Demersal fish communities of the shelf and slope of South Georgia and Shag Rocks (Southern Ocean)

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Abstract

This research is the first to investigate deepwater demersal fish distribution and community structure around South Georgia and Shag Rocks. Analysis of catch data from a trawl survey conducted in 2003 indicated that depth and location have a marked influence over demersal fish community structure in the region. Three distinct, depth stratified fish assemblages were observed. The demersal fish assemblage found on the shelf to depths of around 400m was dominated by nototheniids and was comprised largely of species endemic to the Southern Ocean and Scotia Sea. At the greatest depths sampled (>600m) the demersal fish community was dominated by gadiform fishes including members of the Macrouridae and Moridae, many of which are not endemic to the Southern Ocean. From 400-600m there was a transitional zone with demersal fish representatives of both the shelf and deeper slope communities. Clear geographic differences in the shelf community were apparent with differences observed in community structure between South Georgia and Shag Rocks to depths of around 400m. These data provide valuable baseline information to aid environmental management decisions and assess potential impacts of rapid ocean warming around South Georgia.

Keywords: South Georgia • fish • demersal • slope • community • distribution

Introduction

Fish assemblages are comprised of all the species in a particular area, regardless of whether they interact with each other or not (Wootton 1990) and there are many factors that will influence both the size and diversity of those communities. Depth is well recognised as a key factor in structuring a community (Merrett & Haedrich 1997), however abiotic factors such as a physical lack of space (for example on small plateaux), substrates/habitats that are unsuitable as nursery grounds, isolation caused by oceanic current patterns, and both current and historical fishing pressures, can all impact the community structure with potential effects on both the size structure and diversity of an assemblage (Bianchi et al. 2000; Neat & Campbell 2011; Sundblad et al. 2013, Young et al. 2015).

Deepwater fisheries are generally deemed to be those that target species which routinely live at depths greater than 400-500m (Thiel 2003; Gordon 2005). Patterns of species richness in deep-sea demersal fish assemblages can be determined by local phenomena, and a combination of physical factors and prey availability can regulate the diversity of the fish community (e.g. Priede et al. 2010). It is recognised however that our knowledge of deep sea fish assemblages may be biased by the types of sampling gear used (Gordon 2005) and that the use of different fishing methodologies and baited cameras can enhance knowledge of community structures (Priede et al. 1994, 2010).

South Georgia and Shag Rocks are outcrops of the Scotia Arc, a predominantly undersea ridge that forms the boundary of the Scotia Sea in the Atlantic sector of the Southern Ocean. The continental shelf that surrounds the islands has an average depth of 200m and extends 30-150km in width before dropping away to the abyssal plain. The waters around the islands are highly productive, lying south of the Polar Front and in the path of the Antarctic Circumpolar Current which transports krill to the region from the colder waters of the Antarctic Peninsula and Weddell Sea. Since 1987 twenty one groundfish surveys have been carried out at the sub-Antarctic islands of South Georgia and Shag Rocks (CCAMLR sub-area 48.3). These random stratified bottom trawl surveys have principally been designed to obtain standing stock estimates to assess stock status of the commercial finfish species *Champsocephalus gunnari* (mackerel icefish) and also to provide an index of abundance of pre-recruit Patagonian toothfish (*Dissostichus eleginoides*). In addition they have provided information on the relative abundance and ecology of species taken as by-catch in the *C. gunnari* fishery whilst providing estimates of abundance and demographic data on many of the demersal fish species found on the shelf region of South Georgia, including previously over-exploited species. These surveys have largely been confined to the shelf region, covering relatively shallow areas up to maximum depths of ~500m but with the majority sampling at depths less than 350m. Data from these surveys has contributed substantially to our understanding of the ecology of the demersal fish assemblage of the South Georgia and Shag Rocks shelves (Belchier 2013) and has provided data on many of the individual species which are found in this habitat (e.g. Everson et al. 1999; Reid et al. 2007; Belchier & Collins 2008; Main & Collins 2011; Gregory et al. 2014). In contrast, research into the ecology of species found at greater depths on the continental slope around South Georgia has been much more limited.

Ecosystem based fisheries management (EBFM), such as that practised by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Constable et al. 2000), requires a thorough understanding of the biology and ecology of the target species, the dependent prey and by-catch and sympatric species found within the ecosystem. The relatively recent development (since 1988) of a deepwater demersal long line fishery for Patagonian toothfish (*Dissostichus eleginoides*) has greatly increased our understanding of the demersal fish assemblage found on the South Georgia slope. However sampling has been limited to the target species and those caught as by-catch (e.g. Marlow et al. 2003; Morley et al. 2004; Endicott 2010). The rough bathymetry and deepwater of the slope has meant that fisheries independent surveys have been very limited, restricted to a handful of studies of the scavenging fauna using baited camera systems (Yau et al. 2000 & 2002; Collins et al. 2002 & 2003) and cephalopods (Collins et al. 2004). There has, to date, been no research undertaken which has specifically focussed on the demersal fish assemblages found at greater depths of the continental slope at South Georgia.

In addition to informing fisheries management decisions, baseline information on biodiversity and species interactions in the region is increasingly important at a time when South Georgia is facing rapid ocean warming (Whitehouse et al. 2008) and new marine protected areas are being introduced to protect the ecosystem (Trathan et al. 2014). In January 2003 a deepwater bottom trawl survey was undertaken to investigate the biota found on areas of the shelf and continental slope at depths down to 1000m. This is the only deepwater demersal trawl survey that has been successfully carried out to date at South Georgia and this paper reviews the data collected during that survey and examines the distribution and community structure of demersal fish species in the region.

Materials and Methods

2003 Deepwater Survey sample collection

The survey was carried out on the research vessel *Dorada* between 11th and 31st January 2003 (Collins et al. 2004). A radial transect design was used, with trawls undertaken at pre-determined locations along transects aligned onshore/offshore at Shag Rocks and South Georgia. Historically the study area has been divided into five sectors when carrying out research surveys – Shag Rocks and four distinct sectors around South Georgia (North East, North West, South East and South West). We have used the same geographic boundaries to divide the survey area in our analyses to allow comparisons with previously published work. Each transect comprised five hauls, one within each pre-designated depth strata (0-199m, 200-399m, 400-599m, 600-799m and 800-1000m). Hauls were carried out using a commercial sized FP120 trawl net with a rubber 'Rockhopper' bobbin rig (see Pilling & Parkes 1995) with tows lasting 30 minutes (bottom time) at a speed of approximately four knots, giving a trawled distance of approximately two nautical miles at each station. A total of 45 trawls were carried out in nine transects (three transects at Shag Rocks and six at South Georgia) (Fig 1; Appendix 1, Table 3). Sensor failure during trawl 11 (NW) and trawl 60 (SE) meant no depth data were recorded so these hauls have been excluded from all analyses. Trawls 20 and 36 (both at Shag Rocks) were aborted after <12 minutes bottom time due to the net coming fast and being badly damaged, although the catches from these hauls have been included in species presence/absence analysis.

