fishing observer was responsible for the recording of all
data on fishing operations (setting and hauling) and to maintain the EM system.
*In situ* observations from setting and hauling were made from a safe vantage
point where details such as number of the event, GPS position, weather/light
conditions, date and time were all recorded. During both setting and hauling,
monitoring was carried out simultaneously by the fishery observer and the EM
system. In order to standardise the procedure used, observations were always
made from the same point.

Video footage recorded during these events were analysed using the
Videoviewer© software. The software allows the video viewers (here referred
just as a viewer) to zoom, pause, increase or decrease play speed. The system
allowed the synchronised viewing of the footage of all cameras at same time
displaying date, time and camera name details.

Footage recorded at sea was matched with at-sea observations and separated
into sessions termed 'slots'. Time spent analysing video footage slots was
compared with time spent at sea during the same event (setting and hauling) in
order to calculate the viewing ratio per slot/viewer. The start and end time of a
setting or a hauling operation followed the CCAMLR (2011) definition which
considers the deployment (setting) or recovery (hauling) of the anchor as the start and does not include time spent setting or hauling buoy lines.

All statistical tests were performed using the software Minitab® 15. T-test (with significance set at $p = 0.05$) was first used to test differences from time used during setting by the different methods of observation (sea observer and video viewer). It was also used to test potential differences in day and night viewing times of each video viewer and sea observer during hauling.

The non parametric Friedman test ($p = 0.05$) was applied to the number of hooks hauled per second observed at sea and the numbers viewed by the 3 video viewers in order to test possible differences in the speed of observations.

### 3.3.6. Settings

During the EM line settings trial, all deployments were monitored by the at-sea observer. Data gathered included the start and end time, deployment of the bird scaring streamer line (Melvin et al., 2004), the status of vessel's lights (on/off), the discard of offal (yes/no) and the deployment of the fishing line including its weight regime for increasing the sink rate of the gear (Agnew et al., 2000; Bialek, 2003; Robertson et al., 2008a).

In order to assess the efficiency of the system at reducing time spent observing the sets through video observations, time from settings operations gathered *in situ* at sea were compared with time spent analysing the same events using video footage by a video viewer.
3.3.7. Hauling

*In situ* line hauling observations took place at randomised times, following the CCAMLR observer protocol, from the deck of the vessel covering different fishing locations, light and weather conditions. Hauling operations occurred during day and night time. At-sea observer and video viewers conducted specimen counts during both conditions to test the influence of light. These observations included monitoring of the quantity of all target and bycatch species, total number of hooks observed, hook disposal methods, loss of fishing gear, rate of (caught) fish loss, method of releasing skates and any interaction with sea birds and marine mammals.

Slots recorded from hook-line observations at sea were matched with observer hook-line observations. The recorded footage was then viewed by the at-sea observer (Video viewer 1) as well as two other trained viewers (Video viewers 2 and 3) (Table 3.2). The identification was based on standard CCAMLR vertebrate and invertebrate ID guides (see CCAMLR 2009; 2011). The viewers recorded the same information as the *in situ* line observations previously described. The identification of all catch used the 3 letter code system adopted by CCAMLR.

Table 3.2 - Summary of sea observer and video viewers experience and training time.

<table>
<thead>
<tr>
<th>Experience</th>
<th>Sea observer/Viewer 1</th>
<th>Viewer 2</th>
<th>Viewer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sea days</td>
<td>1800</td>
<td>128</td>
<td>17</td>
</tr>
<tr>
<td>Worked as CCAMLR observer before</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Previous ID experience</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
3.4. RESULTS

3.4.1. Settings

A total of 284,800 hooks distributed in 31 line settings were recorded and analysed on the EM system totalling 1922.85 minutes of footage. The number of hooks set per line varied from 7,680 to 10,240 (mean 9,187) hooks according to the fishing strategy (Table 3.3).

Table 3.3 - Summary of setting data analysed by sea observer and video viewer. Total time spent: time (minutes) spent observing the deployment of the line; Ratio time: Ratio between time spent viewing the video footage and time observed at sea (1 = real time) and SD: standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Number of sets</th>
<th>Number of hooks</th>
<th>Average of hooks per set</th>
<th>Total time spent (mins)</th>
<th>Average time per set (mins)</th>
<th>Ratio time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea observer</strong></td>
<td>31</td>
<td>284,800</td>
<td>9187.1</td>
<td>1922.9</td>
<td>62.03</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>672.22 (SD)</td>
<td>5.85 (SD)</td>
</tr>
<tr>
<td><strong>Video viewer</strong></td>
<td>31</td>
<td>284,800</td>
<td>9187.1</td>
<td>214.5</td>
<td>6.92</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>672.22 (SD)</td>
<td>1.48 (SD)</td>
</tr>
</tbody>
</table>

The video viewer spent far less time than sea observer during all line setting observations (Figure 3.3). The average time spent observing each setting at sea was 62.03 minutes contrasting with the average of 6.92 minutes spent to watch video footage analyses of the same events (Table 3.3). During settings, the video viewer was able to see the video footage at speeds of 4-32 times real time. The average ratio for time spent analysing settings was 0.11 to real time (sea observation). A paired sample t-test between time spent at sea and video analyses per setting showed a significant difference ($T = 49.30; p <0.001$) between sea observer and video viewer time.
The comparison of CCAMLR line setting data coverage requirements from at-sea observations and video analyses are shown on Table 3.4. Data collected includes deployment of streamer line, weight regime, deck lights condition, night setting and the discard of offal. It showed no significant difference between data gathered by the video viewer (EM system) and the at-sea observer during in situ observations. Both methods recorded 100% fulfilment of all CCAMLR setting requirements during the 31 setting events observed.

Table 3.4 - Percentage of fulfilment of CCAMLR requirements during settings observed by sea observer and video viewer.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Streamer line deployment</th>
<th>Weights deployed</th>
<th>Deck lights off</th>
<th>No discard</th>
<th>Night setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea observer</strong></td>
<td>31</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Video viewer</strong></td>
<td>31</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

3.4.2. Hauling

During hauling operations, 476,240 hooks distributed in 54 hauls totalling 378 hours and 19 minutes were recorded by the EM system (Figure 3.4). A total of 62 fishing events (slots) totalling 58,660 hooks were randomly selected and
analysed (Table 3.5). Of these 58,660 hooks, 30,247 (51.6%) were hauled in daylight, with the remaining 48.4% at night.

Figure 3.4 - Example of footage recorded by the EM using a zoom lens (12 mm) and a wide lens (3.6 mm) positioned on the boom of the bird scaring device. (A) Toothfish hooked on the line during daylight; (B) South Georgia skate *Amblyraja sp. anon* at sunset; (C) Screen shot of a grenadier; (D) A live (lithodid) crab; (E) Screenshot from a wide angle camera showing the hauling area during a night operation; (F) Screenshot from a wide angle camera showing the hauling area during daylight; (G) Toothfish gaffed during daylight; (H) Grenadier caught during night time. The type of camera lens is shown in the white rectangle on the bottom right corner of each picture (12 mm = Zoom camera; 3.6 mm = Wide camera).
The average number of hooks observed per slot was 916.58 (SD=352.85) and 979.76 (SD=331.13) at day and night respectively. The total time spent at sea observing hauling events was 2480.88 minutes. Video footage analysed during the day was slightly longer than at night: 1265.48 day minutes (51.01%) against 1215.4 night minutes (48.99%) (Table 3.5).

Table 3.5 - Summary of time (min) spent and ratio time on hauling events (slots) divided by day and night. Light: Day or night condition; Number of hooks: Total number of hooks observed; Average of hooks per slot: total number of hooks divided by the number of slots; (SD): standard deviation; SO (min): Total time spent by sea observer to watch hauling; V V1(min): Total time spent by video viewer 1 to analyse the footage; V V2(min): Total time spent by video viewer 2 to analyse the footage; V V3(min): Total time spent by video viewer 3 to analyse the footage; RT (V V1): Ratio time between time spent viewing the video footage by video viewer 1 and time observed at sea (1 = real time); RT (V V2): Ratio time between time spent viewing the video footage by video viewer 2 and time observed at sea (1 = real time) and RT (V V3): Ratio time between time spent viewing the video footage by video viewer 3 and time observed at sea (1 = real time).

<table>
<thead>
<tr>
<th>Light</th>
<th>N</th>
<th>N of hooks</th>
<th>Ave hooks per slot</th>
<th>SO (min)</th>
<th>V V1 (min)</th>
<th>V V2 (min)</th>
<th>V V3 (min)</th>
<th>RT (VV1)</th>
<th>RT (VV2)</th>
<th>RT (VV3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>33</td>
<td>30247</td>
<td>916.58</td>
<td>1265.48</td>
<td>384.40</td>
<td>443.57</td>
<td>421.53</td>
<td>0.30</td>
<td>0.35</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>51.56%</td>
<td>352.85 (SD)</td>
<td>51.01%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night</td>
<td>29</td>
<td>28413</td>
<td>979.76</td>
<td>1215.4</td>
<td>458.08</td>
<td>506.88</td>
<td>484.47</td>
<td>0.38</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>48.44%</td>
<td>331.13 (SD)</td>
<td>48.99%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>58660</td>
<td>N/A</td>
<td>2480.88</td>
<td>842.48</td>
<td>950.45</td>
<td>906</td>
<td>0.34</td>
<td>0.38</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td>Ave</td>
<td>Ave</td>
<td>Ave</td>
<td>Ave</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The average ratio of time spent observing hauling operations by video viewers 1, 2 and 3 were 0.34, 0.38 and 0.37 of real time respectively (Table 3.5). Data from each slot observed by the at-sea observer and video viewers showed time spent at sea by the at-sea observer was higher than the time spent on video counting by the three video viewers for all slots (Figure 3.5A, B).

In individual slots, video viewer 1 was fastest 38 times (61.29%), viewer 2 on 5 occasions (8.06%) and video viewer 3 was fastest in 19 (30.64%) of all slots.
Figure 3.5 - (A) Total time (minutes) per slot spent on hauling observations by the at-sea observer and video viewers. (B) Boxplot of median hooks per second grouped by sea observer and video viewers 1, 2 and 3. The horizontal line in the box is the median, vertical lines are lower and upper quartile, with asterisks beyond the whiskers representing outliers.

Results of a Friedman test (Table 3.6) for the number of hooks observed per second showed that the time spent by the sea observer was significantly different from the three video viewers (1, 2 and 3). Comparison between the three video viewers showed that the time spent by viewer 1 was significantly
different from that by viewers 2 and 3 but that video viewers 2 and 3 were not significantly different (Table 3.6).

Table 3.6 - Results from Friedman test comparing number of hooks observed per second at sea by the sea observer and video viewers during video counting. (SD): standard deviation; (SO): (Sea observer); (VV1): Video viewer 1; (VV2): Video viewer 2; (VV3): Video viewer 3

<table>
<thead>
<tr>
<th></th>
<th>Average ranks</th>
<th>Sum ranks</th>
<th>SD</th>
<th>Median</th>
<th>Multiple comparisons</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Observer</td>
<td>1</td>
<td>62</td>
<td>0.028</td>
<td>0.398</td>
<td>SO and VV1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Video Viewer 1</td>
<td>3.581</td>
<td>222</td>
<td>0.219</td>
<td>1.206</td>
<td>SO and VV2</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Video Viewer 2</td>
<td>2.5</td>
<td>155</td>
<td>0.193</td>
<td>1.041</td>
<td>SO and VV3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Video Viewer 3</td>
<td>2.912</td>
<td>181</td>
<td>0.225</td>
<td>1.083</td>
<td>VV1 and VV2</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Friedman (Fr)</td>
<td>133.684</td>
<td></td>
<td></td>
<td></td>
<td>VV1 and VV3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>VV2 and VV3</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>p value</td>
<td>&lt; 0.0001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relationship between observation time and hook number was approximately linear (Figure 3.6A). The high coefficient ($R^2 = 0.96$) showed that the speed of hauling operations at sea was almost constant. A lower coefficient was found for all video viewers ($R^2 = 0.762; 0.747$ and $0.707$). This could be caused by different speeds and numbers of video pauses used by video viewers in order to count specimens during video analyses.

Data on the number of hooks hauled per second were divided into two groups (night and day). This aided identification of differences in the at-sea-speed of counting and analysing the video footage at different light levels. Video viewers and at-sea observer data were paired and tested (Figure 3.6B).
Figure 3.6 - (A) Time spent at sea and analysing video footage by the number of hooks per slot. (B) Number of hooks per second viewed by at-sea observer and video viewers by night and day time. Dashed boxes are for day observations and blue boxes are night data. The line segment in the box is the median and vertical lines are lower and upper quartile. 

T-tests indicated that there was a significant difference between day and night for all viewers in the rate of hook viewing (Video viewer 1: $t = 7.52 \ p < 0.001$; Video viewer 2: $t = 6.28 \ p < 0.001$; Video viewer 3: $t = 8.01 \ p < 0.001$). Video viewers observing video recorded by day were able to analyse footage faster than at night. No significant differences were found between night and day hauling during sea observations, showing that vessel hauled hooks at similar speeds during both periods.
3.4.3. Species composition

Catch composition was assessed for every hauling slot by the at-sea observer and the three video viewers. The sea observer and video viewers used the same taxonomic category groups for identification defined by CCAMLR (CCAMLR 2009; 2011). Data was divided into two groups (vertebrate and invertebrate) for analyses. The occurrence of vertebrate categories is presented in Table 3.7, in which a breakdown of the number of specimens counted per group by the sea observer and video viewers during all 62 slots are shown.

The same 9 vertebrate categories were discernible to both the at-sea observer and video viewers. The target species Patagonian toothfish (*D. eleginoides*) was the most frequent vertebrate seen using both methods of observation followed by grenadiers (*Macrourus* spp.) and blue antimora (*Antimora rostrata*). Counts of vertebrate specimens were fairly constant across all video viewers and sea observer. Total *D. eleginoides* counts varied by just 9 specimens (0.83%) between the highest and smallest estimation. Skates had 100% of agreement between all methods of observation. The giant petrel was also identified by both methods but only one specimen was caught (and later released). When analysed as a single group (total), the number of individual counts showed a high level of accuracy across video viewers (video 1 = 99.45%; video 2 = 99.11% and video 3 = 98.83%) and sea observer.

The at-sea observer identified 17 different categories of invertebrate whilst only 12 were recorded from footage seen by video viewers. The recorded catch of invertebrates was low and infrequent during the hauls. The level of agreement of number of specimens caught between video monitoring and at-sea
observation differed substantially. Six categories including sea cucumbers - Holothuroidea (CUX), crabs Lithodidae (KCX); *Neolithodes diomedeae* (NDW), black corals - Antipatharia (AQZ), sea stars - Asteroidea (STF) and basket stars - Euryalida (OEQ) had a high level of agreement between the at-sea observer and video viewers' counts. In total, the at-sea observer counted 131 specimens for these 6 groups against 128, 131 and 130 specimens for video viewer 1, 2 and 3 respectively (Table 3.8).

For gorgonians - Gorgonacea (GGW), sponges - Porifera (PFR), sea anemones - Actiniaria (ATX), hydrocorals - Stylasteridae (AXT), sea lilies – Crinoidea (CWD), stony corals - Scleractinia (CSS), tube worms - Serpulidae (SZS), soft corals - Alcyonacea (AJZ), sea squirts - Ascidiacea (SSX), bryozoans -Bryozoa (BZN) and unknown (UNK), the level of agreement was very poor (Table 3.8).
Table 3.7 - Total number of vertebrate specimens counted by the sea observer and video viewers. **TOP** = *Dissostichus eleginoides* (Patagonian toothfish); **TOP lost** = *Dissostichus eleginoides* dropped at sea during hauling; **GRV** = *Macrourus* spp. (grenadiers); **GRV lost** = *Macrourus* spp. dropped at sea during hauling; **ANT** = *Antimora rostrata* (Blue antimora); **ANT lost** = *Antimora rostrata* (blue antimora) dropped at sea during hauling; **SRX** = Rajiformes (skates) released; **SRX discarded** = Rajiformes kept by vessel; **MBX** = *Macronectes* spp. (giant petrel) released alive.

<table>
<thead>
<tr>
<th></th>
<th>TOP</th>
<th>TOP lost</th>
<th>GRV</th>
<th>GRV lost</th>
<th>ANT</th>
<th>ANT lost</th>
<th>SRX</th>
<th>SRX discarded</th>
<th>MBX</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea observer</td>
<td>954</td>
<td>29</td>
<td>372</td>
<td>41</td>
<td>37</td>
<td>4</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>1456</td>
</tr>
<tr>
<td>Video viewer 1</td>
<td>953</td>
<td>28</td>
<td>363</td>
<td>44</td>
<td>37</td>
<td>4</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>1448</td>
</tr>
<tr>
<td>Video viewer 2</td>
<td>949</td>
<td>26</td>
<td>364</td>
<td>42</td>
<td>39</td>
<td>4</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>1443</td>
</tr>
<tr>
<td>Video viewer 3</td>
<td>945</td>
<td>27</td>
<td>361</td>
<td>44</td>
<td>40</td>
<td>3</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>1439</td>
</tr>
<tr>
<td>Average</td>
<td>99.48</td>
<td>93.10</td>
<td>97.49</td>
<td>-5.69</td>
<td>-4.50</td>
<td>91.67</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>99.1</td>
</tr>
</tbody>
</table>


Table 3.8 - Total number of invertebrate specimens counted by sea observer and video viewers, and percentage of agreement between video viewers (average) and at-sea observer counts. CUX = Holothuroidea (Sea cucumbers); GGW = Gorgonacea (Gorgonians); PFR = Porifera (Sea sponges); KCX = Lithodidae (Crab); NDW = Neolithodes diomedeae (Antarctic king crab); AQZ = Antipatharia (Black corals); ATX = Actiniaria (Sea anemones); AXT = Stylasteridae (Hydrocorals); CWD = Crinoidea (Sea lilies); CSS = Scleractinia (Stony corals); OEQ = Euryalida (Basket stars); STF = Asteroidea (Sea stars); SZS = Serpulidae (Tube worms); AJZ = Alcyonacea (Soft corals); SSX = Ascidiacea (Sea squirts); BZN = Bryozoa (Lace corals); UNK = Unknown invertebrate.

<table>
<thead>
<tr>
<th></th>
<th>CUX</th>
<th>GGW</th>
<th>PRF</th>
<th>KCX</th>
<th>NDW</th>
<th>AQZ</th>
<th>ATX</th>
<th>AXT</th>
<th>CWD</th>
<th>CSS</th>
<th>OEQ</th>
<th>STF</th>
<th>SZS</th>
<th>AJZ</th>
<th>SSX</th>
<th>BZN</th>
<th>UNK</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea observer</td>
<td>54</td>
<td>42</td>
<td>16</td>
<td>50</td>
<td>15</td>
<td>3</td>
<td>6</td>
<td>14</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>21</td>
<td>247</td>
</tr>
<tr>
<td>Video viewer 1</td>
<td>54</td>
<td>13</td>
<td>4</td>
<td>50</td>
<td>15</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>Video viewer 2</td>
<td>55</td>
<td>8</td>
<td>2</td>
<td>50</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>Video viewer 3</td>
<td>54</td>
<td>5</td>
<td>2</td>
<td>50</td>
<td>15</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>Average agreement (%)</td>
<td>-0.6</td>
<td>20.6</td>
<td>16.7</td>
<td>100</td>
<td>100</td>
<td>7.8</td>
<td>7.1</td>
<td>11.1</td>
<td>0</td>
<td>91.7</td>
<td>73.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26.9</td>
<td>60.59</td>
<td></td>
</tr>
</tbody>
</table>
3.5. DISCUSSION

Electronic monitoring systems have previously been used on bottom longliners to identify target and bycatch vertebrate species (McElderry et al., 2003; Ames et al., 2007). Previous studies have dealt mainly with EM as an autonomous method, collecting fishing data and surveillance on fishing vessels as an alternative to human observers (Ames, 2005; Evans and Molony, 2011; Stanley et al., 2011; Kindt-Larsen et al., 2011). This study investigates the application of a dependent EM system operated directly by the at-sea observer as a tool to assist with daily tasks.

At-sea observers have an important role collecting scientific fishing data on toothfish longliners. Conservation Measure (CM) 41-02/2011 (see CCAMLR, 2013) states that toothfish licensed vessels must deploy at least one international scientific observer. Benoit and Allard (2009) found that the deployment of observers on all fleets minimise bias during catch composition estimations and increase regulatory compliance. However, observer bias could be considerable as it is difficult to cover all fishing activities on the vessel.

In CCAMLR Subarea 48.3 all vessels operate 24 hours a day making the observation of all fishing operations unfeasible by the at-sea observer. These observers follow the sampling requirements protocol established by CCAMLR (Sabourenkov and Appleyard, 2005).

A daily sampling routine has been adopted where all observers should divide their time between different tasks during hauling and setting operations. Furthermore, the capacity of the EM in recording long hours without any disturbance, make it possible for the entire haul to be recorded and analysed in
contrast to human observers who need breaks (for safety). Furthermore using the EM system, observers are able to monitor the fishing activity during bad weather and increase coverage time, potentially reducing the chances of data bias.

Setting operations are a major component of a longline operation and it is a daily task on a fishing vessel. Vessels try to set the lines at particular spots to maximise their catches. According to Varty et al. (2008), setting is a major problem for bird populations as this component of the fishery is the biggest source of mortality of sea birds. CCAMLR classified Subarea 48.3 as high risk area for bird interactions and setting observations, and as such requires that all sets are, at least partially, observed. At-sea observers are required to verify the deployment of the streamer line, light conditions on the vessel, use of the correct weight regime, night setting and the discard of offal. However, this is rarely achieved by at-sea observers due to lack of time and fatigue. Setting can last all night due to the high number of hooks deployed and navigation time spent between setting locations.

Ames et al. (2005) studied the use of an EM system on monitoring streamer lines during settings and concluded that EM could be used to monitor deployments of the bird deterrent including its effectiveness and the aerial extent of the streamer during daylight. In Subarea 48.3, CCAMLR does not require collection of performance data. Settings only take place at night which makes the collection of this kind of data impractical. However our observations showed that all CCAMLR requirements for setting operations can be, and were, monitored successfully using the EM system.
There are obvious benefits for the at-sea observer using the EM system to monitor settings. Footage from all 3 setting cameras deployed could be viewed simultaneous giving a considerable time saving on this duty. The viewing ratio time found was 0.11 of real time (observations at sea). Ames et al. (2005) found much higher rates showing that video viewers were spending much more time looking at the footage. However, video viewers were assessing performance data including measurements of the streamer, which contrast with the present study in which no measurements were taken. Moreover, it is also important that recorded images could be easily used by fishery inspectors in case of any breach of rules during settings.

The comparative analyses of the hauling events showed substantial time savings between at-sea observer and video viewers. That is, video viewers were able to drastically reduce the time required to observe hauling when compared with the at-sea observer. When slots observed at sea were compared with video viewers’ time, it showed that the video method requires less time to analyse the same number of hooks (Figure 3.5). Viewer 1 was the fastest which might be attributed to the greater level of experience in the field followed by viewer 3 and 2. However, viewer 3 had much less experience than video viewer 2 and yet analysed the footage faster. This could be due to the low number of species typically found in the toothfish fishery where, potentially, video viewers could be trained without field experience to still be able to identify and count the species.

For video viewer 1, 2 and 3, the average time ratio was 0.34, 0.38 and 0.37 of real time. These low ratios suggest there can be considerable time savings in conducting line observation through EM. This supports previous studies on
longliners (McElderry et al., 2003; Ames, 2005; Ames et al., 2007) which also concluded that EM systems were able to save time when compared with hauling at-sea observations. The average values of 0.78 and 0.66 found by those authors are higher than reported here, however caution is needed when comparing video viewer time ratios across different fisheries. EM can supplement at-sea observations by providing extra coverage which could, for example, allow accurate assessment of bird mortality (currently CCAMLR extrapolates from dead birds seen in the observed period).

Longline methods have a similar principle anywhere in the world (hooks being hauled) but hook spacing and hauling speed differ. The ratio time of observations will depend on such factors plus the number of species/specimens caught by the fishing gear. Also, similarities of shape and colour of the catch will alter the duration of the identification process and determine how easy it is. Consequently, comparison of ratio time between different fisheries should be conservative.

No significant difference was found between hook haul speeds at sea from day to night suggesting that retrieval speed varies little across a diurnal cycle. In contrast, video viewers’ data differed significantly in hook speed rate between night and day hauls. This is likely to be explained by video footage recorded at night time having less resolution causing video viewers to reduce the play speed in order to count and identify the catch to similar levels of accuracy.

The typical longline configuration in Subarea 48.3 has hook spacing ranging from 1.4-1.6 meters. They were hauled one by one making identification of fauna through video imagery or sea observation a straightforward task. Correct identification and counts of fauna are considered the most important
criteria for successful implementation of the EM system. Previous investigations have agreed that the system has strong potential for gathering information on vertebrate species in terms of count and identification (Ames, 2005; Ames et al., 2007; McElderry, 2008; Pria et al., 2008; Stanley et al., 2011; Kindt-Larsen et al., 2011). Levels of efficacy in these studies varied between fisheries and areas.

In Subarea 48.3, the EM system collected catch composition information very effectively for the vertebrate groups. The difference of 0.83% from the highest and smallest estimation of the target species shows a high level of agreement between the methods investigated. Video viewers and the at-sea observer found the same 9 categories, in which 3 of them had 100% of agreement in counts.

Observations in the current study showed that the number of species caught by the fishery was low when compared with other bottom longliner fisheries (McElderry et al., 2003; Ames, 2005). According to Collins et al. (2010), previous investigations into catch on longliners in the same area also found a low variety of catch species composition. The predominant species were toothfish, grenadiers, Antimora rostrata and skates. In the current study, no other fish species were found. These species have different body shapes and colours which facilitate sea observer and video viewer identification.

Numbers of skate specimens counted were identical. The high level agreement for this group could be explained by the CM 33-03-2011 (see CCAMLR, 2013) adopted in the in Subarea 48.3 fishery. This protocol states that fishing vessels have to stop the line in order to individually access the heath conditions of these animals. Specimens are released or kept, depending on their state of health.
When the line is stopped, the specimen is easily recognised through video footage or by the sea observer. Moreover, South Georgia skates could be easily identified at species level due to the low number of species (of skates) present in the area and the distinct body marks. There are 3 species caught by the longline fishery in the area (Endicott and Agnew, 2004) which are the same species found in the present study.

The at-sea observer identified 17 different invertebrate groups, whilst only 12 were identified by the video viewers. Direct observation also led to more specimens being spotted than by video viewers. There was partial agreement on invertebrate identification and count among the groups. Six groups (CUX, KCX, NDW, AQZ, OEQ and STF) were observed to a high level of accuracy by the video system; ~100% of accuracy counts.

Fishing vessels are required by CCAMLR (CM 41-02-2011), to release all live (lithodid) crabs caught during hauling. As happens with skates, the line is stopped making identification an easy task. In this study, no difference was found between the at-sea observer and video viewers in the count for all crab species. The same was observed for AQZ, however just 3 specimens were counted. CUX, OEQ and STF also had high accuracy. The high level of agreement for these groups is likely to be due to the vibrant colour and the large size of specimens, assisting observation of the video footage.

In contrast, the level of agreement between both methods of observation in the 11 other groups was very poor, varying from the lowest with 0% (CSS, SZS, AJZ, SSX and BZN) to the highest with 27.8% (ATX). The poor identification and count of invertebrates of these groups showed a limitation of the system. Identification and tally of these organisms during line observation at sea is a
very hard task for scientific observers. Bycatch is easily mistaken for old baits (squid and sardine) left on hooks or small stones brought onboard. Size seems to be the main factor which could drive this difference of success between invertebrates identification. The elevated number of “unknown” specimens recorded during line observation at sea confirmed the complexity to identify small invertebrates.

Increasing the optical zoom of one camera (increasing focal length) in the hauling area could increase the accuracy in invertebrate count and identification. Thus, this might decrease the speed of viewing the footage as the viewing field is narrowed.

Vulnerable Marine Ecosystems (VMEs) have been monitored in CCAMLR Subarea 48.3. Fishing vessels were asked to retain and report invertebrates caught as bycatch. The invertebrate bycatch should be placed by fisherman in containers for later assessment by the observer. This is used to report the amount of VME data (taxa, number and total weight) and consequently data gathered from this method could be used instead of direct observations of invertebrates on the vessel’s deck.

3.5.1. System assessment

During the present study, the electronic system recorded the fishing activities from all setting and hauling events without major issues. The trustworthiness of the system was also demonstrated by other authors including Ames et al. (2007) and McElderry (2008).

Minor running problems appeared during the study such as condensation or water drops on the lenses, which were promptly fixed prior to haul or setting
operations. Constant checks by the at-sea observer showed that, if well maintained, it is possible to record all fishing activities. Data handling and set up of cameras are easily achievable with prior observer training. Non-autonomous EM systems are much cheaper to install than autonomous equivalents. The total cost of the entire system in the current study was around US$ 4,200.

The practicalities of the toothfish fishery such as the (considerable) distance from commercial harbours, the high autonomy of the fishing vessels (up to 5 months at sea) and the need for fish biological data collection (length, sex and maturity) make this fishery unsuitable for autonomous EM system. The actual observer scheme adopted is presently the only way to have a wide range of different type of data collected, however the scheme still has margin for improvement. The full implementation of an EM system is recommended to the fishery as a tool to be used for observers onboard. Moreover, the high price paid for this fish species makes the EM cost just a small fraction of the fishery money involved.

3.6. CONCLUSION

The demand on the time of at-sea observers has increased in recent years in the South Georgia fishery, which highlights the need to develop tools or methods to optimise the time spent by the at-sea observer on data gathering.

The EM system installed in this study proved to be a reliable and useful tool. It provides low-cost, simple and high quality independent data on setting and hauling operations. Most of data acquisition requirements during hauling and setting can be easily derived from the footage recorded by the system. Settings
were capable to be monitored by the system generating a considerable reduction of time spent at sea observations.

Hauling observations also showed an optimisation of time with high rates of vertebrate identification between sea observer and the EM. Identification and invertebrate counts showed inconsistency of results; a very high accuracy of identification was found for 6 invertebrate groups while 11 groups had low accuracy. Visualisation of small specimens by video cameras proved to be more challenging than direct observation. However, alternatives for collection of invertebrate data through the VME protocol could deliver the data requirements.

The system is capable of recording good quality footage that could be used for auditing and surveillance by fishery inspectors. It gives also an important tool for observers’ coordinators to monitor the sea observer, preventing them from misreporting, manipulating or inputting fake data on reports and databases. It could be used as a quality control of the data gathered.
CHAPTER FOUR
4. NEW INSIGHTS OF DEEP BENTHIC INVERTEBRATE FAUNA AT SHAG ROCKS, SOUTH GEORGIA USING BOTTOM LONGLINE AS A SAMPLING TOOL

4.1. ABSTRACT

South Georgia is a large, old and isolated oceanic archipelago in the Atlantic sector of the Southern Ocean. It is surrounded by a wide continental shelf which is highly productive and rich in biodiversity. Most of the ~1450 species described to date live on the seabed, many are vulnerable as they are rare, endemic or at the edge of their geographic ranges. Yet, current knowledge of the taxonomic diversity and distribution patterns of such biota are still quite poorly known. The longlining fishing of the region has an incidental catch of benthic invertebrates and provides a more frequent and widespread source of samples than scientific vessels, in locations where scientific apparatus would be difficult to deploy (such as areas with complicated 3D bottom topography). In 2011, during the toothfish fishing season a series of fishing lines from two different fishing systems (autoline and Spanish system) were set on the shelf and deep slope of Shag Rocks, South Georgia. An underwater camera was deployed on the fishing lines and the films from these were used to describe the areas sampled. Bycatch collected onboard were classified as indicator taxa of vulnerable marine ecosystems (VMEs) and general invertebrates. Both groups were counted and classified to the lowest taxonomic level possible. In total 199 morphotypes were identified, of which 95 were identified to species level, including one species of Holothuroidea (Laetmogonidae) that was previously undescribed. Accumulation curves for the different taxonomic groups did not approach asymptote. Examination of historical records and biodiversity databases shows that 28 of those found represented new records for the South
Georgia area. Taxonomic composition analyses showed differences between areas and depth but not between the autoline and Spanish system.
4.2. INTRODUCTION

The wide continental shelf and slope around the archipelago of South Georgia supports rich and diverse benthic communities, which include many endemic, rare (Barnes, 2008; Griffiths et al., 2008; Hogg et al., 2011) and edge of range species (Barnes et al., 2009a; 2011). The vast majority of all known biodiversity at South Georgia (as with other Southern Ocean locations) lives on the seabed (see Hogg et al., 2011).

The nature of the benthic fauna around South Georgia is poorly characterised but seems to be quite Antarctic in character (Griffiths et al., 2008). Antarctic sessile deep sea fauna are associated with high complexity benthic communities as they provided structural habitat for many different species. Many of these benthic communities have been considered as Vulnerable Marine Ecosystems (VME) due their fragility, slow growth, longevity and late maturity (see CCAMLR, 2009; Parker et al., 2009).

South Georgia is a global hot spot for benthic biodiversity (Barnes et al., 2011; Hogg et al., 2011) and an important site for a bottom longline fishery. It targets the Patagonian toothfish (Dissostichus eleginoides), which is a large, long-lived and demersal fish, endemic to the Southern Hemisphere (Collins et al., 2010). Two longline methods are deployed in the fishery, the autoline (AU) and Spanish system (SP). Fishing normally takes place on the continental shelf and slope at depths from 700 to 2250 m. In 2014 nearly 9.38 million hooks were set by six vessels (see chapter 2).

Barnes et al. (2011) and Hogg et al. (2011) suggest that to date fisheries vessels are probably responsible for a dominant proportion of all samples ever taken around South Georgia, yet most of the information (collected and
available) from such catches relate to commercial species (recent bycatch records are generally only listed at higher taxonomic levels).

Although scientific expeditions have made collections using a variety of apparatus for more than a century (Fogg, 1992), it is clear from both the very patchy distribution of known samples and the non-asymptotic rate of new record reports that the benthos is far from well known. Fishing vessels undertake more frequent and longer visits to the region than scientific research vessels likely visit a greater variety of locations, yet, to date, remain largely untapped in terms of benthic biodiversity input.

In the last decade there has been a concerted effort to collate records of benthic samples and species into open access databases (see www.SCAR-MarBIN.be). Recently a Darwin Initiative project, between British Antarctic Survey (BAS), GSGSSI and the Shallow Marine Surveys Group of the Falkland Islands worked to collate available data with georeferenced records into a single database (see Hogg et al., 2011).

The data currently available on benthic fauna brought up by longline deployments shows that the most abundant bycatch group are those termed bioconstructors. Bioconstructors include corals, hydrozoans, sponges, bryozoans, polychaete worms and other sessile taxa which build hardened 3-dimensional structures on the seabed. Recent work, on material preserved for further study from South Georgia suggested that octocorals, especially the family Primnoidae form the majority of the bycatch (Taylor, 2011). To date these remain the only group from which detailed biodiversity information has been collected using longlines around South Georgia.
There is an urgent need for a high quality, georeferenced assessment of seabed biodiversity in this region. Increasing knowledge and understanding of South Georgia’s benthic biodiversity is a key factor for ecosystem health and stability that are likely to be important to maintain a sustainable fishery. These cannot be assessed without knowledge of the structure, organisation and processes driving and maintaining benthic biodiversity.

In addition to fisheries for toothfish, icefish and krill, the region is one of the sites most frequently visited sites by tourist ships in the Southern Ocean. Fishing vessels and cruise ships have the potential to carry alien species to the region. Additionally, even within West Antarctic seas, the waters around South Georgia have been warming anomalously throughout the last few decades – and thus there are multiple potential stressors for the rich seabed biodiversity there.

The present study aimed to investigate the type and quality of biodiversity information that can be gained from observations of longlining. More specifically how it can aid science concerning the structure of benthos in a specific area around Shag Rocks, South Georgia, by helping to understand this rich and complex environment. Key questions include: How does bycatch differ across depth and sites? Do different fishing systems catch the same groups of invertebrates? The work also provides new information on range distribution of species of Porifera (Demospongiae), Bryozoa (Gymnolaemata), Cnidaria (Hydrozoa) and Echinodermata (Holothuroidea) caught as bycatch in South Georgia.
4.3. MATERIAL AND METHODS

4.3.1. Study area

The study area around Shag Rocks, South Georgia has been previously described in detail in chapter 1.

4.3.2. Sampling methodology

A total of 34 fishing lines (17 AU and 17 SP), each containing approximately 3550 hooks and measuring 5400 m were set in 3 different, well known toothfish fishing grounds around Shag Rocks, NW of South Georgia (Figure 4.1) during the 2011 toothfish season, using two different fishing vessels.

![Figure 4.1 - Map of the locations of set trials deployed around Shag Rocks from two different fishing vessels and different fishing systems. (Z1, Z2 and Z3 are fishing zones; AU – Autoline fishing system SP – Spanish fishing system).](image)

The Autoline system was deployed from the UK registered fishing vessel Argos Froyanes (Figure 4.2A), which is of Norwegian construction, 52.55 m in length, has a gross tonnage of 1352 and carries 24 crew. The Chilean registered vessel Antarctic Bay (Figure 4.2B) deployed lines using the Spanish system.
She is 44 m in length, gross tonnage of 985, Chinese construction and room for 44 crew. Deployments followed normal fishing gear configuration and operations were described in the chapter 2.

The lines were deployed in 3 different fishing zones (Z1, Z2 and Z3). The first area (Z1) is situated northwest of Shag Rocks and 3 lines from each system (SP and AU) were set at depths of 500, 1100 and 1500 m and further two lines of AU at 750 m. Fishing zone Z2 was situated 70 km East-Southeast of Z1 and 3 lines of each system were set at 500 and 750 m. At Z3, 2 lines only of the Spanish system were deployed at a depth of 700 m, 50 km East-Southeast of Z2 (Table 4.1). These depths were chosen by the fishing master on the basis of previous success in toothfish catches.

All trials were carried out during the normal fishing activity of each vessel and differences in number of lines deployed per zone and depth for both systems are due to the fishing circumstances. Due to the constant movement of each vessel between different fishing areas and the short time spans available, sampling of both gears at all proposal depths (500, 750, 1100 and 1500 m) and fishing zones (Z1, Z2 and Z3) were not feasible.
Table 4.1 - Longline trials deployment details. **LL type:** Longliner type (AU) autoliner and (SP) Spanish system; **Mid lat:** middle latitude point of the line; **Mid lon:** middle longitude point of the line; **Soak time:** difference between the time (hours) from the end of set and start hauling; **Cam set:** camera deployed (Y) yes and (N) no; **Cam rec:** camera worked and useful footage was recorded.

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<td>3387</td>
<td>05:45</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>
4.3.3. Sampling processing

All benthos bycatch were collected by the crew during line retrieval and carefully placed into marked containers according to the line. Samples were removed from the line by cutting the snood before the specimen came into contact with the roller, thus minimising any damage (Figure 4.3).

![Figure 4.3 - Detail of a hooked specimen with a cut snood (A) collected during hauling and samples placed in marked plastic containers (B).](image)

Once hauling was finished, samples were removed from the hauling room and sorted to the lowest taxonomic level practical. Specimens were counted by taxonomic groups following the CCAMLR ID guide (CCAMLR, 2009). Due to the low amount of bycatch on most of the line segments, weight and volume of the samples were not recorded.

When possible species were identified onboard, but when this was not feasible photos and samples were taken for later identification. All specimens (whole or fragments) belonging to VME groups (CCAMLR, 2009) were collected and placed in 90% ethanol or frozen (-20°C) and shipped to BAS. In the laboratory, they were separated by taxonomic group and sent to taxonomic experts around the world in attempt to identify them to the lowest level possible (Table 4.2).
All samples were donated to the institutions which received them. Other groups that were found in very low abundance such the Alcyonacea (soft corals), Antipatharia (black corals), Zoantharia (encrusting anemones) and Brachiopoda (lamp shells) were simply classified by the author in morphotypes. Two groups that contained 209 specimens of Gorgonacea and 158 Stylasteridae were not identified by taxonomists. The first group were not identified and the hard corals were lost in the post. For the full list of morphotypes and species identified please see list of identification Annex 1.

Table 4.2 - List of taxonomist experts and institutions where samples were sent. List of each taxa identified to differing taxonomic levels is given in Annex 1.