Catch processing

Catches were sorted into individual species and a total wet weight for each species within a trawl was measured using motion compensated scales. Any unidentified fish were frozen and returned to the King Edward Point Research Station, South Georgia, for identification using published guides (e.g. Gon & Heemstra 1990). Detailed biological measurements (length, weight, sex, maturity) and samples (stomach contents, otoliths, muscle and liver) were taken from a range of species including nototheniids, channichthyids, macrourids, myctophids and rajids for additional research.

Data analysis

In the context of this study, the term 'demersal fish' refers to both benthic and benthopelagic ichthyofauna (Gordon, 2005). Known meso- and bathypelagic fish (e.g. bathylagids, gempylids, nemichthyids, paralepidids, myctophids, scopelarchids and stomiids) which would most likely have been caught in the water column during net retrieval were excluded from community structure analyses, as were all invertebrates such as crustaceans, cephalopods and medusae. Following recent genetic studies

(Fitzcharles et al. 2012; McMillan et al. 2012) grenadiers identified as *Macrourus whitsoni* on the survey have been reclassified as *Macrourus caml*.

The locations of all hauls were plotted using ArcGIS. The mean species richness (number of fish taxa present) was calculated for the different geographic sectors and depth strata sampled in each area, then ANOVA were used to compare geographic and depth variations. The depth range where each species was caught was also illustrated. The influence of depth and haul location on community structure was analysed using PRIMER-E statistical software, version 6 (Primer-E Ltd, Plymouth, UK). Using non-metric multi-dimensional scaling (NMDS), a resemblance matrix was applied to presence/absence data from each identified fish species with a zero-adjusted Bray-Curtis similarity coefficient and visualised in a two dimensional ordination plot (minimum stress 0.001, 250 restarts). PERMANOVA was used to check for significant differences between the depth zones before hierarchical cluster analysis of presence/absence data was used to identify species assemblages. The contribution of individual species to the assemblages was determined using similarity percentage (SIMPER) analysis. Within assemblages the consolidating species were classed as those that cumulatively contributed >70% to the similarity, and between assemblages species contributing >70% of dissimilarity were classed as discriminating.

Results

The total catch weight of fish species for all trawls was 6,715.8kg (6,565.9kg excluding pelagic species). A total of 69 fish taxa were recorded from the 42 trawls, and of these, 51 were identified to species level, 7 to genus and 11 to family (see Appendix 1, Table 4). Of the fish identified to species level, the highest number were from the suborder Notothenioidei (10 species), with 7 species of Gadiformes, 7 species of Aulopiformes, 3 species of Zoarcidei, 2 species of Rajiformes, and 2 species of Stomiiformes. Other orders were represented by a single species. Eight of the identified species, four of the taxa classified to genus level, and eight of the taxa classified to family level were pelagic which have been discounted from subsequent analyses.

Demersal species richness (number of taxa) for individual trawls ranged from 3 taxa (trawls 24 and 35, both at Shag Rocks, 400-599m) to 13 taxa (trawl 46 - South East, 600-799m). Analysis by sector indicated the largest number of fish species were caught in trawls in the North West sector (30 taxa) with a mean of 9.75 taxa/trawl (Fig 2). The mean number of taxa differed significantly between sectors (ANOVA: F (4, 38) = 8.05, p = <0.0001). A post-hoc Tukey test demonstrated that species richness at Shag Rocks was significantly lower than other sectors. Point estimates indicated the highest species richness occurred in trawls from the depth zone from 600-799m (25 taxa) with a mean of 9.00 taxa/trawl (Fig 3) however this was not found to be significantly greater than mean species number/tow found within the other depth strata. (ANOVA: F (4, 38) = 1.49, p = 0.225).

Community structure

Multivariate analysis based on the presence/absence of each fish species from trawls at South Georgia (all 4 sectors combined) and Shag Rocks showed some degree of community structure differentiation between the sectors (Fig 4), however a greater structuring influence was exerted by the depth zone. PERMANOVA analysis found significant differences in the community structure between all depth zones except 600-799m and 800-1000m (p<0.05) so for further analysis the two deepest zones were pooled into one group, 600-1000m (Fig 5).

Hierarchical cluster analysis showed three major species assemblages at the resemblance level of *c.* 30% (Fig 6). Assemblage A was comprised entirely of shallow trawls (12 in total) – eleven of the twelve trawls in this cluster were <400m at South Georgia plus one Shag Rocks trawls <200m.At a similarity level of ~35% the geographic separation within the assemblage is evident, and at ~50% the division between 0-199m and 200-399m trawls at South Georgia occurs. Assemblage C comprised 14 trawls, and contained the deepest trawls – all the trawls in the 600-1000m range from both Shag Rocks and South Georgia, plus one 400-599m trawl at South Georgia. Assemblage B was comprised of the highest number of trawls (17) which included all remaining trawls <600m at Shag Rocks, and all except one trawl from 400-599m at South Georgia. Again at ~50% similarity a geographic separation within Assemblage B can be seen (Fig 6).

SIMPER analysis showed moderate average within-group similarity ranging from 49.6% to 55.2% (Table 1). The consolidating species differed between assemblages with no single species contributing to all three clusters. The only overlap occurred with *Dissostichus eleginoides* (contributing 28.1% to Assemblage B and 17.7% to Assemblage C) (Table 1).

In Assemblage A *Gobionotothen gibberifrons* contributed the highest percentage (25.6%) to the consolidating species (those cumulatively contributing >70% to the similarity), while the three species of Channichthyidae (*Pseudochaenichthys georgianus*, *Chaenocephalus aceratus* and *Champsocephalus gunnari*) cumulatively contributed another 46.2%. There were only three consolidating species in Assemblage B – *Dissostichus eleginoides* (28.1%), *Mancopsetta maculata antarctica* (a bothid flatfish, 23.7%) and *Lepidonotothen squamifrons* (18.2%). Assemblage C had the greatest number of consolidating species with gadiformes making the highest overall contribution (*Antimora rostrata:* 26.0%; *Macrourus caml*: 10.9%; *Muraenolepis microps:* 9.0%; and *Macrourus carinatus:* 7.7%). *D. eleginoides* was the only other consolidating species in Assemblage C (17.7%). (Table 1).

The dissimilarity levels between the assemblages were much higher than the within-assemblage similarities, with the highest dissimilarity (91.5%) between A (the shallowest trawls) and C (the deepest trawls). Assemblage B was mainly comprised of mid-depth trawls and the dissimilarities between A & B and B & C were lower, 74.3% and 73.3% respectively. Discriminating species (those cumulatively contributing >70% of the dissimilarity) between assemblages were more numerous than the consolidating species within assemblages, ranging from 10 to 16 species. Between A & C the dissimilarity was primarily a result of species that were absent from one or other of the assemblages, however between A & B and B & C the dissimilarity was driven more by differences in average abundance rather than presence/absence (Table 2).

Bathymetric distribution

Nototheniodei were found at all trawled depths, however individual species ranges were more localised (Fig 7). *Dissostichus eleginoides* was the only nototheniodei found at all depths, with species such as *Pseudochaenichthys georgianus* and *Artedidraco mirus* restricted to shallow hauls, *Patagonotothen guntheri* and *Lepidonotothen squamifrons* in shallow to mid-range trawls, *Aethotaxis mitopteryx* and *Bathydraco joannae* in mid-range to deep trawls and *Pleuragramma antarcticum* only in deep trawls. Rajids also showed species range differences with *Raja georgiana* being caught in a much wider range of depths compared to *Bathyraja meridionalis*. All species of Aulopiformes and Stomiiformes were found in mid-range trawls, whilst Zoarceidei and Gadiformes were primarily found in the mid-range to deep trawls (with the exception of *Muraenolepis microps* which was also found in shallow trawls) (Fig 7).

Discussion

At the sub Antarctic island of South Georgia three decades of research trawl surveys of the shelf area have provided a considerable body of information on the ecology of the demersal fish assemblage down to depths of approx. 350- 400m (e.g. North 2005; Stowasser et al. 2012). In contrast, our understanding of the demersal fish assemblage found at depths greater than 400m in the shelf-break and slope region is far more limited.

It is widely documented that the composition of fish assemblages changes with depth (Haedrich 1997). Our data demonstrate that at South Georgia water depth plays a clear role in driving the observed patterns in community structure as indicated by the presence of three putative depth–separated demersal fish assemblages. These are represented by a shelf assemblage at depths between 100 and 400m, a 'shallow' slope assemblage located approximately between 400 and 600m and a deeper slope assemblage found at depths > 600m. The bathymetric distribution of demersal fishes has been very poorly studied in the Southern Ocean but our results are in broad agreement with the study of Pakhomov et al. (2006) from the sub-Antarctic Prince Edward archipelago.

In common with all shelf areas of the Southern Ocean, including the seasonal pack ice zone and the High Antarctic Zone (Mintenbeck et al. 2012), the South Georgia and Shag Rocks shelves are dominated by nototheniids and channichthyids (which comprise in excess of 96% of the demersal fish biomass) at depths < 400m. The relatively clear differences seen between the South Georgia and Shag Rocks shelf demersal fish communities (depths < 400m) seen in this study are in broad agreement with the multi–year analyses detailed in Belchier (2013). The lower species diversity at Shag Rocks has been attributed to the reduced number of habitats and reduced shelf area (Belchier 2013) whilst the presence of more temperate, Patagonian species such as *Patagonotothen guntheri* and absence of bathydraconids such as *Psilodraco breviceps* distinguish the Shag Rocks shelf demersal fish assemblage from that found at South Georgia. The reduction in the number of Antarctic species at Shag Rocks has also been observed in other sub-Antarctic seamounts and other islands located on the periphery of the Southern Ocean (Kock 1992).

Many of the species of nototheniid and channichthyid found at South Georgia and Shag Rocks have a broad geographical distribution throughout the seasonal pack ice zone. This includes *Champsocephalus gunnari* and the nototheniids *Lepidonotothen squamifrons, Lepidonotothen larseni* and *Notothenia rossii* which are found south of the Antarctic Polar Frontal Zone (APFZ) across all sectors of the Southern Ocean, whilst other species have a distribution that is restricted to the Atlantic region (*Lepidonotothen nudifrons*, *Gobionotothen gibberifrons* and *Chaenocephalus aceratus*) (Knox 2007) with some endemic to the South Georgia region (*Psilodraco breviceps*) (Gon & Heemstra 1990). Very few of the South Georgia shelf species are found north of the APFZ, the exceptions being *D. eleginoides* which is found at depths < 300m in regions both north and south of the APFZ (Collins et al. 2010) and *P. guntheri* which is found both at Shag Rocks and on the shelf regions of the North Scotia Ridge and on the Patagonian shelf. *D. eleginoides* populations found north and south of the polar front are known to be genetically distinct with the Polar Front acting as a major barrier to gene flow (Shaw et al. 2004; Rogers et al. 2006)

The abundant shelf-dwelling species of nototheniid such as *L. larseni*, *G. gibberifrons* and *Trematomus hansoni* and all of the channichthyids (icefishes) became very scarce or absent in trawls conducted deeper than 400m. The catches within these depths were dominated by two species of nototheniid, *L. squamifrons* and *D. eleginoides*, but was also characterised by the presence of the achiropsettid flatfish *Mancopsetta maculata* (Assemblage B). These results are in very close agreement with the Pakhomov et al. (2006) study from the Prince Edward Islands that recorded *D. eleginoides* and *L. squamifrons* being the dominant species within the shallow slope assemblage. At the Prince Edward Island (Pakhomov et al. 2006) and in the high Antarctic region (Eastman 1993) the highest diversity of the Nototheniidae has been recorded between 300-600m. Whilst overall fish diversity was greatest at these depths at South Georgia, the greatest Nototheniidae diversity was actually recorded over the shelf (Assemblage A). The high diversity within Assemblage B results from it being a transitional region between the shelf and deeper slope communities and therefore having representatives of both.

Assemblage C, found largely at depths >600m at both South Georgia and Shag Rocks is characterised by the presence of gadiform species including representatives of the Macrouridae, Moridae and Muraenolepididae. These families, which comprise a large part of the by-catch of the longline fishery for *D. eleginoides,* are not only distributed throughout the Southern Ocean but also in continental slope regions north of the APFZ (Smith et al. 2011). *Macrourus holotrachys*, *M. caml* and *M. carinatus* caught during our study are widely found in the Ross Sea (Hanchet et al. 2013) and the sub Antarctic islands of the Indian ocean sector of the Southern Ocean such as Heard Island (van Wijk et al. 2000), Prince Edward Island, Crozet and Kerguelen (De Broyer et al. 2014) and many of the seamounts of the sub Antarctic region (Wiff et al. 2012). *M. holotrachys* is caught as by catch in demersal longline fisheries operating in the Patagonian shelf region of the SW Atlantic (Laptikhovsky 2005) and has been recorded as far north as the Juan Fernandez Archipelago at 33ºS (Niklitschek et al. 2010). Many of the species of deepwater gadiforms found between 600-1000m at South Georgia have broad geographic distributions, for example the morids *Halargyreus johnsonii* and *Antimora rostrata* are known to have a global distribution and are ubiquitous in the north Atlantic (Mauchline & Gordon 1984).