<table>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Taxonomist</th>
<th>Institution</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holothuroidea</td>
<td>Dr. Mark O’Loughlin</td>
<td>Museum Victoria – Australia</td>
<td>Identified</td>
</tr>
<tr>
<td>Cnidaria, Hydrozoa</td>
<td>Dr. Alvaro Cantero</td>
<td>Universidad de Valencia - Spain</td>
<td>Identified</td>
</tr>
<tr>
<td>Echinodermata</td>
<td>Dr. Chester Sands</td>
<td>BAS - Cambridge, England</td>
<td>Identified</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Dr. David Barnes</td>
<td>BAS - Cambridge, England</td>
<td>Identified</td>
</tr>
<tr>
<td>Cnidaria, Actiniaria</td>
<td>Dr. Estefania Rodriguez</td>
<td>American Museum of Natural History New York, United States</td>
<td>Identified</td>
</tr>
<tr>
<td>Porifera</td>
<td>Rachel Downey</td>
<td>Forschungsinstitut und Naturmuseum Senckenberg - Frankfurt am Main, Germany</td>
<td>Identified</td>
</tr>
<tr>
<td>Scleractinia &amp; Stylasteridae</td>
<td>Dr. Marcelo Kitahara</td>
<td>Universidade São Paulo - Brazil</td>
<td>Lost/post</td>
</tr>
<tr>
<td>Cnidaria, Gorgonacea</td>
<td>Dr. Michele Taylor</td>
<td>University of Oxford - UK</td>
<td>IDs not returned</td>
</tr>
<tr>
<td>Serpulidae</td>
<td>Dr. David Barnes</td>
<td>BAS - Cambridge, England</td>
<td>Identified</td>
</tr>
</tbody>
</table>

4.3.4. Camera deployments

In order to investigate the composition and biological coverage in situ of the study site, the Benthic Impacts Camera System (BICS, Figure 4.4) designed by the Australian Antarctic Division (Kilpatrick et al., 2011) was deployed initially to record the movements and impacts of the fishing line on the seabed. In this study, no attempts were made to investigate the impact/movements of the gear
on the seabed. The main purpose of camera deployments in the current study was to see whether this new tool and the fishing industry, could be used to gain insights into benthic biodiversity composition to compliment scientific studies.

The camera system was deployed on 15 fishing lines aiming to record at least two sets of footage (one from each gear) from the same depth/area. Due a series of technical faults footage was successfully only captured from 8 deployments (Table 4.1) covering all areas/depth. Just in the area Z1 at 500 m, footage was recovery from a Spanish and autoline system deployment.

Figure 4.4 - Detailed diagram of the Benthic Impacts Camera System attached to the fishing gears during the trials around South Georgia (From Kilpatrick et al., 2011).

Video data was downloaded to an external hard drive and analysed later using Adobe Premiere Pro®. Viewing set up and procedures followed Davies et al. (2001). Footage from all sets recorded was observed by the author in slow motion using freeze-frame as required aiming to count and identify as many species as possible. During hauling, the camera recorded a series of moving images of the seabed where elements of the benthos structure could be observed (Figure 4.5).
To standardise the viewing/sampling area for all deployments, 4 transects (two on each side) with same size were drawn parallel to the fishing line on the footage (Figure 4.5). Benthic fauna on these transects were identified and counted. Bottom types (e.g. fine silt/sand with pebble/drop stones) and biological coverage were scored and reported using a scale (Table 4.3). Counts and identification of benthic fauna using the camera system are limited due the quality of footage. Estimates of benthos observed using the system here are likely to be conservative, however it gives a general idea of the site where the line was set.

Figure 4.5 - South Georgia seabed as seen from camera deployment on fishing line. (A) Fine silt sediment bottom with Serpulid sp on a pebble – black lines are transects; (B) Fine silt sediment with whip corals (Cnidaria) on a small drop stone.

Table 4.3 - Scale used to classify seabed biological coverage.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 5%</td>
</tr>
<tr>
<td>2</td>
<td>6 - 15%</td>
</tr>
<tr>
<td>3</td>
<td>16 - 30%</td>
</tr>
<tr>
<td>4</td>
<td>31 - 50%</td>
</tr>
<tr>
<td>5</td>
<td>51 - 75%</td>
</tr>
<tr>
<td>6</td>
<td>76 - 100%</td>
</tr>
</tbody>
</table>
4.3.5. Data analysis

Analyses of variance (one-way ANOVA, with significance threshold of $p = 0.05$) were performed on total abundance of specimens counted per transect, on video analyses divided by depth and areas. When necessary, the dependent variables were transformed to fulfil the assumptions for parametric testing (normality and homogeneity of variance). Tukey's post hoc test was used to detect differences among groups. Statistical tests and charts were performed using the software R (R Core Team, 2016) and Minitab® 15.

The influence of fishing system (AU vs SP) on benthic invertebrate bycatch taxon composition was investigated by subjecting the data to Multivariate Analysis using PRIMER v6 software (Clarke and Gorley, 2006).

The Bray-Curtis Similarity Index was applied to the presence/absence of biological data, and a Non-metric Multidimensional Scaling (nMDS) was used to visualise data structure and explore any sample clustering and levels of similarity between samples. Significance tests were performed using ANOSIM (Clarke, 1993).

In order to analyse potential differences between bycatch taxon composition between fishing areas (Z1 x Z2) and depths (500, 750, 1100 and 1500 m), non-metric Multidimensional Scaling (nMDS) analyses were carried out. The relationships illustrated in the nMDS plot were tested for significance according to relevant factors using ANOSIM on Bray-Curtis similarity measures. When there were differences between groups of samples, the SIMPER test was applied, which identifies the main species that have contributed to significant differences between groups.
Similarity in composition at species level was investigated between bathymetric areas (shelf and slope) and fishing areas (Z1 X Z2) for the most diverse groups identified by taxonomists (Bryozoa, Porifera and Hydrozoa) using ANOSIM (p <0.05) and SIMPER tests (on Bray-Curtis similarity scores).

When Area Z3 data was included in preliminary multivariate analyses the low number of replicates (just 2 fishing lines) drove stress levels of nMDS beyond acceptable limits. Thus Z3 data were then omitted to bring nMDS stress limits below 0.25 (the critical level at which the technique is considered a valid representation of multidimensional space in 2D). In contrast to the n=2 of Z3, Areas Z1 and Z2 had 20 and 12 fishing lines respectively.

Species accumulation curves were generated for each study depth (500, 750, 1100 and 1500 m) and pooling all depths using PRIMER.

4.3.6. Geographic range

Range distribution of the species identified by experts was matched against existing information in order to determine species range extensions and depths of occurrence for the study area. These data were collated using a series of online databases such as the World register of marine species (www.marinespecies.org), Scientific Committee on Antarctic Research marine biodiversity information network (www.SCARMarBIN.be) and in published scientific papers. Scientific nomenclature was checked according to the World register of marine species (WoRMS) in January of 2016. Species found to have new extension range were selected and maps were generated using the software ArcGIS 13 were new and existing information were plotted.
4.4. RESULTS

4.4.1. Characterisation of the benthic habitat at the study sites

**Area 1 (Z1) - 500 m:** Two successful footage sequences of each fishing gear (AU and SP) were recovered from this area. The site was on the continental shelf and both video footage sequences observed showed that the benthic habitat was characterised by compacted sand with pebbles and many drop stones. Biological coverage was estimated to be 51 to 75% around the autoline deployment (Figure 4.6) and between 31 to 50% for the Spanish system. The biodiversity seen in both deployments were characterised by large specimens except for part of the footage from the Spanish system, where a large area was observed with similar taxonomic faunal composition, except being much smaller in size and reduced abundance (Figure 4.7F).

For both deployments the most frequent fauna observed during video footage at 500 m (Z1) were colonies of octocorals, such as Primnoidae and Plexauridae (gorgonians), *Stereochinus* (Echinoidea) sea urchins, hydrocorals (Stylasteridae), crabs (Lithodidae) and glass sponges (Hexactinellida), (Figure 4.6A – B; Figure 4.7G – H). Figure 4.6C - D and Figure 4.7G – H show part of the bycatch collected onboard. Fauna observed onboard were similar in both deployments, dominated by octocorals, followed by Stylasteridae and Porifera. No *Stereochinus* sea urchins were collected by fishing gear. Bycatch brought onboard also included specimens of brittle stars (Echinodermata, Ophiuroidea) and feather stars (Comutulida) that were not seen during camera observations.
Figure 4.6 - (A-B) Pictures of line deployment at 500 m on Z1 and (C-D) pictures of bycatch collected onboard. (1) Porifera Hexactinellid; (2,4,6,11) Gorgonacea; (3,7) Styloasteridae; (5) Sterechinus on a Gorgonacea; (8) Dead Stylasteridae on a drop stone; (9) Sterechinus on a Stylasteridae; (10) *D. eleginoides*; Echinodermata (13) Ophiuroidea and (12) Comatulida (Feather stars).

Figure 4.7 - (E-F) Pictures of line deployment at 500 m on Z1 and (G-H) pictures of bycatch collected onboard. (1,10) Porifera Hexactinellid; (2,3,4,5,8) Gorgonacea; (6,9) Styloasteridae; (7) Sterechinus sea urchin; (2) Ophiuroidea.
**Z1_750 m:** At this site the camera only recorded the landing and just 1 frame of this was available for analysis. The profile was flat and the substrate was mud with few pebbles and couple of small drop stones. Biological coverage was estimated to be 0 to 5%. Dominant fauna observed on the underwater photo frame was Serpulidae worms on pebble or drop stones, small Stylasteridae (Figure 4.8A). Figure 4.8B and C show part of bycatch collected onboard including all groups cited above and an exoskeleton of a dead black coral.

![Picture of line deployment at 750 m on Z1 and (B-C) pictures of bycatch collected onboard.](image)

Figure 4.8 - (A) Picture of line deployment at 750 m on Z1 and (B-C) pictures of bycatch collected onboard. (1,3,4) Serpulidae worms on a pebble; (2) Stylasteridae on a pebble, (5) an unknown fish and (6) a burrowing sedentary Polychaeta and a (7) dead black coral.

**Z1_1100 m:** This site, as at 750 m, was mainly flat and muddy with a few pebbles and some drop stones. Biological coverage was estimated to be
between 5 and 15%. Dominant fauna on the footage were large colonies of Primnoidae followed by Serpulidae worms and Stylasteridae (Figure 4.9A - B). Other groups observed but much less frequently included Asteroidea (sea stars) and Holothuroidea (sea cucumbers). Figure 4.9C and D show part of bycatch collected onboard.

Figure 4.9 - (A-B) Pictures of line deployment at 1100 m on Z1 and (C-D) pictures of bycatch collected onboard. (1,3) Stylasteridae on a small drop stone; (2) Serpulidae worms on a pebble and (4) Primnoidae

Z1_1500 m: This site was located on the deep slope and the substrata there was sand with pebbles and some drop stones. Biological coverage was estimated to be between 5 and 15% across the site. Dominant fauna counted on the footage from there was Stylasteridae. Primnoidae were mainly seen on drop stones and pebbles and the size of specimens were predominantly small (compared with those at the site at 500 m (Figure 4.10A and B). Holothuroidea,
Asteroidea, Demospongiae (silicious sponges) and Serpulidae worms were also seen in the footage but in much lower density. Figure 3.10C and D show part of the bycatch collected onboard including the stony coral (Scleractinia), which was not observed in the footage.

Area 2 (Z2)

Z2_500 m: This site showed strong patchiness along the camera track. During the first 20 m the bottom was flat with compacted sand and peddles. Biological coverage was scant (0 to 5%), limited to Serpulidae worms and small hard structures thought to be Stylasteridae. Once the camera started to move sideways, the bottom structure became different, alternating between flat and
bumpy. Drop stones of a wide range of sizes were frequently observed and sometimes edges of bedrock were exposed under the sediment. In this area, biological coverage increased to between 15 and 30%. Benthic fauna was dominated by large Stylasteridae, octocorals Primnoidae, Sterechinus sea urchins, Plexauridae, Anthothelidae, Serpulidae worms, Hexactinellida (glass sponges), Euryalida, the brittlestar *Gorgonocephalus chilensis* and Lithodidae crabs (Figure 4.11A and B). Figure 4.11C and D show part of bycatch collected onboard.

![Images of bycatch](image)

Figure 4.11 - (A-B) Pictures of line deployment at 500 m on Z2 and (C-D) pictures of bycatch collected onboard. – a (1) Serpulidae worms on a pebble; (2) small Stylasteridae; large drop stone containing various (3) Gorgonacea, (7) Stylasteridae and a (4) Sterechinus sea urchins; (5) Lithodidae crab; (6) Porifera,

**Z2_750 m:** The area observed was mainly mud with biological coverage of 0 to 5%. The profile was flat with occasional pebbles and drop stones. Groups frequently observed during video analyses were Primnoidae on drop stones,
Serpulidae worms on the pebbles, Lithodidae crabs, small Stylasteridae and burrowing sedentary Polychaeta (Figure 4.12A and B). Figure 4.12C and D show part of bycatch collected onboard.

Figure 4.12 - (A-B) Pictures of line deployment at 750 m on Z2 and (C-D) pictures of bycatch collected onboard (1) Lithodidae crabs; (2) Gorgonacea (whip corals) and Serpulidae worms on a drop stone; (3) small Stylasteridae; (4) small Scleractinia and (5,6) Primnoidae.

Area 3 (Z3)

Z3_750 m – This deep shelf site was covered by sand with pebbles and some very large drop stones. Biological coverage ranged from 5 to 15%. Taxa observed to be dominant were Primnoidae, followed by Stylasteridae, Serpulidae worms, Porifera and one registered of Asteroidea (Figure 4.13A and B). Figure 4.13C and D show part of bycatch collected onboard.
4.4.2. Underwater camera counts

Footage of 4 autoline and 3 Spanish system line deployments were recorded and analysed. Groups counted and identified on the footage as VME indicator were summed and the means per transect are shown in Figure 4.14. An Anova one-way test showed significant difference in abundance of benthos among depths and areas ($F = 118.23; p < 0.001$). Post hoc comparisons using the Tukey test indicated that the mean VME counts are not statistically different from set 2 and set 5 ($p = 0.99$), set 2 and set 7 ($p = 0.26$), set 3 and 4 ($p = 0.23$) and finally from set 5 and 7 ($p = 0.64$). All other combinations were found to be statistically different ($p < 0.01$).
Sediment type was plotted against the counts per transect and it showed that sand with pebbles and drop stones (DS) contained the highest amount of VME specimens per transect followed by sand, pebble, fine silt with drop stones, fine silt with pebble and finally fine silt where no VME specimens were counted (Figure 4.15). The increase in the number of VME specimens when drop stones were present can be seen by the high standard deviation on the fine silt /DS and sand pebble/DS.
4.4.3. Similarity of benthic fauna at different areas and depths

At least 199 benthic taxa were identified [to morphotypes] as bycatch from the 34 study line deployments (Table 4.1) of autoline and Spanish system gear. To evaluate the selectivity, in terms of taxa composition caught by each gear, a Bray–Curtis similarity test was applied supplemented by a nMDS (non Metric Multi Dimensional Scale) plot for the presence and absence dataset of all taxa found (Figure 4.16).

![Figure 4.16 - Non metric multidimensional scaling (nMDS) ordination based on Bray-Curtis similarity of the autoline (AU) and Spanish system (SP) bycatch taxa composition.](image)

No statistically significant difference was found between benthos taxa caught between gears ($p = 0.33; R = 0.008$). The low R value (0.008) shows that no meaningful groupings were detected in terms of presence and absence of taxa composition. This suggests that the autoline and Spanish system catch similar benthic taxa.
Since the gear type was not found to influence the composition of taxa caught as bycatch, benthic taxa associated with different depths and areas were analysed without considering gear type further as a factor.

An ANOSIM analysis of all taxa indicated significant differences between depths ($p = 0.01; R = 0.371$). In addition, when areas (Z1 and Z2) were included, the nMDS plot (Figure 4.17) showed a clear partitioning between areas and depths (clusters around 500, 750, 1100 and 1500 m) and these were significant different ($p = 0.0; R = 0.782$).

![nMDS plot showing benthic bycatch taxa composition in different fishing areas and depths](image)

Pairwise tests showed that all groups of different depths and areas were significantly different ($p = 0.02$) with strong separation (R value) between them (Table 4.4). The Z1 500m group is most dissimilar to others but the most similar group to it was Z2 500m rather than deeper at the same (Z1) area. At Z2 there was limited overlap between bycatch composition at 500 m and 750 m
but the benthic bycatch at these shelf and shelf-break depths are distinct from the deeper slope depth (1100 and 1500 m) bycatch.

Table 4.4 - Values of R statistic and significance level (p) between fishing areas and depths.

<table>
<thead>
<tr>
<th>Groups</th>
<th>R</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1 500 m x Z1 1100 m</td>
<td>0.967</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 500 m x Z1 1500 m</td>
<td>0.917</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 500 m x Z1 500 m</td>
<td>0.904</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 500 m x Z1 750 m</td>
<td>0.977</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 1100 m x Z1 1500 m</td>
<td>0.555</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 1100 m x Z2 500 m</td>
<td>0.836</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 1100 m x Z2 750 m</td>
<td>0.838</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 1500 m x Z2 500 m</td>
<td>0.759</td>
<td>0.02</td>
</tr>
<tr>
<td>Z1 1500 m x Z2 500 m</td>
<td>0.849</td>
<td>0.02</td>
</tr>
<tr>
<td>Z2 500 m x Z2 750 m</td>
<td>0.713</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The SIMPER test showed the most important taxa which contributed to the difference between groups at Z1 500m were Stylasteridae Unk (8.2%), Plexauridae (8.2%), Thouarella sp1 (8.2%), Thouarella sp2 (8.2%), Polychaeta sp2 (5.7%) and Idmidronea sp (5.7%). Z1 750m group taxa were Demospongidae (8.3%), Stylasteridae Unk (7.8%), Thouarella sp2 (7.8%), Primnoidae sp (7.8%), Actiniaria sp1 (7.8%) and Serpula narconensis (7.8%). and at Z1 at 1500 m, taxa contributions were Laetmogonidae sp (13.1%), Stylasteridae Unk (13.1%), Primnoidae sp (13.1%), Polychaeta sp1 (8.8%), Isididae sp2 (8.6%) and Demospongidae (8.2%).

Likewise key taxa contributing to group differences in area Z2 were; at 500 m, Demospongidae (13.3%), Stylasteridae Unk (12.6%), Serpula narconensis (12.64%), Polychaeta sp1 (12.6%), Desmophyllum dianthus (7.5%), and Primnoidae sp (7.5%) were the most important taxa. At Z2 750m the most important taxa contributing to differences were Desmophyllum dianthus
(16.9%), Primnoidae sp (16.9%). *Primnoella* sp (10.3%), *Serpula narconensis* (10.3%), *Fenestrulina proxima* (10.3%) and *Thouarella* sp2 (6.9%).

**4.4.4. Bryozoans (Phylum Bryozoa)**

Bryozoans were represented by at least 56 different taxa across 2 orders and 20 families. The species composition showed significant differences between areas Z1 and Z2 ($p = 0.03; R = 0.24$). Figure 4.18 shows high dispersion in both areas, although there is a suggestion that samples in Z2 were of two types; 6 differed from those in Z1 and 5 were represented in Z1.

![Figure 4.18 - nMDS ordination comparing similarity in Bryozoan species composition between area 1 (Z1) and 2 (Z2).](image)

The species that most contributed to the formation of distinct groups in area Z1 were *Stomhypselosaria watersi* (33.63%), *Chaperiopsis signyensis* (11.58%) and Cyclostome sp2 (7.89%). *Fenestrulina proxima* (59.76%), *Exochella hymenae* (26.89%) and *Stomhypselosaria watersi* (5.19%). No compositionally significant differences were found across depth in the bryozoans ($p = 0.069; R = 0.092$) (Figure 4.19).
Figure 4.19 - nMDS ordination comparing similarity in Bryozoan composition between deep shelf (500-750 m) and deep slope (1100-1500 m).

4.4.5. Sponges (Phylum Porifera)

Sponges were represented by 41 different taxa. These taxa were taxonomically diverse, from at least 5 orders and 19 families. No significant difference was observed ($p = 0.24; R = 0.032$) between the species composition of the different areas (Figure 4.20A). Two highly distinct clusters were formed which were not similar to each other, but these clusters did not correspond to geographical areas or bathymetric zones.
Figure 4.20 - (A) nMDS ordination comparing similarity in Porifera composition between area Z1 and Z2 and (B) nMDS comparing similarity in Porifera composition between deep shelf (500-750 m) and slope (1100-1500 m).

Similarly, when these taxa were analysed for differences between deep shelf and slope, no significant differences were found \( (p = 0.07, R = 0.071) \) (Figure 4.20B). However this analysis did reveal that one of the across-area clusters was entirely on the shelf (Figure 4.20B, right) whilst the other was mixed shelf-slope. Thus unlike with hydroids, the shelf fauna had two compositionally separate faunas which both occurred in Z1 and Z2.
4.4.6. Hydroids (Phylum Cnidaria, Class Hydrozoa)

Investigation of hydroids samples revealed at least 33 different taxa belonging to 2 orders and 9 families. ANOSIM analyses showed no statistical differences between the hydroid fauna of the two fishing areas Z1 and Z2 (p = 0.08). More dispersion of Z2 samples can be seen in Figure 4.21, showing that of the two areas the hydroid compositions in Z1 varied less. In Z2, hydroid samples had significantly greater variability in their composition (R = 0.19). The SIMPER analysis showed that the species *Lafoea dumosa* (10.38%), *Halecium* Sp1 (8.97%) and *Eudendrium* Sp3 (8.43%) contributed most to the distinction between the two areas.