In 2002 Yau et al. described scavenging fauna observed using baited cameras around South Georgia at depths from 625-1520m. Only eight fish species were observed during the camera deployments, a fraction of the species caught during the groundfish survey. The most commonly observed fish species during camera deployments was a benthopelagic zoarcid (tentatively identified as *Lycodapus antarcticus*) which were seen at depths from 625m, however catches of this species were low in the groundfish survey and it made no contribution to assemblage similarities and <4% to the dissimilarity in community structure. Differences in trawl catches compared to camera observations are not unexpected as the sampling methodologies can target different components of the fish community in terms of both species and size composition (Priede et al. 1994). Camera derived data can be biased by factors such as bait predominately attracting scavengers and predators that use olfactory cues (King et al. 2006; Bailey et al. 2007), oceanographic conditions affecting fish response to bait (Zinten et al. 2012), and an inability to discriminate between rare species (Priede et al. 2010). Underwater imagery can however complement extractive studies by allowing observations of species and age classes not targeted by nets or hooks (Priede et al. 1994, 2010) and offers a non-destructive method of sampling vulnerable species (McLean et al. 2014).

We are aware that there were limitations in the sampling design and the spatial extent covered by the survey. Consequently, whilst this study represents the most extensive fisheries independent sampling of the deepwater demersal fish assemblages of South Georgia to date, it does not provide a complete inventory of all the demersal fish species of South Georgia. During the survey only one haul occurred within 12nm of the coast and consequently a number of shallow water coastal species such as members of the Harpagiferidae and the rock cod *Notothenia coriiceps* were not sampled effectively. Similarly at the greatest depths sampled, concerns over gear damage or loss meant that the rougher areas of seabed were avoided. Limited numbers of hauls conducted within each of the depth strata coupled with uncertainty over bottom contact time and net damage in deep tows (> 600m) meant that a fully quantitative assessment of species density (i.e. through calculation of CPUE by species) was not considered to be appropriate. It is highly likely that increased sampling effort within the deeper depth strata will yield a greater number of fish species than were seen in this study.

We can conclude that the deepwater demersal fish assemblage of the slope of South Georgia is characterised by the presence of gadiform species that have wide ranging distributions that extend far beyond the northern limits of the APFZ. The composition of this assemblage at South Georgia appears very similar to those found on the slopes of other archipelagos and continental shelf margins both within the APFZ and to the north. The composition of the deepwater slope assemblage contrasts with that found on the shelf which is comprised predominantly of nototheniid species almost all of which are endemic to the Southern Ocean and some of which are endemic to the South Georgia shelf.

The APF forms a very strong barrier to the migration and dispersal of marine organisms including fish between the Southern Ocean and the more temperate waters located to the north of South Georgia in the South Atlantic (Strugnall & Allcock 2013). Consequently there are very few demersal species that are found on continental shelves on either side of the APF. *Patagonotothen guntheri* is one of the only species that is found either side the APF and its distribution to the south is restricted to the comparatively warmer waters of the Shag Rocks shelf. However, the Polar Front does not act as a barrier to the migration and dispersal of slope species in deeper habitats. The eurybathic nature of many slope species such as the Macrouridae (i.e. Laptikhovsky et al. 2008) coupled with water temperatures on the slope consistently well above freezing provides a more homogeneous environment over which the range of these species can extend. Similar contrast between the heterogeneous shelf assemblages and the more homogenous slope fish assemblage has recently been reported in the Antarctic Peninsula region (Amsler et al. 2016). The North Scotia Ridge which extends as a series of sub surface seamounts from the Patagonian shelf to South Georgia may also provide an additional mechanism which links the slope habitats of the Patagonian shelf with that at South Georgia.

Further fisheries independent surveys are required to provide greater detail and quantitative data in order to better understand the observed patterns of demersal fish distribution in this highly productive but isolated environment.

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Fig 1 Location of individual trawls grouped into the nine transects carried out at Shag Rocks and the four sectors around South Georgia. The 200m and 1000m isobaths are shown

Fig 2 Mean number of demersal fish taxa (excluding pelagics) caught in the four sectors around South Georgia and at Shag Rocks during the 2003 groundfish survey (all depths). Error bars show standard deviation

Fig 3 Mean number of demersal fish taxa (excluding pelagics) caught around South Georgia and Shag Rocks (all sectors combined) during the 2003 groundfish survey based on depth zone. Error bars show standard deviation

Fig 4 Two dimensional ordination plot illustrating community structure differences between South Georgia (all four sectors combined) and Shag Rocks [South Georgia: triangle; Shag Rocks: circle. Numbers indicate the trawl ID]

Fig 5 Two dimensional ordination plot illustrating community structure differences based on species presence/absence and the influence of depth (South Georgia and Shag Rocks combined) [triangle: 0-199m; circle: 200-399m; cross 400-599m; square 600-1000m]

Fig 6 (a) Dendrogram and (b) ordination in two-dimensions using multidimensional scaling (MDS) showing the three fish community assemblages (Assemblages A, B and C) at Shag Rocks and South Georgia in 2003 based on species presence/absence (30% similarity level)

Fig 7 Depth ranges of fish species caught during the 2003 groundfish survey [Black bars: demersal species; grey bars: pelagic species (not included in analyses). A: nototheniidae; B: channichthyidae; C: bathydraconidae; D: rajidae; E: zoarcidae; F: macrouridae; G: moridae; H: other demersal fish species; I: myctophidae; J: paralepididae; K: stomiidae; L: scopelarchidae; M: other pelagic fish species]

Table 1 SIMPER results of demersal fish species contributing >70% of similarity for the three community assemblages (A, B & C) identified using cluster analysis

Assemblage A

Average similarity: 55.22

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Gobionotothen gibberifrons	1	14.15	4.84	25.62	25.62
Chaenocephalus aceratus	0.92	11.21	2.05	20.3	45.91
Pseudochaenichthys georgianus	0.83	8.65	1.42	15.66	61.57
Champsocephalus gunnari	0.67	5.64	0.83	10.21	71.78

Assemblage B

Average similarity: 51.53

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Dissostichus eleginoides	0.88	14.5	1.68	28.14	28.14
Mancopsetta maculata antarctica	0.82	12.23	1.35	23.74	51.89
Lepidonotothen squamifrons	0.71	9.39	0.92	18.23	70.12

Assemblage C

Average similarity: 49.63

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Antimora rostrata	1	12.91	4	26.01	26.01
Dissostichus eleginoides	0.86	8.78	1.5	17.7	43.71
Macrourus caml	0.71	5.39	0.97	10.85	54.56
Muraenolepis microps	0.64	4.48	0.8	9.03	63.59
Macrourus carinatus	0.57	3.82	0.64	7.7	71.28