![Figure 4.21 - nMDS ordination comparing similarity in hydroids species composition between area Z1 and Z2.](image)

Analysis of the bathymetric distribution of hydroids suggested differences but these were just short of significant (p = 0.054) between deep shelf fauna (500-750 m) and those living on the continental slope (1100-1500 m). There was little difference in dispersion between shelf and slope faunas and in addition, no distinct groupings (Figure 4.22) were formed (R = 0.1).
4.4.7. Overall benthic biodiversity

The 199 different benthic taxa were identified to members of 10 different phyla, 19 classes and 30 orders (ANNEX 2). The most diverse Phylum was the Cnidaria, with 60 different morphotype species, followed by Bryozoa (56 sp), Porifera (41 sp), Echinodermata (20 sp), Arthropoda (9 sp), Annelida (4 sp) and Chordata (3 sp). Hemichordata and Brachiopoda were represented by just one morphotype each (Figure 4.23).
The number of species by depth and area is shown in Table 4.5. The three richest sites were all found in area 1. The highest number of taxa was found at 500 m (98), followed by the deepest site at 1500 m (78) and then at 1100 m (74). In area 2, the site with more taxa was at 500 m (49) followed by 750 m (35). For all these sites 6 lines were deployed. The lowest numbers were found at 750 m in area 1 (24) and 3 (30) however just two lines were set per area.
Table 4.5 - Numbers of phyla, classes, orders and species recorded from all trials per area and depth around South Georgia.

<table>
<thead>
<tr>
<th>Phyla</th>
<th>Class</th>
<th>Order</th>
<th>Z1</th>
<th>Z2</th>
<th>Z3</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>500 m</td>
<td>750 m*</td>
<td>1100 m</td>
<td>1500 m</td>
</tr>
<tr>
<td>Annelida</td>
<td>Polychaeta</td>
<td>Sabellida</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Polychaeta</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Σ Annelida</strong></td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Arthropoda</td>
<td>Malacostraca</td>
<td>Amphipoda</td>
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<td>0</td>
<td>2</td>
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<td></td>
<td>Isopoda</td>
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<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Maxillopodida</td>
<td>Cirripedia (infraclass)</td>
<td>1</td>
<td>0</td>
<td>1</td>
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* N = 6 fishing lines (3 AU and 3 SP) apart from Z1 750 m and Z3 750 m where just two lines were used.
4.4.8. Species accumulation curves

Rarefaction curves of species accumulation by depth show that sampling at none of the four depths approach asymptote (Figure 4.24). The rate of species detection was similar at shelf and slope depths, but lower at the shelf break (750 m). The overall pattern reflected that at shelf and slope depths because there was so little sampling at the shelf break. The value of sampling across four different shelf/slope depths is shown by the total species being nearly double that of the richest single depth.

![Species accumulation curve graph]

Figure 4.24 - Cumulative number of taxa per line in the different depths of the study area.

4.4.9. New range distribution

In total, 95 taxa were identified to species level. Examination of historical records and biodiversity databases showed that nearly 30% (28) of those represent new records for South Georgia and one species of Holothuroidea (Laetmogonidae) is previously undescribed (Table 4.6).
These new records are from 4 different classes; the highest number of records was found in the Demospongiae (Porifera) with 14 species, followed by Hydrozoa (Cnidaria) with 7, Gymnolaemata Bryozoans with 5 and 2 Holothuroidea (Echinodermata) including the new species.

For many of these species, the first occurrence in Shag Rocks, South Georgia represents a considerable extension of its distribution with the next nearest location being thousands of kilometres away. Bathymetric distributions also showed a large expansion with 17 species found deeper and only one reported in shallower water than previous records.
Table 4.6 - List of all species found to be new records for South Georgia area.

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4.4.9.1. Phylum Bryozoa

Class Gymnolaemata – Order Cheilostomatida

Family Bugulidae - Genus Bugulella

**Bugulella gracilis** Nichols, 1911

Distribution: Species previously recorded in the Pacific Ocean around New Zealand and in the Weddell Sea at depths from 505 to 1403 m (Bock, 2015a).

Known range extension: Species present on rocks collected by longline on west of Shag Rocks and west of South Georgia extending its geographic and bathymetric range (1461 to 1501) (Figure 4.25).

Figure 4.25 - Map of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of *Bugulella gracilis* (Nichols, 1911). The dotted line around Antarctica represents the mean position of the Polar Front. 1 = Tierra del Fuego, 2 = Falkland Islands, 3 = Antarctic Peninsula, 4 = Bouvet Island, 5 = Prince Edward Islands.
Family Cellariidae - Genus *Cellaria*

*Cellaria coronata* Liu & Hiu, 1991

Distribution: Species previously recorded in Southern Chile, Antarctic Peninsula, Weddell Sea and Ross Sea at depths from 106 to 405 m (Bock, 2015b).

Known range extension: Species present on rocks collected by longline west of Shag Rocks from 516 to 1540 m, much deeper than previous records (Figure 4.26A).

Family Exochellidae - Genus *Exochella*

*Exochella rogickae* Hayward, 1991

Distribution: Species previously recorded in the Amundsen Sea, Weddell Sea and Ross Sea at depths from 121 to 1541 m (Bock, 2015c).

Known range extension: Species present on rocks collected by longline northwest of Shag Rocks at depths around 520 m (Figure 4.26B). This makes Shag Rocks its northernmost range limit.

Family Microporidae - Genus *Apiophragma*

*Apiophragma hyalina* Waters, 1904

Distribution: Species previously recorded in the Amundsen Sea, west of the Antarctic Peninsula, Weddell Sea and Ross Sea at depths from 286 to 1541 m (Bock, 2015d).

Known range extension: Species present on a rock collected by longline west of Shag Rocks making this its northernmost range limit but not extending its known bathymetric range (1390 m) (Figure 4.26C).
Family Sclerodomidae - Genus *Cellarinella*

**Cellarinella laytoni** Rogick, 1956

Distribution: Species previously recorded around the Antarctic including the Antarctic Peninsula, Weddell Sea and Ross Sea at depths from 20 to 1133 m (Bock, 2015e).

Known range extension: Species present on rocks collected by longline to the northwest and east of Shag Rocks extending its furthest north known locality (at depths from 518 to 805 m (Figure 4.26D)).

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**Figure 4.26** - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Bryozoa *Exochella rogickae* Hayward, 1991; *Cellaria coronata* Liu & Hiu, 1991; *Apiophragma hyalina* (Waters, 1904) and *Cellarinella laytoni* Rogick, 1956. The dotted line around Antarctica represents the mean position of the Polar Front.
4.4.9.2. Phylum Cnidaria

Class Hydrozoa – Order Leptothecata
Family Campanulariidae - Genus *Campanularia*

*Campanularia tulipifera* Allman, 1888

Distribution: Species previously recorded in north of the Heard Island at 274 m (Schuchert, 2015a).

Known range extension: Species collected by longline northwest of Shag Rocks at 1134 m deeper than previous record and greatly extending its known range to the west (Figure 4.27A).

Family Haleciidae - Genus *Halecium*

*Halecium jaederholmi* Vervoort, 1972

Distribution: Species previously recorded off southern Argentina and in the Antarctica including the Antarctic Peninsula and Weddell Sea at depths from 17 to 710 m (Schuchert, 2015b).

Known range extension: Species collected by longline to the northwest of Shag Rocks, South Georgia, at depths of 730 to 800 m (Figure 4.27B).

Family Phialellidae - Genus *Phialella*

*Phialella belgicae* Hartlaub, 1904

Distribution: Previously recorded on the shelf south of La Plata estuary, Argentina, Patagonian shelf, the Antarctic Peninsula, Weddell Sea, Kerguelen Islands, Ross Sea and on the shelf of east Antarctica at depths from 2 to 650 m (Schuchert, 2016).

Known range extension: Species collected by longline northwest of Shag Rocks and south of South Georgia in areas much deeper than previous records (1400 to 1780m) (Figure 4.27C).
Family Sertulariidae - Genus *Sertularella*

*Sertularella jorgensis* El Beshbeeshy, 2011

Distribution: Species previously recorded on the Southern Patagonian self. Depth was not available (Schuchert, 2015c).

Known range extension: Species collected by longline northwest of Shag Rocks from 1126 to 1500 m (Figure 4.27D). This is the first Southern Ocean record.

Figure 4.27 - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Cnidaria *Haleclium jaederholmi* Vervoort, 1972; *Campanularia tulipifera* Allman, 1888; *Phialella belgicae* (Hartlaub, 1904) and *Sertularella jorgensis* El Beshbeeshy, 2011. The dotted line around Antarctica represents the mean position of the Polar Front.
**Sertularella vervoorti** El Beshbeeshy, 2011

Distribution: Species previously recorded in the Patagonian shelf, east coast of New Zealand and in the south of Tasmania, Australia from depths of 670 to 840 m (Schuchert, 2015d).

Known range extension: Species collected by longline to the northwest of Shag Rocks extending its range further west and deeper than previous records (1120 to 1491 m) (Figure 4.28A). This is the first Southern Ocean record.

Genus **Symplectoscyphus**

**Symplectoscyphus naumovi** Blanco, 1969

Distribution: Species previously recorded in the Antarctic Peninsula, Weddell Sea, on the shelf of east Antarctica and in the Ross Sea from depths of 50 to 1286 m (Schuchert, 2015e).

Known range extension: Species collected by longline northwest of Shag Rocks at a depth of 1152 m (Figure 4.28B). This makes Shag Rocks its northernmost range limit.

Family Tiarannidae - Genus **Stegopoma**

**Stegopoma plicatile** Sars, 1863

Distribution: Species previously known from the Arctic Ocean, Saguenay Fjord in Canada, East North and West North Atlantic, Southern Patagonian self, the Antarctic Peninsula, North of Japan and in the Philippine Sea in depths from 87 to 1624 m (WoRMS, 2004).

Known range extension: Species collected by longline northwest of Shag Rocks and southeast of South Georgia at areas deeper than previous records (1450 to 1780 m) (Figure 4.28C).
Figure 4.28 - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Cnidaria *Sertularella vervoorti* El Beshbeeshy, 2011; *Symplectoscyphus naumovi* Blanco, 1969 and *Stegopoma plicatile* (Sars, 1863). The dotted line around Antarctica represents the mean position of the Polar Front.

### 4.4.9.3. Phylum Echinodermata

Class Holothuroidea – Order Dendrochirotida

Family Cucumariidae - Genus *Staurocucumis*

*Staurocucumis krzysztofi* O’Loughlin, 2013

Distribution: Species previously recorded off the South Shetland Islands, King George Island, Admiralty Bay in depths from 60 to 500 m (Paulay, 2015).
Known range extension: Species collected by longline to the northwest and east of Shag Rocks at depths of 524 to 1529 m, deeper than previous records (Figure 4.29A). This makes Shag Rocks its northernmost range limit.

Family Laetmogonidae - Genus *Staurocucumis*

*Staurocucumis new specie*

Two specimens collected in Shag Rocks at depth of 1520 and 1614 m (Figure 4.29B). The species is being described by Dr. Mark O'Loughlin.

![Maps showing range extension of *Staurocucumis* and *Laetmogone*](image)

**Figure 4.29** - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Echinodermata *Staurocucumis krzysztofi* O'Loughlin, 2013 and *Staurocucumis new specie*. The dotted line around Antarctica represents the mean position of the Polar Front.

### 4.4.9.4. Phylum Porifera

Class Demospongiae – Order Suberitida

Family Halichondriidae - Genus *Hymeniacidon*

*Hymeniacidon insutus* Koltun, 1964

Distribution: Species previously recorded in the Antarctic Peninsula in the South Shetland Islands at 385 m (van Soest, 2016a).
Known range extension: Species collected by longline to the northwest of Shag Rocks at depths of 1142 m, deeper than previous record (Figure 4.30A). This makes Shag Rocks its northernmost limit.

Family Chalinidae - Genus Haliclona

*Haliclona tylotoxa* Hentschel, 1914

Distribution: Species previously recorded in East Antarctica (337 m) and Weddell Sea (no depth recorded) (van Soest, 2016b).

Known range extension: Species collected by longline to the northwest of Shag Rocks at depths from 518 to 1142 m deeper than previous record (Figure 4.30B). This makes Shag Rocks its northernmost range limit.

Family Phloeodictyidae - Genus Pachypellin

*Pachypellina fistulata* Kirkpatrick, 1907

Distribution: Species previously recorded in the Antarctic Peninsula and in the Ross Sea from depths of 51 to 367 m (van Soest, 2016c).

Known range extension: Species collected by longline northwest of Shag Rocks at depths from 524 to 1137 m deeper than previous record (Figure 4.30C). This makes Shag Rocks its northernmost range limit.

Family Acarnidae - Genus Iophon

*Iophon pluricorne* Topsent, 1913

Distribution: Species previously recorded in the Antarctic Peninsula and in the East Antarctica from depths up to 17 m (van Soest, 2016d).

Known range extension: Species collected by longline northwest of Shag Rocks, and east of South Georgia at depths from 586 to 1175 deeper than
previous record (Figure 4.30D). This makes Shag Rocks its northernmost range limit.

Family Cladorhizidae - Genus *Chondrocladia*

*Chondrocladia schlatteri* Lopes, Bravo & Hajdu 2011

Distribution: Species previously recorded off the south coast of Chile (Tierra del Fuego) at a depth of 1800 m (Vacelet & van Soest, 2016).

Known range extension: Species collected by longline to the north and northwest of Shag Rocks at depths from 1195 to 1504 m shallower than the previous record (Figure 4.30E). This is the first Southern Ocean record.

Family Coelosphaeridae - Genus *Inflatella*

*Inflatella bellii* Kirkpatrick, 1907

Distribution: Species previously recorded in the South of Chile, Falkland Islands, the Antarctic Peninsula, Weddell Sea, East Antarctica and Ross Sea at depth of 2 to 1774 m (van Soest, 2016e).

Known range extension: Species collected by longline on east of Shag Rocks, South Georgia at depths from 536 m (Figure 4.30F).
Figure 4.30 - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Porifera *Hymeniacidon insutus* Koltun, 1964; *Haliclona tylotoxa* (Hentschel, 1914); *Pachypellina fistulata* (Kirkpatrick, 1907); *lophon pluricorne* Topsent, 1913; *Chondrocladia schlatteri* Lopes, Bravo & Hajdu 2011 and *Inflatella bellii* (Kirkpatrick, 1907). The dotted line around Antarctica represents the mean position of the Polar Front.
Genus Lissodendoryx

*Lissodendoryx inominata* Burton, 1929

Distribution: Species previously recorded in the Weddell Sea and Ross Sea at depths from 200 to 250 m (van Soest, 2016f).

Known range extension: Species collected by longline on northwest of Shag Rocks, South Georgia at depths from 524 to 580 m (Figure 4.31A). This makes Shag Rocks its northernmost range limit.

*Lissodendoryx styloderma* Hentschel, 1914

Distribution: Species previously recorded in the East Antarctica and Scotia Sea at depths from 330 to 608 m (van Soest, 2016g).

Known range extension: Species collected by longline on northwest of Shag Rocks, South Georgia at depths from 536 to 757 m (Figure 4.31B). This makes Shag Rocks its northernmost range limit.

Family Desmacellidae - Genus Desmacella

*Desmacella koltuni* Göcke & Janussen, 2013

Distribution: Species previously recorded in the Antarctic eastern Weddell Sea at depth of 600 m (van Soest, 2013a).

Known range extension: Species collected by longline on northwest of Shag Rocks, South Georgia at depths from 1438 to 1481 m (Figure 4.31C). This makes Shag Rocks its northernmost range limit.

Family Esperiopsidae - Genus Amphilectus

*Amphilectus rugosus* Thiele, 1905
Distribution: Species previously recorded in the south of Chile, south of La Plata estuary (Argentina), Falkland Islands, Namib shelf, Tristan Gough Island and Ross Sea at depth from 79 to 289 m (van Soest, 2016h).

Known range extension: Species collected by longline on northwest and east of Shag Rocks, South Georgia at depths from 518 to 1420 m (Figure 4.31D). This is the first West Antarctic record.

Family Latrunculliidae - Genus Latrunculia

*Latrunculia bocagei* Ridley & Dendy, 1886

Distribution: Species previously recorded in the Kerguelen Island at depth of 73 m (van Soest, 2010).

Known range extension: Species collected by longline on east of Shag Rocks, South Georgia at depths from 805 m extending its previous distribution to west and deeper (Figure 4.31E). This is the first Antarctic record.

Family Tedaniidae – Genus Tedania

*Tedania tantula* Kirkpatrick, 1907

Distribution: Species previously recorded in the Antarctic Peninsula, Amundsen Sea, Weddell Sea, Bouvet Island, Ross Sea and east Antarctica at depth from 60 to 2600 m (van Soest, 2013b).

Known range extension: Species collected by longline east and northwest of Shag Rocks, South Georgia at depths from 555 to 1457 m (Figure 4.31F). This makes Shag Rocks its northernmost range limit.
Figure 4.31 - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Porifera *Lissodendoryx innominata* Burton, 1929; *Lissodendoryx styloderma* Hentschel, 1914; *Desmacella koltuni* Göcke & Janussen, 2013; *Amphilectus rugosus* (Thiele, 1905); *Latrunculia bocagei* Ridley & Dendy, 1886 and *Tedania tantula* (Kirkpatrick, 1907). The dotted line around Antarctica represents the mean position of the Polar Front.
Tedania oxeata Topsent, 1916

Distribution: Species previously recorded from the Patagonian Shelf, Antarctic Peninsula, Weddell Sea, east Antarctic shelf and Ross Sea at depths from 66 to 1200 m (van Soest, 2016i).

Known range extension: Species collected by longline northwest of Shag Rocks, at depths from 518 to 1148 m (Figure 4.32A).

Tedania gracilis Hentschel, 1914

Distribution: Species previously recorded in the east Antarctic shelf at depths from 90 to 289 m (van Soest, 2016j).

Known range extension: Species collected by longline northwest of Shag Rocks, South Georgia at depth of 1120 m (Figure 4.32B). This makes Shag Rocks its northernmost range limit and the first record from the Atlantic sector of the Southern Ocean.

Figure 4.32 - Maps of the Southern Ocean and neighbouring regions showing the previous (red dots) and known range extension distribution (blue dots) of the Porifera Tedania oxeata Topsent, 1916 and Tedania gracilis Hentschel, 1914. The dotted line around Antarctica represents the mean position of the Polar Front.
4.5. DISCUSSION

South Georgia could be argued to be a hotspot for most of the key scientific, commercial and political issues facing the Southern Ocean and human society at high latitudes (see e.g. Barnes et al., 2009b). With biodiversity, threats to biological richness and methods to mitigate such threats are all under the international spotlight, South Georgia is unusually rich and ‘pristine’. Furthermore, South Georgia is very rich in endemic species and so-called vulnerable marine ecosystems (Barnes et al., 2011; Hogg et al., 2011). Yet many of the threats to global biodiversity – rapid warming through ‘climate change’ (Whitehouse et al., 2008), invasive species (South Georgia has recently been subject to reindeer, rat and mice eradication), human pressure (SG is one of the most visited locations in the Southern Ocean) and overharvesting (SG was a whaling and sealing centre) – are all also represented in this remote location. It has long been clear that, at South Georgia as elsewhere, potential solutions lie in pragmatic balancing of use and valuing of the ocean and biodiversity. Most, if not all, prior work concerning fisheries around South Georgia (and again elsewhere) has focussed on impacts. Meaningful assessment of threats and mitigation requires a strong knowledge of how many and what species are where – and how good that knowledge is. The current study utilises the most frequent visitors to South Georgia, and those which visit the widest variety of locations – fishing vessels, to investigate not impact but enhance our knowledge of marine biodiversity and biogeography.

As elsewhere in the Southern Ocean, the overwhelming majority of reported species at South Georgia are small, live on the seabed and are rarely ever seen
apart from by a few scientists and fishermen. Despite the relatively small sample size, the benthic biodiversity recovered in this study from samples from longlines set on Shag Rocks included 45% of the phyla, 37% of the classes and nearly 12% of the species ever reported in South Georgia waters (see Hogg et al., 2011). Such findings across taxonomic scales are perhaps not surprising due the low sample effort/taxonomic studies available for this poorly known area (see e.g. Barnes et al., 2011).

The new biodiversity records are much more significant than that, however; the samples reported here included about half of all known South Georgia bryozoans and sponges and three quarters of cnidarians. Clearly investigation of longlining samples is very much more informative for certain taxa, indeed - remarkable 9% of the bryozoans, 34% of the sponges and 21%, of cnidarians found had not previously been reported from South Georgia waters. Notably the taxa sampled particularly effectively are all considered markers for Vulnerable Marine Ecosystems, and thus of high value to conservation and Marine Protected Area planning. Some of these species are extremely rare and others further emphasise the importance of the region as a hotspot for range edge species (Barnes et al., 2009b), and thus potentially strong climate change indicator species.