Table 2 SIMPER results of demersal fish species contributing >70% of dissimilarity between the three community assemblages (A, B & C) at South Georgia and Shag Rocks in 2003 identified using cluster analysis

Assemblages A & C						
Average dissimilarity = 91.51						
	Assemblage A	**Assemblage C**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib %**	**Cum. %**
Antimora rostrata	0	1	6.79	3.98	7.42	7.42
Gobionotothen gibberifrons	1	0	6.79	3.98	7.42	14.84
Chaenocephalus aceratus	0.92	0	6.07	2.57	6.63	21.47
Pseudochaenichthys georgianus	0.83	0	5.35	2	5.84	27.32
Dissostichus eleginoides	0.08	0.86	5.28	1.74	5.77	33.08
Macrourus caml	0	0.71	4.4	1.51	4.81	37.89
Champsocephalus gunnari	0.67	0.07	4.26	1.24	4.66	42.55
Macrourus carinatus	0	0.57	3.8	1.09	4.16	46.71
Bathydraco joannae	0	0.57	3.55	1.11	3.88	50.58
Muraenolepis microps	0.58	0.64	3.3	0.91	3.6	54.18
Macrourus holotrachys	0	0.5	3.22	0.94	3.51	57.7
Lepidonotothen larseni	0.5	0	3.06	0.97	3.35	61.04
Lepidonotothen nudifrons	0.42	0	2.77	0.79	3.02	64.07
Raja georgiana	0.25	0.29	2.73	0.76	2.99	67.05
Lepidonotothen squamifrons	0.33	0.14	2.67	0.74	2.92	69.98
Mancopsetta maculata antarctica	0.33	0.14	2.66	0.75	2.9	72.88
Assemblages A & B						
Average dissimilarity = 74.30						
	Assemblage A	**Assemblage B**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib %**	**Cum. %**
Chaenocephalus aceratus	0.92	0.06	6.92	2.23	9.32	9.32
Gobionotothen gibberifrons	1	0.18	6.79	1.9	9.14	18.45
Dissostichus eleginoides	0.08	0.88	6.68	1.87	9	27.45
Pseudochaenichthys georgianus	0.83	0	6.37	2.08	8.57	36.02
Mancopsetta maculata antarctica	0.33	0.82	4.85	1.17	6.53	42.55
Champsocephalus gunnari	0.67	0.24	4.75	1.13	6.39	48.94
Lepidonotothen squamifrons	0.33	0.71	4.56	1.09	6.14	55.08
Raja georgiana	0.25	0.53	4.18	0.98	5.62	60.7
Muraenolepis microps	0.58	0.59	4.03	0.93	5.42	66.12
Lepidonotothen nudifrons	0.42	0.29	3.76	0.89	5.06	71.18
Assemblages C & B						
Average dissimilarity = 73.33						
	Assemblage C	**Assemblage B**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib %**	**Cum. %**

Antimora rostrata	1	0.06	7.32	2.71	9.98	9.98
Mancopsetta maculata antarctica	0.14	0.82	5.59	1.47	7.63	17.61
Lepidonotothen squamifrons	0.14	0.71	5.13	1.23	6.99	24.6
Macrourus caml	0.71	0.12	4.72	1.35	6.44	31.04
Macrourus carinatus	0.57	0.12	4.24	1.05	5.79	36.83
Bathydraco joannae	0.57	0	4.01	1.12	5.46	42.29
Raja georgiana	0.29	0.53	3.95	0.96	5.39	47.68
Muraenolepis microps	0.64	0.59	3.78	0.91	5.15	52.84
Macrourus holotrachys	0.5	0.06	3.69	0.94	5.03	57.86
Lycodapus antarcticus	0.43	0	2.95	0.84	4.03	61.89
Lepidion spp	0.43	0	2.95	0.85	4.02	65.91
Halargyreus johnsonii	0.36	0	2.87	0.72	3.91	69.82
Patagonotothen guntheri	0	0.35	2.67	0.71	3.64	73.45

Appendix One

Table 3 2003 deepwater survey haul locations at South Georgia and Shag Rocks

Event	Date	Start Time (UTC)	Duration (mins)	Start Latitude		Start Longitude		End Latitude		End Longitude		Heading (deg)	Minimum Depth (m)	Maximum Depth (m)	Mean Depth (m)
				Degs	Mins	Degs	Mins	Degs	Mins	Degs	Mins				
1	11/01/2003	19:57	30	-54	1.67	36	35.05	54	2.36	36	31.79	108	160	177.5	170
3	12/01/2003	09:02	33	-53	49.08	36	9.32	53	48.84	36	6.23	77	810	928	884
4	12/01/2003	13:43	30	-53	49.27	35	49.25	53	47.39	35	49.66	0	653	765	721
5	12/01/2003	17:12	31	-53	52.9	35	47.11	53	51.27	35	48.53	333	507	564	533
7	13/01/2003	08:09	32	-53	24.68	37	1.21	53	24.96	36	57.79	97	858	964	917
10	14/01/2003	10:33	30	-53	32.18	37	2.23	53	31.56	36	59.11	68	697	706.9	700
11 [a]	14/01/2003			-53	34.69	37	18.03	53	34.69	37	18.03				
12	14/01/2003	16:38	30	-53	34.69	37	18.03	53	34.87	37	21.37	271	487	519	508
13	14/01/2003	19:45	30	-53	42.28	37	30.39	53	42.08	37	26.83	84	297	330	317
14	15/01/2003	14:16	30	-53	54.92	39	1.35	53	54.69	38	57.85	163.2	150	179	
15	15/01/2003	17:19	30	-53	53.52	39	11.81	53	51.97	39	8.93	41	275	290	281.9
16	15/01/2003	21:09	30	-53	47.22	39	18.6	53	49.1	39	19.07	200	452	464	457.6
18	16/01/2003	09:24	31	-53	48.93	39	24.37	53	49.72	39	27.2	250	699	709	703
19	17/01/2003	07:34	30	-53	45.66	40	30.12	53	45.51	40	30.97	284	840	845	843
20 [b]	17/01/2003	11:49	2	-53	44.38	40	35.04	53	44.39	40	34.84	92	881	881	881
23	18/01/2003	10:35	30	-53	48.61	40	33.78	53	48.8	40	30.65	96	579.2	607.3	597.3
24	18/01/2003	17:34	23	-53	41.33	40	42.49	53	40.31	40	40.07	53	439	445	442
26	20/01/2003	12:00	30	-53	39.52	40	47.63	53	41.39	40	46.65	162	309	312	310
27	20/01/2003	15:25	30	-53	37.16	41	0.39	53	37.37	40	57.29	98	156	162	159
28	20/01/2003	17:22	30	-53	38.27	41	2.7	53	38.26	40	59.29	92	129.6	144.5	137
29	21/01/2003	09:58	30	-53	53.87	41	22.88	53	53.77	41	19.11	88	218	225	221
30	21/01/2003	18:03	30	-53	55.32	41	42.26	53	56.44	41	38.71	135	383	408	393
32	22/01/2003	11:53	30	-53	56.71	41	47.16	53	56.63	41	43.47	83	569	605	591
33	23/01/2003	10:37	30	-53	36.04	42	8.1	53	36.46	42	4.57	97	158	180	171
34	23/01/2003	14:45	30	-53	29.38	42	27.41	53	30.63	42	24.61	131	302.3	318	309.1

35	23/01/2003	18:31	30	-53	18.06	42	40.51	53	17.69	42	37.27	79	530.2	553.8	541.3
36 [b]	24/01/2003	07:12	12	-53	16.7	42	40	53	16.26	42	38.86	59	679.1	702.1	685.8
37	24/01/2003	19:13	30	-53	27.5	41	50.01	53	28.29	41	46.7	112	145.6	160.3	155.6
38	25/01/2003	12:02	30	-54	41.91	38	10.29	54	42.59	38	13.6	250	148.6	165.1	159.7
39	25/01/2003	14:35	30	-54	44.99	38	31.33	54	45.81	38	27.87	112	266.1	273.5	270.3
40	25/01/2003	18:38	29	-54	48.27	38	10.69	54	49.12	38	7.27	113	410	515.8	466.5
42	26/01/2003	11:43	27	-54	53.99	38	17.43	54	53.96	38	14.43	89	655.2	689.9	670.2
44	26/01/2003	17:26	26	-54	54.23	38	18.12	54	54.51	38	17.42	143	750.6	925	841.5
46	27/01/2003	11:02	30	-55	25.21	36	13.16	55	23.3	36	14.5	338	651	698	669.4
47	27/01/2003	14:07	30	-55	22.14	36	12.21	55	24.22	36	11.71	173	550.4	567.1	563.5
48	27/01/2003	19:25	30	-55	20.87	36	4.33	55	23	36	4.34	180	434.7	441.6	437.3
50	28/01/2003	10:25	30	-55	30.52	35	36.13	55	29.37	35	39.43	302	295.1	218.2	309.3
51	28/01/2003	14:26	30	-55	14.43	35	37.94	55	14.73	35	41.74	262	150.6	160	154.3
52	29/01/2003	07:09	30	-54	35.7	35	27.85	54	37.27	35	25.42	138	147.5	157.8	153.2
53	29/01/2003	10:18	30	-54	44.7	35	9.47	54	44.77	35	13.17	268	396.6	311.1	308.7
55	29/01/2003	17:26	30	-54	53.46	34	21.29	54	52.37	34	24.55	303	440.8	474.8	459.8
58	30/01/2003	11:25	29	-54	56.98	34	15.89	54	55	34	17.14	340	589.2	623.9	611.9
60 [a]	30/01/2014	16:50	30	-54	51.89	34	21.51	54	51.88	34	21.59				
63	31/01/2003	09:48	30	-53	47.85	35	51.15	53	48.95	35	48.34	124	678.8	719.1	699
65	31/01/2003	17:10	30	-53	56.56	35	55.76	53	58.38	35	57.61	211	252.5	276.1	268.8

[a] indicates sensor failure, haul excluded from analyses; [b] indicates short haul, but species presence/absence data used in analyses

Appendix One

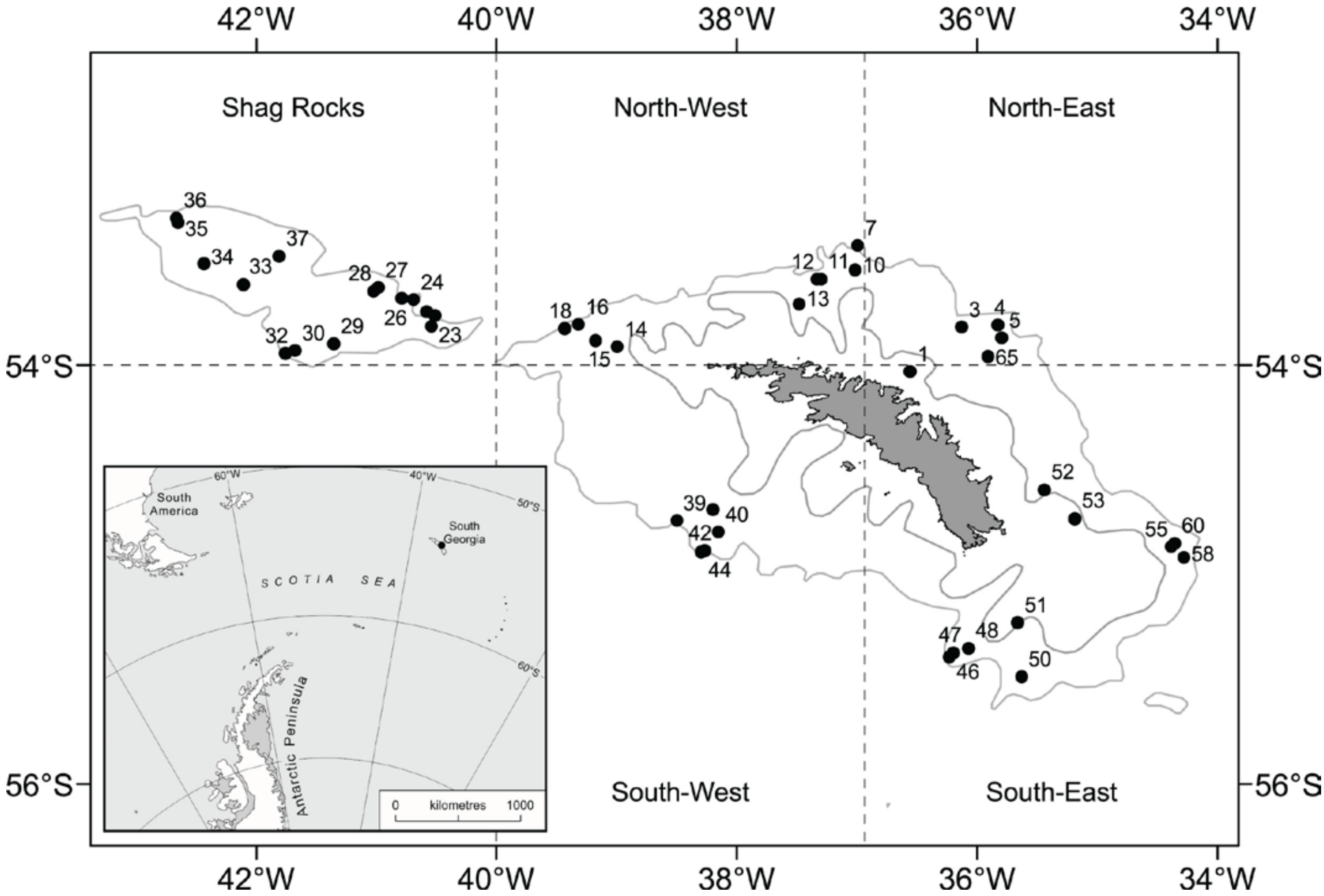
Table 4 Complete catch record of all fish species from the 2003 deepwater survey at Shag Rocks and South Georgia