Direct comparisons between fauna collected in South Georgia and Shag Rocks are difficult to quantify and interpret due to the low sampling effort/studies available. Most of the samples collected in this study came from slope depths which are very poorly sampled in the Southern Ocean (Kaiser et al., 2008). Taylor et al. (2013a) found Gorgonacea to have very high richness and abundance in South Georgia slope samples. Samples were also collected by
longliners which would have made for potentially strong faunal comparisons between South Georgia and the samples collected in the present study at Shag Rocks. Unfortunately, Gorgonaceaes were poorly characterised in this present study as identifications were lost by the taxonomist through circumstances beyond the control of the project.

As with scientific cruises much of the level of taxonomic resolution is limited by the number of available taxonomists per taxon and how busy they are. Further identification of samples collected by the current study by taxonomic experts is needed, and once this is complete, there could yet be a further considerable increase in the number of taxa found especially in cnidarians (as discussed above). However most samples were considered by expert taxonomists, which showed many considerable findings. The records of fourteen species were new northern limits (of Antarctic endemics) and some could prove important as indicators of response to climate-forced warming. In contrast four were the first Southern Ocean records, and merit investigation as to whether these are native or new exotic arrivals. Other records are crucial ‘link-species’ filling unexplained gaps in distributions and some are so rare that they have only been recorded once or twice before. Clearly such finds are a leap forward in terms of meeting Convention on Biological Diversity (CBD) targets but also add huge value to the newly designated Marine Protected Area (MPA). South Georgia region has just become even more important as a hotspot for endemic, rare, edge-of-range and threatened species.

Historically virtually all the primary records for species presence around South Georgia have been obtained by research vessels. The majority of these studies used samples from apparatus such as Agassiz trawls, epibenthic sledges, box
corers, or underwater imagery (Brandt et al., 2007; Jones and Lockhart, 2011). As is the case around Antarctica (Griffiths, 2010), most of the sampling effort around South Georgia has been concentrated on the shelf (Barnes et al., 2011; Hogg et al., 2011). Successful deployment criteria for most scientific sampling gear characteristics, especially trawls, sledges and cores are that the profile of the seabed is neither too steep nor rugose (bumpy), thus biasing the types of areas most targeted. The South Georgia GIS database (http://www.sggis.gov.gs) shows that commercial fishery samples are also clearly biased by targeting particular areas but these differ from scientific sample biases in being spread deeper and independent of bottom topography. Given that the waters around South Georgia are currently the largest cold water MPA in the world and now included in the CBD, the government and conservation professionals are much in need of fast-tracking the ‘biodiversity knowledge requirement’ component so that progress can be made with assessment of threats, monitoring and mitigation. None of the latter can be done without a strong grounding in the former. To date the scientific approach, such as the recent Darwin Initiative funded RRS James Clark Ross cruises (JR262 & JR287), have generated new finds but not quickly enough. The bias towards shallow shelf sampling around South Georgia (Hogg et al., 2011) has left other areas, such as toothfish fishing grounds (deep shelf and slope) relatively unsampled. In the absence of benthic data from slope areas, alternative ways to address this (lack of scientific sampling) problem need to be found. Only recently has it been recognized that bottom longlines generate benthic invertebrate bycatch but in the last few years it has started to become used as a tool to collect scientific samples (Parker and Bowden, 2010; Munoz et al., 2011; Taylor et al., 2013b; Mylitineou et al., 2014).
Previous studies based on catch rate from SP and AU have been purely quantitative for VME groups and no comparisons between taxa composition within these groups were made (Martin et al., 2012; Gerrodette and Watters, 2012). In the present study, bycatch taxonomic composition between Spanish and autoline systems were not found to differ, this enabled pooling to increase sample size and potential resolution in other areas of investigation such as depth and site. The depth and site differences found (in the pooled data) were complex and differed across phyla – mostly likely explained by subtle differences in the nature of habitat type. For example, two striking different sponge faunas are shown in Figure 4.20B were independent of depth and site. Similar differences in megafauna composition could be seen on scales of metres to 10s of meters in the video recorded on some camera deployments (though only at a higher level of taxonomic resolution - class/order). No clear pattern was apparent in which taxonomic groups were driving the faunistic differences between depths and sites. It is possible that it is trophic levels or functional groups, rather than taxonomy, driving faunistic alteration. For example, one might expect fauna to change from suspension feeding on hard surfaces to deposit feeders at sediment surfaces, which are somewhat independent of taxonomic group. Alternatively, South Georgia region has more predators (e.g. lithodid crabs, lobsters, skates, rays and other fish) than found in Antarctic conditions, so maybe these too contribute to shaping the composition of benthos. Looking forward, one of the key challenges for maintaining and advancing MPA effectiveness will be to gain a much better understanding of the clearly rich biodiversity at this locality. However with few, if any, richness accumulation curves approaching asymptote, it seems there is still much work
to do on assessing what is there. This chapter suggests that fishing and fishing vessels can play their part in this.
CHAPTER FIVE
5. DISTRIBUTION AND COMPARISON OF BENTHIC INVERTEBRATE BYCATCH FROM THE DEMERSAL LONGLINE FISHERY AT SOUTH GEORGIA

5.1. ABSTRACT

Global longline fisheries have attracted considerable conservation and scientific interest through their interactions with biota such as cetaceans, seabirds and deep water benthic communities. This is of particular pertinence around isolated Southern Ocean islands, such as South Georgia where there is a rich abundance of rare and endemic species. Most of the focus to date has concerned the impact of longlines, however these fishing vessels can also be a potentially important sampling tool, in a region where few scientific vessels travel and little is known of benthic biodiversity. The present study uses longline bycatch data from at-sea observers to investigate the distribution of benthic invertebrate bycatch, particularly Vulnerable Marine Ecosystems. The 12522 bycatch specimens belonged to 17 different VME groups, the most abundant of which were the tall, calcified, branching gorgonians (GGW, 59.72%) and hydrocorals (AXT, 14.17%). Data from a trial using bycatch data from 30 fishing lines (15 from Autoliner and 15 using the Spanish system) each consisting of approximately 3550 hooks and 5400 m in length were investigated at two toothfish fishing grounds around Shag Rocks, NW of South Georgia. Observer data from the same area was then compared to check observer quality data. Across-taxon historic hotspots of bycatch were West Shag Rocks and the gulley between Shag Rocks and South Georgia, which are now closed areas. However, there were notably other more taxon-dependent hotspots in West Shag Rocks, NWN and West South Georgia, which remain fished. Fishing gear type (Autoline vs Spanish), observer identity, observation method...
and depth, all had significant effects on bycatch as well as geography – but hook type and soak time were not. The current work has provided a list of recommendations to improve observer invertebrate data collection, has lodged identified voucher specimens and developed a new photographic guide with representative images of each CCAMLR VME code – this is attached as an annex 2.
5.2. INTRODUCTION

A demersal longline fishery has been operating in South Georgia since the late 1980s targeting the Patagonian toothfish *Dissostichus eleginoides* (Agnew, 2004). Currently the autoline (AU) and Spanish longline (SP) systems are deployed in the fishery on continental shelf and slope at depths from 700 to 2250 m (see Chapter 2).

The toothfish fishery is the most important fishing activity around South Georgia and it is recognised as well managed and sustainable by the Marine Stewardship Council (MSC, 2014). One of the key points of the fishery is the adoption of the observer scheme of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) where all vessels are required to carry an independent scientific observer (Sabourenkov and Appleyard, 2005).

Observers are required to carry regularly line observations to estimate catch and bycatch from the hooks. Evidence of sessile invertebrate bycatch in the toothfish fishery were first reported by these observers in the end of 1990s, but no detailed identification or quantification took place. One of the conditions of the first MSC certification of the fishery (MSC, 2004), was that benthic bycatch data be systematically collected and that interactions between benthic sessile fauna and fishing gear be investigated in South Georgia (MSC, 2004). The MSC concluded that such a matter was of immediate importance and that observers needed to gain more detailed information for more meaningful assessment.

The United Nations General Assembly (UNGA) Resolution 61/105:80 ‘Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the
precautionary approach and ecosystem approaches, to sustainably manage fish stocks and protect vulnerable marine ecosystems (VMEs), including seamounts, hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain' (UNGA, 2007).

Following these concerns, and based on studies conducted using observer bycatch data, the Government of South Georgia and the South Sandwich Islands (GSGSSI) introduced a series of measures to reduce fishing impacts such as the introduction of depth limits (see Chapter 2) and the implementation of Benthic Closed Areas (BCAs) (Agnew et al., 2007; Martin et al., 2012)

Benthic invertebrate communities are recognised to have an important role in the structure and functioning of marine ecosystems worldwide Kaiser et al., (2007). In the Southern Ocean, benthic marine fauna shows a high degree of biodiversity (Brandt et al., 2007; Clarke et al., 2005). In addition to high biodiversity, South Georgia also has many endemic and range edge species (Barnes, 2008; Griffiths et al., 2008; Hogg et al., 2011). However most of this biodiversity data came from samples collected by research vessels on the South Georgia shelf and little is known about the biodiversity of benthic associations in the deep sea around South Georgia (Barnes et al., 2011).

The distribution of benthic invertebrate bycatch from longliners have been previously assessed around South Georgia. The data currently available for longlining deployments show that the majority are what are termed bioconstructors. Bioconstructors include corals, hydrozoans, sponges, bryozoans, polychaete worms and other sessile taxa which build hardened 3-dimensional structures on the seabed (Wakeford et al., 2006). Octocorals are
the most abundant benthic taxa found as bycatch around South Georgia (Taylor, 2011).

Studies of benthic fauna especially in remote locations such South Georgia are normally very expensive to perform, logistically challenging and thus data on benthic distribution is patchy and scant (Welsford et al., 2014). In contrast, licensed longliners operate in the South Georgia Maritime Zone every year setting lines on a variety of grounds such deep shelf and slope. It gives a great opportunity to sample areas where little or no biodiversity information exists.

In the past few years, there has been increasing interest worldwide on interaction between bottom longline fisheries and deep-sea benthic communities (Munoz et al., 2011; Taylor et al., 2013; Mytilineou et al., 2014; Pham et al., 2014; Parker and Bonden, 2010). It is now well recognised that, whilst longlines can impact sessile benthic fauna, they can also be an important sampling tool.

There is an urgent need for a high quality, georeferenced assessment of seabed biodiversity in this region. Increasing knowledge and understanding spatial patterns of the South Georgia’s benthic biodiversity is vital for ecosystem health and stability and can help inform spatial management of the longline fishery. These cannot be assessed without knowledge of the structure, organisation and processes driving and maintaining benthic biodiversity.

The present study uses longline by-catch data to investigate the distribution of benthic invertebrate bycatch around South Georgia. It will also investigate the possible differences on catch rates between the two longline systems deployed in South Georgia and look at the quality of the data gathered from observers.
5.3. MATERIALS AND METHODS

5.3.1. Study area

The study area around South Georgia has been previously described in detail in Chapter 1.

5.3.2. Fishing data collection

Fishery observers under the CCAMLR scientific observation scheme (see Sabourenkov and Appleyard, 2005) were deployed on all longliners targeting toothfish around South Georgia during 2006 to 2015. These observers carried out hook line observations aimed to monitor at least 25% of the total numbers of hooks hauled per vessel.

During the hook-line observation period, target and bycatch species, including invertebrate benthic fauna, were counted. Observers also collected detailed information on a line by line basis on fishing effort (number of hooks, length of line, soak time etc), gear description (type of gear, type of hook, hook spacing etc) and high resolution spatial distribution data of sets (start - end latitude/longitude and depth).

Hooks should be observed by the fishing observer from a point where the incoming line and its catch, including any catch that drops off the line ("drop offs") could be clearly seen. This is normally on deck above the hauling room.

Fishing observers use two different approaches for counting and identifying benthic bycatch. Observers count and identify bycatch directly during line observations and also request to the crew to keep aside in containers all benthic groups for close inspection once line observation is finished.
All data collected is entered into a database prior to disembarkation from the vessel. Data is then transferred to the CCAMLR Observer database where part of the data for this chapter came from.

### 5.3.3. Invertebrate bycatch identification

Identification of benthic bycatch in the 2006/07 season was undertaken by scientific observers using an ID guide produced by British Antarctic Survey (BAS). In 2008, CCAMLR developed its own guide based on implementation of specific research on the vulnerable marine ecosystems (VMEs) (see Jones and Lockhart, 2011). Although CCAMLR requirements for VME collection data are not applied in South Georgia, the guide was adopted by the entire CCAMLR observer program. Initially the guide had 13 different taxonomic groups that were later updated to its current version with 22 groups (CCAMLR, 2009). The guide uses the international 3-alpha identifier codes managed by Fisheries and Aquaculture Statistics and Information Service (FIPS) from the Food and Agriculture Organization of the United Nations (FAO). Benthic invertebrate classification contained in the guide is limited to Phylum for lamp shells (Brachiopoda), sponges (Porifera) and bryozoans (Bryozoa); class for sea squirts (Ascidacea); and family for hydrocorals (Stylasteridae) and barnacles (Bathylasmatidae). All other groups were classified to order level.

Identification of benthic Invertebrate groups during longline trials were carried out onboard by the author using a series of benthos ID guides. Pictures were also taken from all specimens divided by groups and later they were checked by Dr David Barnes from British Antarctic Survey (BAS). When discrepancies were found, they were double checked and corrected.
5.3.4. Longline trials

A total of 30 fishing lines (15 AU and 15 SP) each consisting of approximately 3550 hooks and measuring 5400 m in length were set in 2 different well known toothfish fishing grounds around Shag Rocks, NW of South Georgia (Figure 5.1) using two different fishing vessels. Two lines set on Z3 and Z1 at 750m previous reported on Chapter 4 were removed due the low sampling effort.

The autoline system was deployed from the UK registered fishing vessel Argos Froyanes, a 52.55 m (LOA) Norwegian built vessel, with gross tonnage (GRT) of 1352 tonnes and capacity for 24 crew. The Chilean registered vessel Antarctic Bay deployed lines using the Spanish system. She is 44 m long (LOA), Chinese built vessel, with GRT of 985 and capacity for 44 crew. Deployments followed normal fishing gear configuration and operations were described in Chapter 2.

The lines were deployed in 2 different fishing zones (Z1 and Z2). The first area (Z1) is situated northwest of Shag Rocks and 3 lines from each system (SP and
AU) were set at depths of 500, 1100 and 1500 m. Fishing zone 2 (Z2) was situated 70 km East-Southeast of Z1 and also 3 lines of each system were set at 500 and 750 m (Figure 5.1).

All trials were carried out during the normal fishing activity of each vessel and differences in the number of lines deployed per zone and depth for both systems were due to the particular fishing circumstances.

Each fishing line was divided into 3 equal line segments using colour marks. During hauling, all hooks were observed and all VME specimens caught were counted and identified by groups per each line segment from the area above the hauling room (called here line observation - LO). Identification for both methods used the same ID strategy ranging from Phylum to family. Crew were also asked to keep all invertebrate bycatch separated by segments aside in a container on deck (called here deck observation - DO) for later identification and assessment.

Bycatch identified and counted per segment from LO was compared with the bycatch collected and kept aside by crew using DO method. Both methods were carried out by the same observer. This allowed investigation of the effectiveness of bycatch identification and counting by observers using both methods.

5.3.5. Data analysis

Prior to the analyses, all data collected by scientific observers were assessed for reliability. First, georeferenced sets were plotted and sets where positions did not match with fishing grounds were excluded. Records with wider depth ranges (start and end depth of the set) greater than 200 m were also excluded.
Data sets were then scanned manually for identification of potential errors such typographic mistakes leading to wrong ID codes. Entire fishing trips were removed when observers identified all benthos bycatch using a general code for invertebrate (INV) or when observers only identified a limited range (3 or less) of invertebrate groups during the trip.

ArcGIS version 13 was used to plot high resolution catch data gathered by at-sea observers layered on top of the bathymetric features of South Georgia in order to investigate spatial distribution and hotspots around the island of the most abundant VME groups catch as bycatch. The area was divided into square grids with each box representing 10 km² of area (Figure 5.2A).

Using observer data, possible differences in the catch rate between the autoline and Spanish system gear types were analysed using a General Linear Model (GLM). Factors such as hook type, length of the line, depth, soak time and area fished were investigated. The GLM was developed and run using the software R (R Core Team, 2016). In order to compare them and reveal any trends on bycatch variability, South Georgia was divided into 5 distinct geographic areas to facilitate analysis of the fishery (Figure 5.2B). The areas were defined as Shag Rocks, Northwest, Northeast, Southwest and Southeast.

Catch per unit effort (CPUE) was used for standardisation of all bycatch data (longline trails and observer data sets). The CPUE used in the present study is defined as number of specimens caught per every 1000 hooks hauled/observed.

Bycatch rate from the longline trials were analysed using Minitab statistical software. Prior to the statistical test, normality and homogeneity of variance
were verified (using Kolmogorov-Smirnov and Levene tests, respectively) and dependent variables which did not meet the assumptions for parametric testing were transformed using a square root transformation.

One-way ANOVA (analysis of variance) (p < 0.05) was then applied (when all assumptions for parametric statistics were fulfilled) to test differences between the amount of bycatch collected by the two fishing methods (AU and SP) per depth and fishing area. If the variable (CPUE) still violated normality and homoscedasticity assumptions, the non-parametric test Kruskal-Wallis was employed to test differences between the two fishing systems.

Figure 5.2 - Map of South Georgia (area 48.3) showing (A) fishing data aggregated into squares divided into grids of 10 km². (B) Map of South Georgia showing all lines deployed (red dots) divided into grids of 55 x 68 km then into 5 geographic areas: Shag Rocks, Northwest, Northeast, Southwest and Southeast.
Quantitative data from longline trails were used to analyse potential differences between methods of observation onboard (Line observation vs Deck observation - LO x DO). Significance tests were applied using ANOSIM (p <0.05) and SIMPER test for total counts of bycatch from all depths. The same methodology was applied for each depth (500, 750, 1100 and 1500 m).
5.4. RESULTS

5.4.1. Fishing effort and invertebrate bycatch from observer database

Line deployments from 26 fishing trips (8 AU and 18 SP) set approximately 31.78 million hooks around South Georgia, of which 28.6% (10.02 million) of those were observed by sea observers (Table 5.1).

Table 5.1 - Fishing effort and number of hooks observed per year from deployments selected for this study only. * Average. Note: Data from 2007 and 2008 were excluded due the double entry records by observers in different data tables. It was not possible to link with number of hooks observed.

<table>
<thead>
<tr>
<th>Fishing system</th>
<th>Year</th>
<th>Number of vessels</th>
<th>Hooks set</th>
<th>Hooks observed</th>
<th>% hooks observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU</td>
<td>2006</td>
<td>1</td>
<td>507,534</td>
<td>172,951</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>2</td>
<td>2,674,800</td>
<td>867,922</td>
<td>32.4</td>
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<tr>
<td></td>
<td>2010</td>
<td>1</td>
<td>1,316,681</td>
<td>430,736</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>2</td>
<td>2,169,861</td>
<td>758,961</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>1</td>
<td>1,536,135</td>
<td>611,208</td>
<td>39.8</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>1</td>
<td>1,776,434</td>
<td>615,839</td>
<td>34.7</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total AU</strong></td>
<td><strong>8</strong></td>
<td><strong>9,981,445</strong></td>
<td><strong>3,457,617</strong></td>
<td><strong>34.8</strong>*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>2006</td>
<td>3</td>
<td>3,610,181</td>
<td>922,335</td>
<td>25.5</td>
</tr>
<tr>
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<td>2009</td>
<td>5</td>
<td>6,537,315</td>
<td>1,859,186</td>
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</tr>
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<td>974,467</td>
<td>40.0</td>
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<tr>
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<td>2011</td>
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<td>261,514</td>
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<td>736,553</td>
<td>34.2</td>
</tr>
<tr>
<td><strong>Total SP</strong></td>
<td><strong>18</strong></td>
<td><strong>21,806,120</strong></td>
<td><strong>6,566,900</strong></td>
<td><strong>31.2</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total SP/AU</strong></td>
<td><strong>26</strong></td>
<td><strong>31,787,565</strong></td>
<td><strong>10,024,517</strong></td>
<td><strong>32.7</strong>*</td>
<td></td>
</tr>
</tbody>
</table>

Deployment of fishing lines was distributed around South Georgia and Shag Rocks (Figure 5.2). A reduction in the proportion of lines set in depths up to 700 m was observed due the restriction of depth limits imposed since 2010 (550 m) and in 2011 (700m). Fishing effort for both gears were concentrated between 1100 and 1500 m, where 59.58% of the lines were deployed (Table 5.2).
Fishing observers reported a total of 12522 specimens as bycatch from the autoline and Spanish system. These specimens belonged to 17 different VME groups from a total of 22 groups on the CCAMLR VME taxa guide. VME invertebrates not identified corresponded to 7.34% (919) of total number of specimens. The most abundant groups were gorgonians (GGW) with 59.72% (7478), hydrocorals (AXT) with 14.17% (1774) followed by sponges (PFR) with 3.51% (440) (Table 5.3).

Others invertebrate groups were also part of the longline bycatch from the toothfish fishery (see Annex 2). These included groups such as Phylum Echinodermata (Class Asteroidea, Orders Ophiurida, Holothuroidea, Comatulida and Camarodona), Annelida (Class Polychaeta - segmented worms), Bryozoa (Order Cheilostomatida - encrusting form), Arthropoda (Subphylum Chelicerata), Crustacea (Subphylum) including the orders Amphipoda and Isopoda and finally the Phylum Mollusca (Classes Bivalvia and Gastropoda). These groups were not constantly monitored by observers and thus reliable data was not available for analyses.
Table 5.3 - Numbers of specimens of benthic invertebrate bycatch classified as VME observed during line observations from 2006 to 2015 from 26 vessels. *CPUE - number of specimens observed per 1000 hooks for Spanish and autoline system; ** Echinodermata include Hyocrinida (sea lilies), Cidaroida (pencil urchins) and Euryalida (basket stars).

<table>
<thead>
<tr>
<th>ID Code</th>
<th>Classification</th>
<th>Taxonomic level</th>
<th>Total bycatch</th>
<th>% bycatch</th>
<th>CPUE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AJZ</td>
<td>Alyconacea (Soft corals)</td>
<td>Order</td>
<td>167</td>
<td>1.33</td>
<td>0.017</td>
</tr>
<tr>
<td>AQZ</td>
<td>Antipatharia (Black corals)</td>
<td>Order</td>
<td>204</td>
<td>1.63</td>
<td>0.020</td>
</tr>
<tr>
<td>ATX</td>
<td>Actiniaria (Sea anemones)</td>
<td>Order</td>
<td>290</td>
<td>2.32</td>
<td>0.029</td>
</tr>
<tr>
<td>AXT</td>
<td>Stylasteridae (Hydrocorals)</td>
<td>Family</td>
<td>1774</td>
<td>14.17</td>
<td>0.177</td>
</tr>
<tr>
<td>AZN</td>
<td>Anthoathecatae (Hydroids)</td>
<td>Order</td>
<td>292</td>
<td>2.33</td>
<td>0.029</td>
</tr>
<tr>
<td>BRQ</td>
<td>Brachiopoda (Lamp shell)</td>
<td>Phylum</td>
<td>11</td>
<td>0.09</td>
<td>0.001</td>
</tr>
<tr>
<td>BZN</td>
<td>Bryozoa (Lace coral)</td>
<td>Phylum</td>
<td>249</td>
<td>1.99</td>
<td>0.025</td>
</tr>
<tr>
<td>CSS</td>
<td>Scleractinia (Stony corals)</td>
<td>Order</td>
<td>94</td>
<td>0.75</td>
<td>0.009</td>
</tr>
<tr>
<td>ECH**</td>
<td>Echinodermata (Echinoderms)</td>
<td>Phylum</td>
<td>334</td>
<td>2.67</td>
<td>0.033</td>
</tr>
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<td>GGW</td>
<td>Gorgonacea (Gorgonians)</td>
<td>Order</td>
<td>7478</td>
<td>59.72</td>
<td>0.746</td>
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<tr>
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<td>Pennatulacea (Sea pens)</td>
<td>Order</td>
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<td>0.002</td>
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<td>PRF</td>
<td>Porifera (Sponge)</td>
<td>Phylum</td>
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<td>0.044</td>
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<td>SSX</td>
<td>Ascidacea (Sea squirts)</td>
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<td>Family</td>
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<td>0.012</td>
</tr>
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<td>Zoantharia (Encrusting anemones)</td>
<td>Order</td>
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<td>0.001</td>
</tr>
<tr>
<td>INV</td>
<td>General invertebrate</td>
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<td>919</td>
<td>7.34</td>
<td>0.092</td>
</tr>
</tbody>
</table>

5.4.2. Spatial distribution and hotspots of VME bycatch fauna

The areas fished around South Georgia and Shag Rocks were divided into grid cells of 10 km². CPUE of VME groups caught as bycatch were calculated and the 9 most abundant groups and the total of VMEs were plotted on maps to show abundance and general distribution (Figure 5.3; Figure 5.4; Figure 5.5 and Figure 5.6).
Figure 5.3 - Distribution and relative abundance of bycatch from selected deployments from 2006 to 2015. (A) Gorgonacea - gorgonians (GGW); (B) Stylasteridae - hydrocorals (AXT) and (C) Porifera - sea sponge (PFR). CPUE is the number of specimens per 1000 hooks. Closed benthic areas for bottom longline fishing are shown on black rectangles and contain data from deployments before the implementation of the areas and research lines deployed annually there. The blue line is the 500 m depth contour. Note that a limited amount of longlining is permitted in the closed areas to tag toothfish.
Spatial distribution of gorgonians (GWW) (Figure 5.3A) and hydrocorals (AXT) (Figure 5.3B) around South Georgia showed similar patterns with both groups represented in most of the areas and similar hotspots. Gorgonians were found in 239 grids (66.76%) and AXT in 159 (44.41%) from a total of 358. Sponge (PFR) hotspots were almost exclusively distributed around Shag Rocks and in the slope area located between Shag Rocks and South Georgia (Figure 5.3C). Sponges were rare in the South and South East area.

Echinodermata (ECH) and hydroids (AZN) had limited distribution in the South of South Georgia and increased in abundance further west, notably in the area between Shag Rocks/South Georgia and in the western part of Shag Rocks (Figure 5.4D – E). Sea anemones (ATX) were also common in the area between Shag Rocks and South Georgia, they were less abundant in samples from around Shag Rocks but found east of South Georgia near the latitude 54°S (Figure 5.4F).

Samples containing bryozoans (BZN) (Figure 5.5G) and soft corals (AJZ) (Figure 5.5H) had very limited distributions with the majority of specimens caught between Shag Rocks and South Georgia. In Shag Rocks, soft corals were most abundant in a small area located west of Shag Rocks. In contrast, bryozoans were found predominantly in the southern part of Shag Rocks. Black corals (AQZ) (Figure 5.5I) were most abundant around Shag Rocks and along the east of South Georgia in a similar pattern to that of sea anemones.
Figure 5.4 - Distribution and relative abundance of bycatch from selected deployments from 2006 to 2015. (D) Echinodermata* (ECH); (E) Anthoathecatae - Hydroids (AZN) and (F) Actiniaria – sea anemones (ATX). CPUE is the number of specimens per 1000 hooks. Closed benthic areas for bottom longline fishing is shown on black rectangles and contain data from deployments before the implementation of the areas and research lines deployed annually there. The blue line is the 500 m depth contour.* ECH group include Hyocrinida (sea lilies), Cidaroida (pencil urchins) and Euryalida (basket stars).
Figure 5.5 - Distribution and relative abundance of bycatch from selected deployments from 2006 to 2015. (G) Bryozoa lace corals (BZN); (H) Alcyonacea - soft corals (AJZ) and (I) Antipatharia – black corals (AQZ). CPUE is the number of specimens per 1000 hooks. Closed benthic areas for bottom longline fishing is shown on black rectangles and contain data from deployments before the implementation of the areas and research lines deployed annually there. The blue line is the 500 m depth contour.
The CPUE of all VME groups sum are shown in Figure 5.6. Benthic sessile invertebrates classified as VME were observed in samples around most of the fished areas, except part of the deep slope to the north of South Georgia and to the north-west of Shag Rocks. Fishing occurred in 358 grid cells and in 80 (22%) of them no VME bycatch was reported. The most abundant areas were between the shelf of South Georgia and Shag Rocks and along the western part of Shag Rocks. Most of the hotspots are inside the benthic closed areas, however 3 very dense areas were observed outside of the closed areas. The biggest one is situated west of South Georgia just outside of the South Georgia shelf followed by one around Shag Rocks and one in northwest of South Georgia (Green ellipses, Figure 5.6).

![Figure 5.6 - Distribution and relative abundance (CPUE) of all VME groups together from selected deployments from 2006 to 2015. CPUE is the number of specimens per 1000 observed hooks. Closed benthic areas for bottom longline fishing is shown on black rectangles and contain data from deployments before the implementation of the areas and research lines deployed annually there. The blue line is the 500 m depth contour. Green ellipses mark 3 hotspot areas outside of the benthic close areas.](image)

Spearman’s rank correlation was applied to catch rates of VMEs and toothfish (TOP) of each fishing line. Relationships between benthic invertebrate bycatch and catch rates of the target specie (toothfish) by the longline fishery were
positive but very weak (GGW x TOP $r = 0.06$; AXT x TOP $r = 0.04$ and all VME x TOP $r = 0.08$; all p-values significant ($p < 0.001$)).

Invertebrate bycatch (VME groups) bathymetric distribution ranged from 507 to 2125 m around the fishing area. Bycatch rate (CPUE) for the two most abundant groups (GGW and AXT) declined with increasing depth for both fishing gears (Figure 5.7A - B). The same pattern was observed for catch rate of all VME groups summed together (Figure 5.7C). Mean bycatch of VME benthic invertebrates was consistently higher with the Spanish system gear compared from autoline (Figure 5.7A - B - C).

![Figure 5.7 - Bathymetric distribution of the catch rate (CPUE per 1000 hooks) of the most abundant groups and the sum of all of VME groups together around South Georgia divided in 8 depth (m) strata (500-700, 700-900, 900-1100, 1100-1300, 1300-1500, 1500-1700, 1700-1900m and 1900-plus) and fishing gear system. Chart A = GGW – Gorgonians; Chart B = AXT – Hydrocorals and Chart C = All VMEs groups. CPUE is shown as number of specimens per 1000 hooks. Axes Y have different scales. Individual standard deviations are used to calculate the intervals.](image)

In order to test possible differences between catch rates of VMEs (CPUE) with fishing gear (type of gear * type of hook * soak time) and fishing areas (depth*5 grids (areas) - Figure 5.2), a general linear model was developed and applied.
Soak time was similar for both gears types. It increased with depth and ranged from 3.8 to 74.96 hours (average = 22.71; SD = 11.68) for autoline and 4.26 to 74.51 hours (average = 20.62; SD = 10.78) for the Spanish system. Figure 5.8A shows mean hours of soak time per fishing gear and depth and Figure 5.8B catch rate of VMEs by soak time. Lines with less than 5 hours soak time were removed due the low occurrence (n = 6).

Two types of hook (straight (J) and circle) were observed but circle hooks were only used on the autoline system (Figure 5.9). The GML interaction showed that hook type (p = 0.98) and soak time (p = 0.26) were not significant factors and did not interact with the catch rates of the VMEs (Table 5.4). They were removed to simplify the model and consequently produced a lower AIC value (3459.5 to 3157.5).
Figure 5.9 - Catch rate (CPUE per 1000 hooks) of VMEs from the autoline system by circle (1) and straight (2) hooks. Depth bins are in meters (200). Individual standard deviations are used to calculate the intervals.

Catch rates were significantly different between the Spanish and autoline gear types. The Spanish system CPUE of bycatch was higher than on autolines. Statistical differences were also found between areas but only the South East was statistically different to others (p < 0.05). No difference in catch ratios of VME catches between Shag Rocks and North West, South West and North East were found.

Table 5.4 - Parameters of the GLM used. First model includes soak time and hook type, but they were removed from the second model.

| First model          | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|---------|
| (Intercept)          | 2.436e+00| 3.901e-01  | 6.245   | 4.24e-10*** |
| Areas                | -1.129e-01| 2.135e-02 | -5.288  | 1.24e-07 ***  |
| Depth_bin            | -2.179e-03| 2.464e-04 | -8.847  | 2e-16 ***   |
| Line_type            | 1.214e+00| 1.036e-01 | 11.717  | 2e-16 ***   |
| Hook_type            | -2.460e-03| 1.514e-01 | -0.016  | 0.982     |
| Soak_time            | -2.495e-02| 3.465e-03 | -7.201  | 0.265     |
| Areas:Depth_bin      | 8.032e-05| 1.681e-05 | 4.780   | 1.76e-06 ***|

*Significant codes = 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

| Second model          | Estimate | Std. Error | z value | Pr(>|z|) |
|-----------------------|----------|------------|---------|---------|
| (Intercept)           | 2.432e+00| 3.053e-01  | 7.967   | 1.63e-15 *** |
| Areas                 | -1.128e-01| 2.118e-02 | -5.328  | 9.93e-08 ***  |
| Depth_bin             | -2.179e-03| 2.457e-04 | -8.871  | 2e-16 ***   |
| Line_type             | 1.214e+00| 8.753e-02 | 13.875  | 2e-16 ***   |
| Areas:Depth_bin       | 8.030e-05| 1.674e-05 | 4.797   | 1.61e-06 ***|

*Significant codes = 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
5.4.3. Comparison of two methods of observation and bycatch abundance from trial lines

The two different observation methods used by sea observers to count and identify bycatch of invertebrate benthic fauna were tested. The first is to count all benthic bycatch during line observations (LO) and in the second, crew members who are hauling the fishing line are asked to keep all benthic bycatch in a separate container for later assessment on the deck (DO).

During the LO period the observer counted 698 VME specimens from 14 taxa compared with 1185 specimens from 17 taxa during DO. To test the efficacy of both methods a series of analyses were conducted. First a nMDS plot (Figure 5.10) was generated, which showed significant separation between methods of observation for all samples (LO and DO - p = 0.01; R = 0.403). There was similar dispersion across both methods and it is clear that observation methods strongly influenced what was counted and reported in bycatch composition.

Figure 5.10 - nMDS ordination comparing similarity in bycatch numbers and composition between directly line observation (LO) and deck observation (DO) counts.
When partitioned by depth, comparisons of composition and amount of benthos bycatch using LO and DO showed significant differences (ANOSIM) and separation between the two methods (500 m (p = 0.01; R = 0.52); 750 m (p = 0.01; R = 0.29); 1100 m (p = 0.01; R = 0.76) and at 1500 m (p = 0.01; R = 0.32). The nMDS analyses for each depth are shown on Figure 5.11. The methods were most distinct at upper slope depths (1100 m) and least distinct at the shelf break (750 m).

![Figure 5.11 - nMDS ordination comparing similarity in bycatch composition between directly line observation (LO) and deck observation (DO) counts from different depths (500, 750, 1100 and 1500 m).](image)

The number of specimens counted from the 8 most abundant VME taxa groups (area Z1 and Z2) by line segment and methods of observations (LO x DO) are investigated below.

Bycatch rate was higher for all VME groups counted using the deck observation method (Figure 5.12 and Figure 5.13). The differences between groups varied significantly according to the VME groups.
Figure 5.12 - Means of CPUE of the most abundant VME bycatch group per line segment for area Z1. Standard deviations are used to calculate the intervals.
Figure 5.13 - Means of CPUE of the most abundant VME bycatch group per line segment for area Z2. Standard deviations are used to calculate the intervals.
Bycatch rate was higher for all VME groups counted using the deck observation method (Figure 5.12 and Figure 5.13). The differences between groups varied significantly according to the identity of the VME groups. Bycatch rates between LO and DO were not significantly different for the groups GGW and AXT at any depths (500, 700, 1100 and 1500 m) in the two distinct areas (Z1 and Z2) (Table 5.5).

Table 5.5 - Summary of statistics to test differences between CPUE rates from direct line observation (LO) and deck observation (DO) per fishing area (Z1 and Z2). GGW = Gorgonacea (gorgonians); AXT = Stylasteridae (hydrocorals); PFR = Porifera (sponges). ANOVA one way values are shown in black (F-value and p). Kruskal-Wallis test values are shown in blue (H-value and p). p values <0.05 are shown in bold. * Statistics tested were not performed due to the zeros counts during line observation method (LO).

<table>
<thead>
<tr>
<th>Area Z1</th>
<th>GGW</th>
<th>AXT</th>
<th>PFR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value - H value</td>
<td>p</td>
<td>F value - H value</td>
</tr>
<tr>
<td>AU 500</td>
<td>0.03</td>
<td>0.87</td>
<td>0.23</td>
</tr>
<tr>
<td>SP 500</td>
<td>0.01</td>
<td>0.904</td>
<td>0.39</td>
</tr>
<tr>
<td>AU 1100</td>
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<td>0.19</td>
</tr>
<tr>
<td>SP 1100</td>
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<td>0.506</td>
<td>0.33</td>
</tr>
<tr>
<td>AU 1500</td>
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<td>0.819</td>
<td>0.01</td>
</tr>
<tr>
<td>SP 1500</td>
<td>0.01</td>
<td>0.909</td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>AXT</th>
<th>PFR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value - H value</td>
<td>p</td>
<td>F value - H value</td>
</tr>
<tr>
<td>AU 500</td>
<td>0.44</td>
<td>0.508</td>
<td>0.01</td>
</tr>
<tr>
<td>SP 500</td>
<td>0.01</td>
<td>0.965</td>
<td>0.44</td>
</tr>
<tr>
<td>AU 750</td>
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<td>0.566</td>
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</tr>
<tr>
<td>SP 750</td>
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<td>0.251</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Porifera (PFR) counts at Z1 were statistically different at SP 500m and SP 1100 but not at SP 1500 m (Table 5.5). No PFRs were counted during autoline observations at 500, 1100 m and at 1500 m a very low amount was recorded. In comparison using the DO methodology, PFR were counted on all line segments (Figure 5.12). In area Z2, PFR was counted constantly during DO but only once at SP 750 m during LO (Figure 5.13) and they are not statistically different (p = 0.289).
For hydroids (AZN), one specimen was counted at AU 1500 m in area Z1 and one in area Z2 at SP 750 m but it was counted at all depths and areas using the DO method (Figure 5.12 and Figure 5.13).

All other groups followed similar pattern with counts using LO methodology being much lower than the DO. Specimens from groups such ATX, CSS and SZS were, in most cases, not counted by LO method.

From 30 lines (15 SP and 15 AU) deployed and using deck observation method, 1185 specimens were counted, of which 1159 were identified to 17 VME taxa groups (Table 5.6). A total of 174 stones with bycatch encrusted or fixed were also counted during observations as they normally come attached to the VME specimens. Bycatch occurred in all lines and both fishing gears caught specimens from all VME groups. In general, the Spanish system caught more specimens with 677 comparing with 508 of autoline.

The most abundantly caught groups in the entire study area were Gorgonacea (GGW) with 405 specimens (224 SP; 181 AU) counted as bycatch. The other most abundant bycatch taxa were Stylasteridae (AXT) with 235 (146 SP; 89 AU), Bryozoa (BZN) 146 (68 SP; 78 AU), and Porifera (PFR) with 99 (53 SP; 46 AU) specimens. Catch data per system and area was standardised using CPUE catch rate per 1000 hooks and its show on Table 5.6.

Catch data from the longline trails (CPUE) were compared between fishing gears (AU and SP) by depth and areas. The mean of bycatch rates was higher for the majority of all VME groups on the Spanish system when compared with autoline system per area and depth (Figure 5.12 and Figure 5.13).
Table 5.6 - Median of CPUE (per 1000 hooks) bycatch per VME group counted by deck observation method. Area: **Z1** = zone 1; **Z2** = zone 2; Gear: **AU** = Autoline; **SP** = Spanish system; Depth in meters; **AJZ** = Alcyonacea (Soft corals); **AQZ** = Antipatharia (Black corals); **ATX** = Actiniaria (Sea anemones); **AXT** = Stylasteridae (Hydrocorals); **AZN** = Hydroidolina (Hydroids); **BRQ** = Brachiopoda (Lamp shells); **BWY** = Pachylyasmatidae (Goose barnacles); **BZN** = Bryozoan (Lace corals and sea moss); **CVD** = Echinoidea Cidaroidea (Pencil sea urchins); **CWD** = Stalked crinoids (Sea lilies); **CSS** = Scleractinia (Stony corals); **GGW** = Gorgonacea (Gorgonians); **OEQ** = Euryalida (Basket stars); **PFR** = Porifera (Sea sponges); **SSX** = Ascidiacea (Sea squirts); **SZS** = Serpulidae (Tube worms); **ZOT** = Zoantharia; Stone = Pebbles or stones brought onboard and VME = All VME groups combined together. Groups in bold are part of the VME taxa guide (CCAMLR, 2009)

<table>
<thead>
<tr>
<th>Area</th>
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<th>Depth</th>
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<th>AQZ</th>
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<th>AZN</th>
<th>BRQ</th>
<th>BWY</th>
<th>BZN</th>
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<th>CWD</th>
<th>CSS</th>
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<tbody>
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</tr>
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When data was pooled (all VME groups together), mean SP catch rate was higher at all depths and areas but only statistically different at 1100 m ($p = 0.004$) and 750 m ($p = 0.048$) in area Z1 and Z2 respectively (Figure 5.14 and Figure 5.15).