Order/Family/Species	Catch (kg)
Rajidae	
Bathyraja meridionalis	1.26
Raja georgiana	67.22
Rajidae spp. [a]	0.03
Notacanthidae	
Notacanthidae sp.	0.33
Nemichthyidae	
Nemichthys curvirostratus [a]	0.05
Bathylagidae	
Bathylagus spp. [a]	0.71
Astronesthidae	
Astronesthidae sp.	0.03
Stomiidae	
Borostomias antarcticus [a]	0.29
Stomias boa [a]	0.05
Stomiidae spp [a]	0.01
Scopelarchidae	
Benthalbella macropinna [a]	0.05
Benthalbella elongate [a]	0.10
Scopelarchidae sp. [a]	0.13
Notosudidae	
Scopelosaurus hamiltoni [a]	0.37
Paralepididae	
Magnisudis prionosa [a]	0.23
Notolepis annulata [a]	0.03
Notolepis coatsi [a]	0.10
Notolepis rissoi [a]	0.72
Myctophidae	
Electrona antarctica [a]	0.46
Electrona carlsbergi [a]	0.10
Electrona spp. [a]	0.22
Gymnoscopelus bolini [a]	16.18
Gymnoscopelus braueri [a]	0.60
Gymnoscopelus hintonoides. [a]	1.27
Gymnoscopelus nicholsi [a]	89.65
Gymnoscopelus opisthopterus [a]	3.76
Lampanyctus achirus [a]	0.05
Myctophidae spp. [a]	32.88
Protomyctophum spp. [a]	0.02
Muraenolepididae	
Muraenolepis microps	45.50
Moridae	
Antimora rostrata	192.41
Halargyreus johnsonii	28.29
Lepidion sp.	2.57

Macrouridae	
Coryphenoides subserrulatus	0.46
Macrouridae spp. [a]	7.44
Macrourus caml	44.52
Macrourus carinatus	32.01
Macrourus holotrachys	15.67
Carapidae	
Echiodon cryomargarites	0.03
Melamphaidae	
Poromitra crassiceps	0.57
Liparidae	
Careproctus sp.	0.02
Liparidae spp. [a]	4.80
Zoarcidae	
Lycodapus antarcticus	0.33
Lycodapus pachysoma	0.02
Lycodapus sp. [a]	0.05
Melanostigma gelatinosum	2.42
Melanostigma spp. [a]	0.45
Seleniolycus sp. [a]	0.05
Zoarcidae spp. [a]	0.20
Nototheniidae	
Aethotaxis mitopteryx	0.50
Dissostichus eleginoides	239.16
Gobionotothen gibberifrons	251.37
Lepidonotothen larseni	3.70
Lepidonotothen nudifrons	6.60
Lepidonotothen squamifrons	2580.10
Notothenia rossii	29.83
Patagonotothen guntheri	1864.71
Pleuragramma antarcticum	0.01
Trematomus hansoni	3.70
Artedidraconidae	
Artedidraco mirus	0.05
Harpagiferidae	
Harpagifer sp.	0.01
Bathydraconidae	
Bathydraco joannae	0.68
Parachaenichthys georgianus	2.22
Psilodraco breviceps	0.15
Channichthyidae	
Chaenocephalus aceratus	102.83
Champsocephalus gunnari	972.79
Pseudochaenichthys georgianus	53.58
Gempylidae	

Paradiplospinus gracilis [a]	1.96
Achiropsettidae	
Mancopsetta maculata antarctica	6.51

[a] indicates species not included in analyses due to pelagic life history or insufficiently detailed identification



42°W
40°W
38°W
36°W
34°W
Shag Rocks
North-West
North-East
54°S
56°S
South-West
South-East
South America
South Georgia
SCOTIA SEA
Antarctic Peninsula
kilometres
0
1000