![Figure 5.14 - Mean bycatch of VME groups: VME (all VME groups combined), GGW (Gorgonians), AXT (Hydrocorals), PFR (Porifera) and stones (pebble and drop stones) counted from 3 autoline (AU) and 3 Spanish system (SP) deployments for each depth (500, 1100 and 1500 m) and fishing zone Z1. CPUE is per 1000 hooks. Individual standard deviations are used to calculate the intervals. Y-axes have different scales. Statistic tests are shown for each depth and system per bycatch group and number of stones. One-way ANOVA applied when parametric assumptions were fulfilled otherwise Kruskal-Wallis test was applied (marked when text is shown in blue (H-value and p). p values <0.05 are shown in red.]

In area Z1, GGW ($p = 0.024$) and AXT ($p = 0.013$) catch rates were also higher on SP when compared with AU but only statistically different at 1100
Differences were also significant for GGW at 500 m ($p = 0.027$) and AXT ($p = 0.007$) at 750 m in area Z2 (Figure 5.14 and Figure 5.15).

Statistical analysis of the CPUE rate of stones/pebbles detected significant differences at 1100 m (Z1) between SP and AU. The number of stones caught at this depth by the SP was nearly 250% more than AU (Figure 5.14).

Figure 5.15 - Mean of bycatch of VME groups: VME (all VME groups combined), GGW (Gorgonians), AXT (Hydrocorals), PFR (Porifera) and stones (pebble and drop stones) counted from 3 autoline (AU) and 3 Spanish system (SP) deployments for each depth (500 and 750 m) and fishing zone Z2. CPUE is per 1000 hooks. Individual standard deviations are used to calculate the intervals. Y-axes have different scales. Statistical tests are shown for each depth and system per bycatch group and stones. One-way ANOVA applied when assumptions for parametric tests were fulfilled. $p$ values $<0.05$ are shown in red.
5.4.4. Primary and accessory bycatch taxa

Hooked specimens (primary) and non-hooked bycatch specimens (accessory) caught during deck observation were analysed. From a total of 1185 specimens observed, 538 specimens (45.44%) belonging to 12 different taxa were directly caught through direct entanglement by hooks on the Spanish and autoline systems (circled yellow in Figure 5.16). In addition, 174 pebbles and drop stones were counted, which were associated with bycatch specimens, but only 11 (6.32%) of these were observed to be directly hooked (Figure 5.17E). Thus the majority of the specimens observed (54.56%) were classified as accessory bycatch i.e., not directly snagged by the hook (Figure 5.16 and Figure 5.17).

Figure 5.16 - Example of a primary and accessory bycatch caught by an autoline system (detail). A hooked Stylasteridae hydrocoral (primary bycatch) on a large stone (24 kg) with at least 18 different species associated with it, including specimens of Gorgonacea, Porifera, Polychaeta, Bryozoa and Hydrozoa.

Groups such as AQZ (Cnidaria, Antipatharia), BRQ (Brachiopoda, Articulata) and CVD (Echinoidea, Cidaroidea) where all directly entangled by being hooked
and OEQ (Euryalida) had a high percentage of specimens directly hooked (83.33%) however all of them showed very low abundance in samples. The most abundant groups AXT (Stylasteridae, N=235) and GGW (Gorgonacea, N = 405), were usually directly entangled (79.15% and 71.85% respectively) (Figure 5.18).

The benthic groups with a low percentage of specimens directly hooked were SZS (Annelida, Serpulidae, N=91 – 21.98%), AJZ (Cnidaria, Alcyonacea, N=7 –
14.29%) PFR (Porifera, N=99 – 12.12%), BZN (Bryozoa, N=146 – 4.11%), ATX (Cnidaria, Actiniaria, N=35 – 2.86%) and CSS (Cnidaria, Scleractinia, N=43 – 2.33%) (Figure 5.18).

Groups such as CWD (Echinodermata, Crinoidea, stalked crinoids), ZOT (Cnidaria, Zoantharia), BWY (Arthropoda, Crustacea, Cirripedia - goose barnacles) and AZN (Cnidaria, Hydrozoa - hydroids) were all never directly entangled directly by hooks. Other examples of bycatch groups not directly caught by fishing gear, which were not quantified in the present study, included sea urchins without pencil spines (Echinoidea), amphipods, isopods, gastropods, bivalves and burrowing sedentary polychaetes.

Figure 5.18 - Percentage of bycatch (left Y axis) per group catch as primary or accessory bycatch during deck observation. ♦ Total number of specimens observed is shown on the right Y axis. PFR = Porifera (sponges); ATX = Actiniaria (anemones); AJZ = Alcyonacea (Soft corals); BZN = Bryozoa (lace corals and sea moss); GGW = Gorgonacea (gorgonians); AXT = Stylasteridae (Hydrocorals); CSS = Scleractinia (stony corals); AQZ = Antipatharia (black corals); BRQ = Brachiopoda (lamp shells); SZS = Serpulidae (tube worms); OEQ = Euryalida (basket stars); CV = Echnoidea Cidaroida (pencil urchins); Stone = Pebbles or stones brought onboard.
5.4.5. Observer data quality assessment

Bycatch data was available from 82 fishing trips from 2006 to 2015. The data shows high variability in terms of the quantity of specimens recorded and number of taxonomic groups identified by observers in the same fishing area.

Fishing observers on board the longliner Antarctic Bay observed on average more VME taxa groups in their samples than the other vessels. The highest number was observed in 2012 on the San Aspiring. Observers placed on Argos Froyanes and Argos Georgia recorded on average less taxa presence than other ships observers. In total, 2 observers on San Aspiring (2009 and 2015), 4 observers on Argos Froyanes (2012 to 2015) and 4 on Argos Georgia (2010, 2012 to 2014) did not record any VME group for their entire trips. Each vessel had one trip where just one VME taxa group was recorded (Figure 5.19).

![Figure 5.19 - Number maximum per line of VME taxa groups identified by sea observer per vessel and year. VME groups taxa according to CCAMLR invertebrate guide (CCAMLR, 2009).](image)

To investigate these differences or if the lack of VME records was caused by the spatial distribution of fishing effort with vessels targeting areas known to have low VME abundance. Four fishing vessels (3 AU and 1 SP) were chosen to show the distribution of fishing effort and catch rates for the 3 most abundant
VME bycatch groups (GGW, AXT and PFR) per year (From Figure 5.20 to Figure 5.31). These 4 vessels have been fishing together consecutively since 2009.

Figure 5.20 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Argos Froyanes from 2009 to 2015. Dark dots represent line hauls with zero records of GGW (Gorgonians). Yellow circles represent density of specimens (CPUE per 1000 hooks).

Argos Froyanes (AU) fishing distribution showed similarity between the years especially in Shag Rocks and to the north of South Georgia. NW of Shag Rocks was heavily fished from 2009 to 2013, but there was less effort in this
area in 2014 and 2015. Bycatch rates of GGW (Figure 5.20), AXT (Figure 5.21) and PFR (Figure 5.22) showed different patterns. GGW was widely reported in Shag Rocks in 2009 and 2011, but totally absent in all other years. GGW were also abundant in the gully (area between South Georgia and Shag Rocks shelf) and were reported in high abundance from 2009 until 2011, but were unreported in 2012, 2014 and 2015 (Figure 5.20).

Figure 5.21 - Spatial and temporal distribution of fishing effort around South Georgia by the Fishing Vessel Argos Froyanes from 2009 to 2015. Dark dots represent line hauls with zero records of AXT (Hydrocorals). Yellow circles represent density of specimens (CPUE per 1000 hooks).
AXT bycatch records around Shag Rocks and the gully area were similar to the GGW, however in 2010 were different from the GGW in that AXT was not reported (Figure 5.21)

PFR records on Argos Froyanes were observed in 3 areas in 2009 and just a single record in 2011 in the gully area (Figure 5.22).

![ARGOS FROYANES - PFR](image)

Figure 5.22 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Argos Froyanes from 2009 to 2015. Dark dots represent line hauls with zero records of PFR (Sponges). Yellow circles represent density of specimens (CPUE per 1000 hooks).
Antarctic Bay (SP) fishing spatial distribution was normally well distributed apart from South East and, exceptionally in 2009, where the vessel targeted just the gully area. GGW (Figure 5.23) and AXT (Figure 5.24) bycatch was also spread around the fishing area expected in 2010 where zero GGW bycatch was reported.

Figure 5.23 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Antarctic Bay from 2009 to 2015. Dark dots represent line hauls with zero records of GGW (Gorgonians). Yellow circles represent density of specimens (CPUE per 1000 hooks).

PFR were not recorded during fishing operations in 2010 and only one specimen observed in 2015. However fishing spatial activity was very similar to
2014 where sponges were recorded especially around Shag Rocks and south-west of South Georgia (Figure 5.25).

Figure 5.24 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Antarctic Bay from 2009 to 2015. Dark dots represent line hauls with zero records of AXT (Hydrocorals). Yellow circles represent density of specimens (CPUE per 1000 hooks).
Figure 5.25 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Antarctic Bay from 2009 to 2015. Dark dots represent line hauls with zero records of PFR (Sponge). Yellow circles represent density of specimens (CPUE per 1000 hooks).

Observers working on Argos Georgia (AU) only reported VME bycatch in 2011 and in 2015. GGW (Figure 5.26) was observed in 2011 and 2015 and AXT (Figure 5.27) just in 2011. PFR (Figure 5.28) were never recorded by the observers.
Figure 5.26 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Argos Georgia from 2009 to 2015. Dark dots represent line hauls with zero records of GGW (Gorgonians). Yellow circles represent density of specimens (CPUE per 1000 hooks).
Figure 5.27 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel Argos Georgia from 2009 to 2015. Dark dots represent line hauls with zero records of AXT (Hydrocorals). Yellow circles represent density of specimens (CPUE per 1000 hooks).
During the study years, the autoliner San Aspiring set most of its lines to the south of the island. In 2009 and 2010 little fishing effort was undertaken around Shag Rocks. Observers reported GGW as bycatch (Figure 5.29) from 2009 to 2013. However in 2014 and 2015 there was not a single record of GGW.
AXT (Figure 5.30) was observed from 2010 to 2013 but observer only recorded AXT from a single line. The majority of the records were observed around Shag Rocks. PFR (Figure 5.31) observations made by observers were very similar to the AXT.
Figure 5.30 - Spatial and temporal distribution of fishing effort around South Georgia by the fishing vessel San Aspiring from 2009 to 2015. Dark dots represent line hauls with zero records of AXT (Hydrocorals). Yellow circles represent density of specimens (CPUE per 1000 hooks).
5.4.5.1. Comparison between longline trials and general observer data

CPUE of all VME catch and number of VME taxonomic groups were compared between longline trials and observer data selected from a small area (radius of 60 km) around the position of the longline trials (Shag Rocks).

The number of VME taxa groups identified per fishing line was always higher during trials compared with the observer identification for all depths and both gears (AU and SP) (Figure 5.32A and B).
Figure 5.32 - Number of VME groups identified per depth and fishing gear system on a selected area at Shag Rocks. (A) Data from longline trials and (B) from observer deployments. Fish gear (AU = autoline; SP = Spanish system). Depth (m) bins (500 = 500-600; 700 = 650-750; 1100 = 1050-1150 and 1500 = 1450-1550). Note: Y-axes have different scales. Individual standard deviations are used to calculate the intervals.

CPUE bycatch of VMEs were also higher during line trials than observer counts for all depths and gears (Figure 5.33).
Figure 5.33 - CPUE catch data from all VMEs groups per fishing gear and depth on a selected area at Shag Rocks. (A) Data from longline trials and (B) from observer deployments. Fishing gear (AU = autoline; SP = Spanish system). Depth (m) bins (500 = 500-600; 700 = 650-750; 1100 = 1050-1150 and 1500= 1450-1550). Note: Y-axes have different scales. Individual standard deviations are used to calculate the intervals.

To increase size sample, data was pooled without fishing gear as factor and statistics analyses were applied for CPUE and number of VME groups identified. A Kruskal-Wallis test on CPUE data showed that, except for sets at 700 m, counts between observers and sea trials were statistically different (H = 1.63; P = 0.201) (Figure 5.34 – red ellipse).
The number of VME groups identified during the trials were higher than observer’s identification data and statistically different in all depths (Kruskal-Wallis; $H = 182.25$; $P = 0.001$) (Figure 5.35).

Figure 5.34 - CPUE catch data from all VMEs groups per depth and source of data (trial and observer data- OBS) on a selected area at Shag Rocks. Depth (m) bins (500 = 500-600; 700 = 650-750; 1100 = 1050-1150 and 1500= 1450-1550). Individual standard deviations are used to calculate the intervals.

Figure 5.35 - Number of VME groups identified per depth bin on a selected area at Shag Rocks. groups per depth and source of data (trial and observer data- OBS) on a selected area at Shag Rocks. Depth (m) bins (Deep slope (500 = 500-600; 700 = 650-750) and Deep slope (1100 = 1050-1150; 1500= 1450-1550). Individual standard deviations are used to calculate the intervals.
5.5. DISCUSSION

CCAMLR VMEs are defined according to their ecological characteristics including areas containing high abundances of species that are endemic, habitat forming, vulnerable to fishing gears, or requiring decades for recovery from fishing impacts (Parker and Bowden, 2010). Clearly larger more 3 dimensional growth structures are most likely to be snagged on hooks and lines, but whether such taxa are habitat forming, endemic and slow growing requires some detailed regional scientific knowledge of the species in question.

The current study found that members of the Phylum Cnidaria dominated the bycatch designated as VME. These were caught by both AU and SP gear types which is unsurprising given the tall, erect and branching form of many octocorals and gorgonians – which give the largest hard surface area for hooks to entangle in.

Differences were found between observer data and longline trails for the same area. Abundance of Cnidaria was higher in the observer data with 84.78% against 68.02% on line trails. Porifera was the second most abundant group responsible for 3.5% of all records made by observers compared with 8.4% found on trials. Taylor (2011) also found cnidarians dominated South Georgia bycatch (almost 80% of bycatch) using the same source of data (observer database), but from 2005-2009. In the same study, Porifera made around 5% of all samples recorded and Echinodermata was the second most abundant group with ≈7% in contrast with 2.3% found on trials and 2.7% on the observer data. However, it is not clear that Taylor (2011) included just VME groups in the echinoderms (Stalked crinoids, Euryalida and Cidarоidea).
Further differences between studies were found at greater taxonomic resolution within the Cnidaria. 50.2% and 29.1% of all Cnidaria were identified as Gorgonacea and Stylasteridae respectively compared with ≅71% and ≅17% collated by Taylor (2011).

Bathymetric distribution of CPUE bycatch of cnidarians from observer and trial data declined with depth. Wakeford et al. (2006) and Martin et al. (2012) found similar patterns studying similar areas. At depths up to 900 m, the present study found high variability in catch rates of VME groups with high habitat heterogeneity.

Spatial distribution from observer bycatch VME data showed that different groups of VME have contrasting distribution patterns. Gorgonians (GGW) were the most widely distributed VME group in samples, followed by hydrocorals (AXT). GGW were found in 66.76% and AXT in 44.41% of samples across the total fishing area. Wakeford et al. (2006) also found GGW the most well distributed groups followed by the class Hydrozoa. However comparisons of the present study with such data are difficult because of differing levels of resolution (in the present study the class Hydrozoa was separated and it was counted as family (Stylasteridae - Hydrocorals) and order level (Anthoathecatae - Hydroids).

A major aim of the current work was to compare benthic bycatch between the Spanish (SP) and autoline (AU) longline methods. Sessile invertebrates are caught by fishing hooks through physical contact during line movement. These line movements are predominantly during hauling, when the line is dragged on the seabed and, to a lesser extent during setting, while the line settles down.
It is believed that the “snagging” occurs more frequently when the line is being retrieving during hauling. Kilpatrick et al. (2011) studying autolines in the Ross Sea fishery found that line behaviour during hauling is probably responsible for the catch of VME specimens.

Catch rates did reveal significant differences in observer data between AU and SP. Previously the invertebrate bycatch of the Spanish and autoline systems has been reported to have different catch rate. For example, Martin et al. (2012) found that the Gorgonacea bycatch was much higher from vessels using the SP system compared with the AU system at South Georgia. In contrast Gerrodette and Watters (2012), studying all VME groups in the Ross Sea, found that AU vessels caught much more benthic bycatch than those using SP. However, it is thought that observers on Ross Sea autoliners may have been very diligent at reporting bycatch (Collins pers com). In the current study, observer data of SP catches were higher and significantly different from those using AU. The study also indicated no evidence that other components of the gear, such as hook type, influenced the catch rate as no significant differences were found.

Soak time (one hour bins) was also investigated as it can have a direct effect on bait availability on hooks and consequently may change the snagging area of the hook during hauling affecting catchability. Collins et al. (2002) and Yau et al. (2002) found that scavenging fauna, such as lithodid crabs and various amphipods arrive rapidly at bait (see Smale et al., 2007). Video and stills camera observations (e.g. those from the recent RRS James Clark Ross cruise [JR262 and JR287] and from the current study) suggest that scavenger densities and compositions are broadly similar around South Georgia within the
bathymetric shelf-slope range of this study (500 to 1500m). Consumption of bait may depend on many factors (Smale et al., 2007) not least the density of scavengers and the type of bait. Anecdotal observations during trials using mixed bait showed that squid seems to have greater duration on the hook than sardine, perhaps due to its harder flesh. Observer data showed no statistical difference in soak time for CPUE rates for both fishing gears, however, the presence of bait on hooks during hauling may have an effect on the type of benthic bycatch taxa caught that was not tested in the present study. Hooks both with or without bait have been observed catching benthos.

When data from the trials were analysed, SP catch rate was higher on all depths and areas but only statistically different at 750 and 1100 m (Figure 5.14 and 5.15). The low sampling effort (6 lines in each depth) and the reduced spatial coverage of the trails may have biased the results. However, this was the most controlled studied comparing bycatch from the two systems until now. Also, during the same trial no statistically significant differences in species composition were found between gear systems (see chapter 4).

Data at 1100 m (Z1) from SP shows the highest catch rate of VME and drop stones for all trials. Stones are brought onboard mostly because hard structure forms of VME such Stylasteridae and Gorgonacea are attached to them. From 174 stones counted during the trials only 11 of them were hooked directly (Figure 5.17E). The high catch rate of VME species at this particular depth on the SP is due the amount of drop stones caught. Drop stones normally bring VME species associated as they are fixed on the stone increasing the specimen counts. It also should be noted that footage from the underwater camera shows
higher VME per transects in areas were drop stones are presented (chapter 4; Figure 4.36).

According to Hogg et al. (2011) benthos distribution around South Georgia is patchy, although sampling and knowledge levels are also patchy. However real patchiness in richness and abundance was confirmed using line cameras. Underwater footage from fishing line deployments showed over a distance of just few meters that biological coverage could change drastically (see Figure 5.36). Such contrasts in local biodiversity could explain the high variability in catch amount (CPUE) between lines deployed during trials, although this is more likely to be a contributory factor to complex causes. SP and AU lines were set in similar positions, however as described in chapter 2, they use different weight systems so their sink speeds differ and thus they may not land at the same position as desired due to differential drifting.

Figure 5.36 - Underwater footage recorded at 550 m from a Spanish deployment showing patchy distribution of the benthic invertebrate fauna.

Efficient and effective data collection is fundamental and can mean the difference between a successful management or research effort and one that ends in inconclusive or useless information (Johnson and Nielsen 1983).
The CCAMLR scientific observer program, especially in the toothfish fishery, is recognized as one of best in all Regional Fisheries Management Organizations (RFMOs) (Gilman et al., 2012). In South Georgia there is 100% observer coverage (observers are on all fishing vessels) and aim to observe at least 25% of all hooks hauled. Also, observers are required to have minimum scientific qualifications required by the supplier company (historically MRAG – London), which in other areas such as the Ross Sea is not necessarily required.

Observer bias and competency is often an issue with multiple observer data sets. When data sets from observer data and trails were compared, a significant difference was found in the number of VME taxa groups observers were able to identify for the same fishing area. Observers identify in all sampling depths a much lower number of VME taxa groups. When data of distribution of VME taxa is plotted annually it is easy to spot differences in the spatial distribution and amount reported by observers in the same area. It is not clear why this difference appears as all observers are instructed to collect the same data.

Observers onboard of four fishing vessels that operated annually since 2009 did not report a single VME bycatch during 10 fishing trips. From the samples collected during trials and the experience of the author in the area (more than 5 years working as fishing observer) it is impossible that an observer after watching more than 370000 hooks on a trip (average of hooks observed per fishing trip in the last 6 years) did not report a single hooked VME. It seems that some observers are not fully implementing the scientific protocols.

Parker et al. (2009) also found problems with observer identification on New Zealand vessels targeting toothfish in the Ross Sea. They concluded that most
of the time observers were able to distinguish correctly between taxonomic groups at order and class level. However this was likely to vary with taxon, as for some even experts need microscopes.

At South Georgia benthic bycatch data has been recorded by observers since early 2000s, however some of this data is unreliable and not comparable as it was not collected systematically by all observers. Most benthos registered in the early collections were not identified and merely recorded as “invertebrate” or occasionally at Phylum level. This was probably driven by the usability and availability of reliable identification guides, absence of standard ID codes and specific training of observers in identification of benthic bycatch.

Personal observation of observer behaviour showed on a number of occasions that certain taxa, notably sponges, bryozoans and hydroids, especially small specimens, were not identified or reported. Therefore at South Georgia at least, and probably for most geographic locations, observer-recorded invertebrate data must be treated with much caution. As part of the work of this thesis, I have created a new guide, specifically aimed at observers in the South Georgia region, which is attached as an annex 2. The CCAMLR codes are shown beside colour images of each group and clear signals showing if the group is a VME which should aid and speed up observer identification of bycatch. Also a series of vials containing part of the bycatch identified in this work will be sent to the observer provider company. This benthic library would be used as part of training on identification of invertebrate bycatch.

A list of recommendations to improve observer invertebrate data collection was sent to MRAG. Most important actions are:
• A complete update of the invertebrate list codes in the database. For example, basket starts (OEQ) was found in 3 other codes (OWP, OOF and ECH).

• The addition of a general code for VME taxa in the database. If observers do not have the skills or time to identify invertebrates down to order or class at least it could be identified as VME specimens. Currently everything that is not identified by observers are given the code INV (general invertebrate). It means that specimens of sea stars and sea cucumbers, for example, are put in the same group of sponges and corals if not identified.

• Data quality checks were already in place but just for vertebrate species. Database quality control queries for invertebrate should be implemented to calculate the number of VME groups identified by line/trip. Also, spatial distribution of the fishing effort and CPUE of the most important VME groups could inform if the data is valid when compared with historical data.

• A mechanism that data sets should be flagged as inappropriate in the master database if it is the case. This will avoid in the future that the data is used by scientists in general queries.
CHAPTER SIX
6. GENERAL DISCUSSION

Over the last couple of decades a huge body of work has developed on the global, regional and local impact of fisheries. Many scientific studies make the case that, despite massive negative impacts on biodiversity from ‘climate change’, pollution and habitat loss, there is evidence to suggest that overfishing could be the most important impact of all (e.g. see Jackson et al., 2001). Thus interaction of the scientific community and the fishing industry has generally become one of conflict by limiting and reducing catches, quantifying impacts and policing. On a small scale though there have been successful projects all over the world, where the fishing industry and fisherman have been seen as part of a solution to sustainability and conservation of sources (e.g. Nordlund et al., 2013). Rarely however has the fishing industry been suggested as a key scientific tool to investigate marine biodiversity and thereby attempt to bolster and provide support for the management and conservation of resources. The main theme of this thesis was to investigate, exactly that; whether the longline fishery at South Georgia could be a powerful tool in exploring the benthic biodiversity around the remote Southern Ocean archipelago of South Georgia.

The historical context of resource harvesting at South Georgia is perhaps typical of global fishery problems, serial overfishing of target species (e.g. whales) cascading along a value scale. Although the Patagonian toothfish fishery also quickly developed a large unregulated and unsustainable component, this was quite quickly and effectively curbed. As a consequence of the restricted number of licences issued the willingness and scope for enforcement, the relationship and co-operation between fishing companies and the authorities (GSGSSI) around South Georgia, the outlook has become very
positive. The current work shows the value of such close co-operation – in that it is very clear that biodiversity information from fishing vessels can be a considerable and significant support to that from scientific surveys. The thesis describes the two longline systems currently deployed around South Georgia, historically on the continental shelf and slope, but now from the shelf break (~700m) down to lower slope depths. The focus of the research is the mega- and macrofaunal epifauna (the larger animals living on the surface of the seabed), particularly the so-called Vulnerable Marine Ecosystems (VME). The thesis explores such communities by analysis of what forms the invertebrate bycatch caught by both gear types across different areas and depths. In addition, the work developed novel equipment and techniques to visualise the seabed using cameras on fishing lines.

Cameras were also used on board to investigate collection of data by scientific observers. The installation of an electronic monitoring system (EM) used waterproof CCTV cameras on a longliner to compare strengths and weaknesses of human vs remote observers during the toothfish season. There is a limit to the amount of work that scientific observers can be asked to do, so any method of increasing efficiency and accuracy may become crucial to facilitate the collection of further high quality data. It was clear when VME observer data was compared with the trials at Shag Rocks how poor some identification and counting by observers. Electronic monitoring systems would help observers achieve most of their daily tasks quicker. The extra time gain would be crucial to collect quality VME data much needed for South Georgia.
This thesis reports how the South Georgia longlining fishery involves two quite different gear types, the Spanish (SP) and autoline (AU) system, which have been changed over the time. The thesis also documents distinct differences in the way that the gear (between these two types) settles on the seabed and thus interacts with benthic biodiversity. Investigation of the different weighting, hook and fibre regimes used across the SP and AU systems, with respect to invertebrate bycatch, were complicated by potential additional (possibly confounding) influences of depth, area and observer.

Whereas all parts of an AU system from anchor to anchor are in direct contact with the seabed due to the negative buoyancy of all its parts (Welsford et al., 2014) just hooks and weights of SP are in contact with the seabed. When hook type was tested with VME CPUE using observer data, no significant difference was found. However the two hook types tested here (Circle and “J”) were found just on the autoline system. Circle hooks are not deployed in the SP system due the difficulty of manually baiting on curved hooks.

There was an a priori expectation that the contrasts in SP and AU gear configuration would lead to catch different invertebrate bycatch, in both composition and abundance. A common perception amongst observers was that SP catches were associated with more invertebrate bycatch than AU (Martin et al., 2012; Gerrodette and Watters, 2012). The current study, using observer data, found a statistical difference in VME catch rates between gears. CPUE was higher using SP than AU at all depths. Using trial data, statistic difference was only found at 1100 m (Z1) and 750 (Z2) and no clear trend existed. However, sampling effort was limited to 30 lines in total. Notably, both gear types showed high variance in amount of bycatch per line segment.
perhaps explaining the lack of statistical difference between them in other depths. However no significant difference was found in terms of taxon composition of bycatch between AU and SP systems.

Some characteristics of the Spanish system may contribute for the higher CPUE when compared with autoline. Snoods are bigger on SP and once line is being retrieved these long snoods will help hooks stay in contact with the sea floor for more time. Also SP uses a series of weights every 40 m different from the modern autolines which use integrated weight lines without external weights. This external weights (around 9 kg each) will also keep the fishing line for more time on the sea floor during hauling.

Scientific visualising of the seabed (e.g. Camera lander images from the scientific cruises to South Georgia JR262 and JR287) suggested that the dominant megabenthic structures on the seabed at shelf depths were corals of various types. The current study also collected imagery of the seabed from the deep shelf and slope. The cnidarians (corals, gorgonians, hydrocorals etc) dominance of South Georgia shelf and slope habitats was supported by both the cameras deployed on fishing lines and in terms of bycatch by both SP and AU gear types.

It was clear from the underwater footage captured that the sessile benthic fauna is caught during hauling when line movements are observed. In contrast, other mobile invertebrates were caught during soak time as they fed directly on the bait, these included sea stars (asteroid echinoderms) and stone crabs (lithodid crustaceans). Sessile benthic invertebrates were observed to be hooked in two different ways; the first and more common observation was by being hooked on an anchorage point – snagging of branches of gorgonians, hydrocorals or
through holes in the stones they are on. Alternatively, the hook pierced the tissue of softer bodied specimens, such as soft corals, sponges and some gorgonians (Paragorgiidae). Bycatch could be categorising another way - by primary (directly hooked) or accessory (collected due to association with primary catch – e.g. epibiota of a coral caught or encrusting the same rock of a coral caught). By such classification scheme, the majority of the specimens collected in this study were accessory. These characteristics make bycatch of longlines highly selective due the stochastic nature of benthos being caught by hooks or not. The richness of bycatch largely depended on accessory bycatch as snagging of a hydrocoral for example can bring up the rock it is attached to containing many species of bryozoans, sponges and polychaetes. The distribution of biodiversity on the seabed is, as in deeper waters (see Kaiser et al., 2007) intensely patchy, with many species present on 'oases' of boulders with less rich sand and sediment between them.

There is a worldwide concern about impacts caused by deep fishing (Hiddink et al. 2006, UNGA, 2007; Sharp et al., 2009) due to the complexity and potentially slow recovery times of deepwater habitats. To date though, there has been no common agreement on the actual impact of bottom longline but common agreement that is limited (Pham et al., 2014; Welsford et al., 2014). Studies on direct impacts on bottom longline fishery showed potential impacts from not just the movement of the gear during hauling, but also on its lost parts (Bo et al., 2014). This new approach should be considered in South Georgia, especially from SP sets, where the fishing line is regularly snagged due its fragility (3 mm - monofilament; 5 mm - braided polypropylene) compared with 12 mm of AU lines).
Since the introduction of bottom longlines in middle of 1980s, more than 43000 lines have been set by licensed vessels on the shelf and slope, totalling more than 293 million of hooks deployed. In the last 3 years, on average around 9.5 million hooks were set annually. Most of the bycatch caught in this study (~84%) were classified, under CCAMLR categorisation, as VME. VME groups are considered, by definition, very susceptible to fishing impacts (Sharp et al., 2009). VME impacts by longline fishing, especially within the region of a major MPA and highly regulated fishery, raise a number of issues even though impact frequency seems to be low. Some key issues are 1) how much impact is sustainable to such assemblages and thus how much bycatch is acceptable? 2) Is the categorization of VME helpful in describing the key impacts? 3) how valuable is the scientific gain from bycatch information and how much does this offset impacts?

The first and second issue are closely related and it is very difficult to find hard data to support or refute. Sustainability of impact is generally taken as recovery rate, which is closely linked to growth (and development rates), which is then taken as ‘vulnerability’. There is a wide range of scientific literature to demonstrate slow growth in Southern Ocean waters, some of this directly compares growth within taxa across regions (see Kowalke et al., 2001, Clarke et al., 2005, Barnes et al., 2007). In all of these, there is a range of growth rates spanning at least two orders of magnitude within each region. Thus it is only true that the fastest growers in the Southern Ocean are an order of magnitude slower than the fastest elsewhere, and that the slowest growers in the Southern Ocean are an order of magnitude slower than the slowest elsewhere. The majority of literature concerns sponges but the recent collapse of parts of the Larson iceshelf revealed that many ‘slow growing’ sponges may grow very
much more quickly in certain circumstances (see Filinger et al., 2013). An added complication is that VME designation is by growth form, yet growth of encrusting species (not VME) may be no faster than those which grow erect within the same taxon (see Barnes et al., 2007). Furthermore how an assemblage recovers can, unsurprisingly, be quite different to the growth rates of individual species. Smale et al. (2008) followed recovery of benthic assemblages in the shallows following iceberg disturbance and found remarkable variance between each event, perhaps strongly influenced by the composition and density of neighbouring undisturbed benthos. It must be noted that although these studies concerned similar biota and took place in the Southern Ocean, the context differs strongly – in that South Georgia is potentially more isolated from potential recruits and the oceanographic conditions are more extreme (e.g. warmer). Thus many of the species within assemblages at South Georgia are at geographical range extremes (Barnes et al., 2009a) and may be considerably more (or possibly less) fragile and perform differently (to values described in the literature). Finally, an argument could be made that endemics, rare and range edge species are more vulnerable than slow growing ones – but it would be highly impractical to require observers or fishers to identify all taxa to species level – a feat which takes scientific professionals many years to do from a research cruise. Thus the definition seems practical, and in many cases such as with octocorals (Taylor, 2011; Taylor, 2013a), aligns well with vulnerability when considered from many viewpoints. However the current study has shown there is, and will remain for some time, significant value from examination of bycatch for assessment of true richness, distribution and range of South Georgia benthic species. The rarer species are likely to be those which will be detected in the coming years and the
ones for which most protection is important under the CBD. Furthermore the current thesis has shown on which bycatch taxa observer effort should be prioritised (those with steepest species accumulation curves – cnidarians, sponges and bryozoans). The cnidarian component is currently underestimated as the list of octocoral species recovered from the field work is currently still under completion.

At South Georgia most of the fishing effort now takes place on a narrow slope, but knowledge of slope biodiversity and ecology is very much lower than that for the shelf (see e.g. Barnes, 2008). The moving of the fishery to deeper waters (to avoid young toothfish impacts and protecting benthic habitat) seems likely to much reduce damage to benthic assemblages (because of higher densities and better growing conditions) but slope recovery rates are likely to be slower (for the same reasons). Observer contributions have provided key evidence to support that and other decisions within the fishery and clearly are greatly aiding improvement of knowledge of the regional benthic biodiversity. An example of this was the introduction of benthic closed areas (BCAs) around South Georgia restricting commercial fishing (scientific trials are permitted) from areas with a high bycatch of VME (GSGSSI, 2012).

Data gathered also from observers in this study strongly suggest that most of the benthic bycatch is concentrated in depths up to 800 m. Currently, bottom longline is prohibited below 700 m. Increasing depth limit to 800 m would reduce bycatch from longliners.
Audio visual contributions

Underwater and fishing routine footage recorded during the field work has been requested by BBC’s Natural History Unit. Pictures from benthic specimens have been also requested to help on a production of a book identification guide of South Georgia waters produced by the GSGSSI and BAS. A field ID guide for scientific observers covering all benthic groups found as bycatch on longliners was constructed by the author and is shown in the annex 2.

Future work and recommendations

Although the evidence from the trials of this study could not confirm any general trends in amounts of bycatch between the two longlining methods present in South Georgia, further research (increased number of sites and samples) should decrease the high (and potentially confounding) variance. The pioneering and bespoke nature of the camera in the current work meant there were inevitable technical faults which reduced the number of successful deployments. As underwater cameras are in constant, fast development and becoming much cheaper they could be attached to more lines which will make possible comparisons between amount of benthic taxa and bycatch seen on deck.

An assessment of potential impacts of the bottom longline fishery on South Georgia is necessary. To date impacts have been measured by focusing on the amount of benthic fauna collected as bycatch. However it is clear from the video footage that impacts go beyond the removal of specimens. Both SP and AU gears have different footprints but to date scientific studies (within the Southern Ocean) are limited to autoline systems that currently form only half the fleet.
targeting toothfish at South Georgia. An immediate approach could be that vessels using the SP system gear should be encouraged to change large concrete/stone weights for higher density and smaller steel hydrodynamic weights reducing dragging area thus benthic impact without compromising sink rate. Also shorter snoods will minimise the time that hooks drag the sea bed once the lines are lifted.

Deployment of compact underwater cameras on the fishing line is a straightforward and cheap way to investigate line behaviour and important for detection of areas of VME high concentration. Currently, just bycatch amounts are used for VME mapping and this thesis recommends a joint camera film and bycatch approach to VME detection by the GSGSSI to improve the management of possible new benthic closed areas (BCAs).

Scientific observers do not necessarily have a benthic ecological background and thus for meaningful data collection, improvement of new guides are extremely important to improve their capacity for identification. The current benthic ID guide used at South Georgia does cover the most important taxon, however a lack of pictures of local fauna makes identification harder and therefore more time consuming. An example of this is the absence of pictures of whip corals (Cnidaria), sponges and bryozoans; all common bycatch associated with drop stones.

Finally the quality of information reported by fisheries observers might be improved by the electronic monitoring scheme used in the current study (chapter 3). Currently observers find the new onboard sampling regime challenging in terms of time. The installation of electronic monitoring system showed that time spent on a normal observation routine during setting and
hauling can be minimised. This would allow more time for better sampling practices to be adopted by scientific observers. Also the entry of fake data (related in other observer schemes; NOAA (2004)) into the database was apparent during the work for this thesis (video evidence of interviews, available by request to the author) - the electronic monitoring system could be a useful tool offering observers’ managers more control to tackle this minor but potentially serious problem.
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## ANNEX 1 – LIST OF MORPHOTYPES

List of species/morphotypes found divided by Phyla around Shag Rocks, South Georgia.

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<th>Phylum</th>
<th>Species/Morphotypes</th>
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<td>Arthropoda</td>
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<td>Amphiopoda sp2</td>
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<tr>
<td>Antarcturus sp</td>
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<tr>
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SOUTH GEORGIA MARINE INVERTEBRATE LONGLINE BYCATCH

PHOTO FIELD GUIDE FOR SCIENTIFIC OBSERVERS
LONGLINE BYCATCH

Benthic invertebrate is caught on longline operations around South Georgia

1 - Hooked specimens could bring associates specimens from different taxonomic groups.
2 - All specimens should be kept during line observation, identified and counted.
Please see benthos protocol.

TAXONOMIC GROUPS
A – Gorgonians (GGW)
B – Hydrooids (AZN)
C – Hydrocorals (AXT)
D – Sea anemones (ATX)
E - Encrusting anemones (ZOT)

COUNTING
GGW = 9
AZN = 3
AXT = 1
ATX = 2
E = 1
How to use the guide

This guide contains 29 different taxonomic groups including 17 groups classified as VME (see CCAMLR benthic ID guide)

Use only codes present in this guide.

Each Phylum is represented by a different colour:

- Phylum Porifera
- Phylum Cnidaria
- Phylum Brachiopoda
- Phylum Bryozoa
- Phylum Annelida
- Phylum Echinodermata
- Phylum Chordata
- Phylum Arthropoda
### HYDROIDS

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<td>Anthoathecata</td>
<td>Actiniaria</td>
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#### AZN - HYDROIDS

- Image 1: Hydrozoan structure with branched tentacles.
- Image 2: Close-up of hydrozoan polyps.
- Image 3: Hydrozoan colony attached to substrate.

#### ATX - ANEMONES

- Image 4: Anemone feeding on prey.
- Image 5: Anemone tentacles extended for capture.
- Image 6: Anemone with defense tentacles raised.
<table>
<thead>
<tr>
<th>Order</th>
<th>Phylum</th>
<th>VMEME</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEA PENS</td>
<td>NTW Pennatulacea</td>
<td>BZN Bryozoa</td>
</tr>
<tr>
<td>LACE CORAL</td>
<td>BRQ Brachiopoda</td>
<td>GYW Bryozoans Cheilostomatida</td>
</tr>
<tr>
<td>LAMP SHELLS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NTW – SEA PENS**

**BRQ – LAMP SHELLS**

**BZN – LACE CORAL**

**GYW – SEA MOSSES**
WOR - SEGMENTED WORMS

**Phylum Annelida**

Calcareous Tubeworms

Serpulidae

Class Polychaeta
<table>
<thead>
<tr>
<th>Phylum Echinodermata</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEA LILIES</strong></td>
<td>Order <strong>CWD</strong></td>
</tr>
<tr>
<td>Hyocrinida</td>
<td><strong>FEATHER STARS</strong></td>
</tr>
<tr>
<td><strong>PENCIL URCHINS</strong></td>
<td>Order <strong>CVD</strong></td>
</tr>
<tr>
<td>Cidaroida</td>
<td><strong>SEA URCHINS</strong></td>
</tr>
<tr>
<td>Camarodona</td>
<td></td>
</tr>
</tbody>
</table>

**CWD – SEA LILIES**

- Stalked

**CVD – PENCIL URCHINS**

- Large spines

**FEA – FEATHER STARS**

- Non stalked

**URX – SEA URCHINS**

- Small spines or absent
Phylum Chordata
<table>
<thead>
<tr>
<th><strong>SEA SPIDERS</strong></th>
<th><strong>Class</strong></th>
<th><strong>PWN</strong></th>
<th><strong>Pycnogonida</strong></th>
<th><strong>KING CRABS</strong></th>
<th><strong>Family</strong></th>
<th><strong>KCX</strong></th>
<th><strong>Lithodidae</strong></th>
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</thead>
<tbody>
<tr>
<td>Phylum Arthropoda</td>
<td>- Subphylum Chelicerata</td>
<td></td>
<td></td>
<td>Subphylum Crustacea</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **BARNACLES** | **Family** | **BWY** | **Pachylasmatidae** | | | |
|----------------|----------|---------|---------------------|| | | |
| Subphylum Crustacea (Cirripedia) | | | | | | |

<table>
<thead>
<tr>
<th><strong>KCF</strong></th>
<th><strong>KCV</strong></th>
<th><strong>NDW</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Paralomis formosa</td>
<td>Paralomis spinosissima</td>
<td>Neolithodes diomedea</td>
</tr>
</tbody>
</table>
This guide has examples of the most common longlining bycatch groups of invertebrate fauna around South Georgia. It is aimed to increase accuracy on benthos identification by observers. Observers are welcome to contribute to this guide taking good quality pictures of specimens not present here for an ongoing effort to add new species as they are collected.

This Field Guide can be downloaded free of charge from the South Georgia and South Sandwich Islands website at: http://www.gov.gs/

For enquiries/suggestions please contact: ramonbenedet@hotmail.com

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