Figure 1

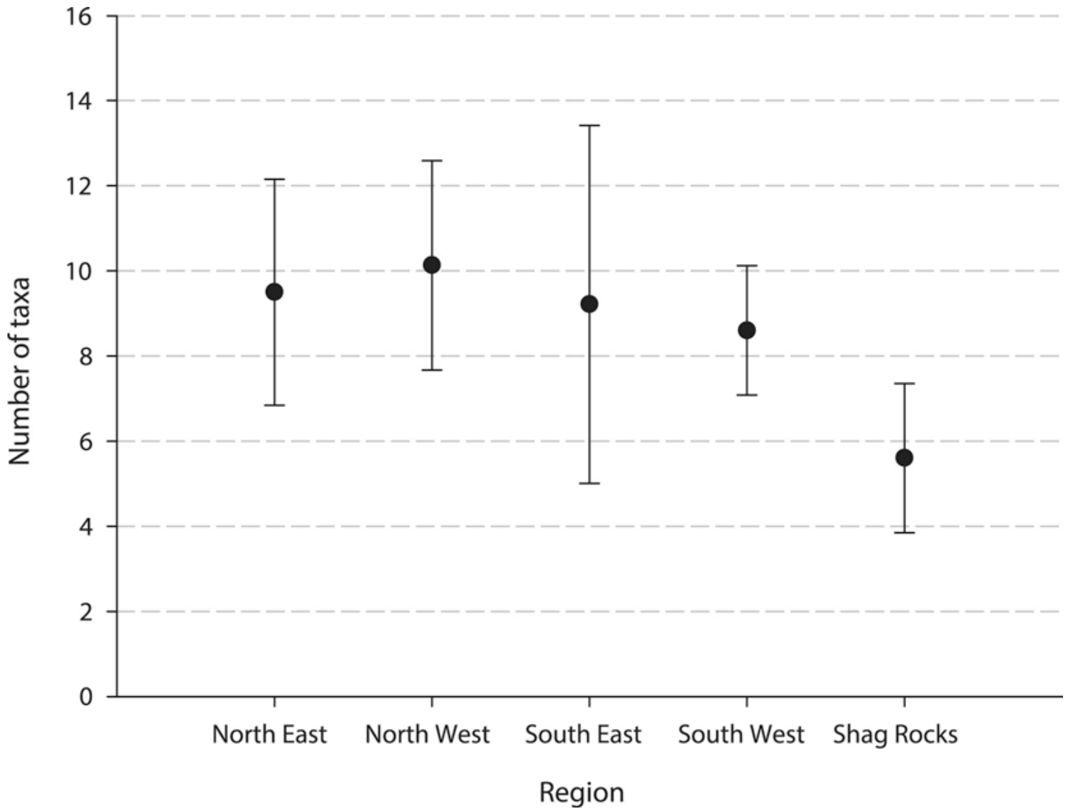
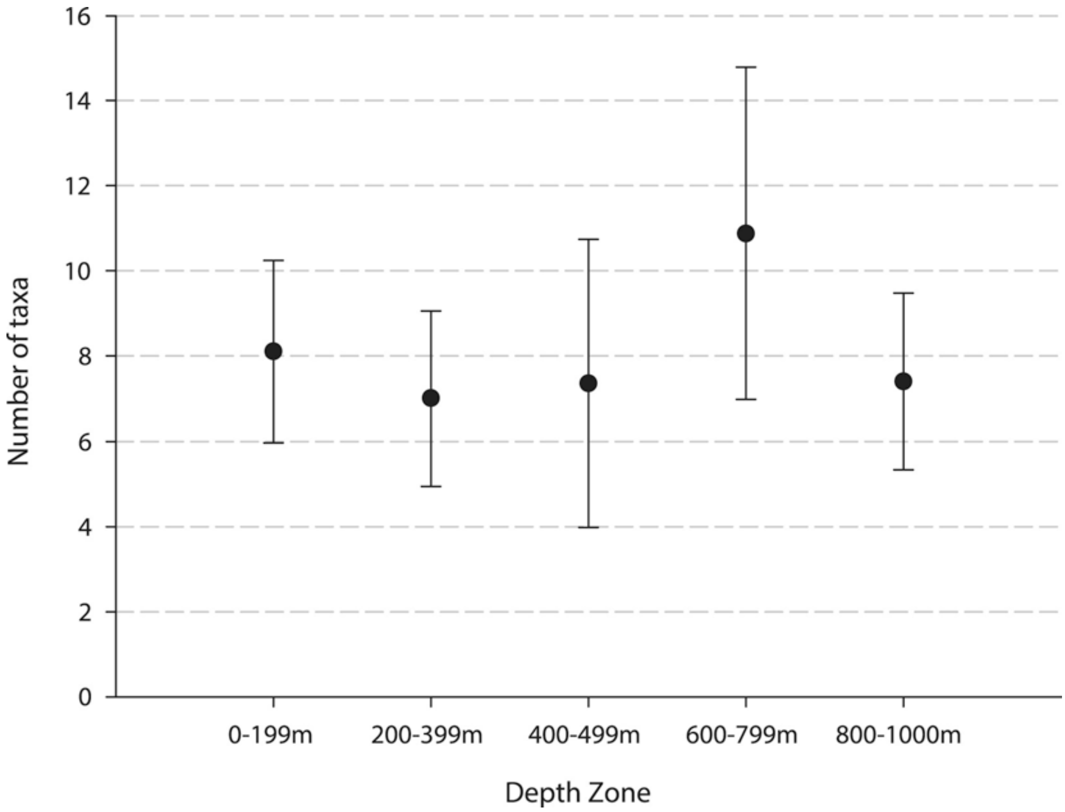

16
14
12
10
8
6
4
2
0
Number of taxa
North East
North West
South East
South West
Shag Rocks
Region

Figure 2



16
14
12
10
8
6
4
2
0
Number of taxa
0-199m
200-399m
400-499m
600-799m
800-1000m
Depth Zone

Figure 3

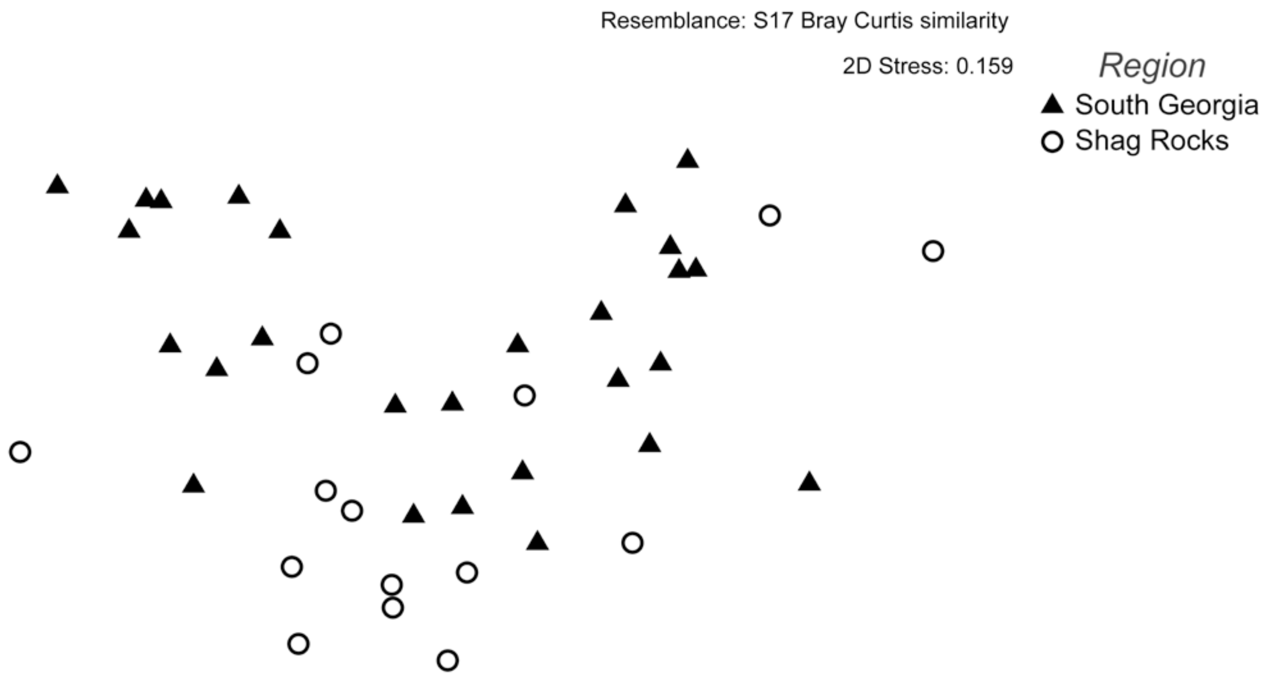

Resemblance: S17 Bray Curtis similarity
2D Stress: 0.159
Region
South Georgia
Shag Rocks

Figure 4

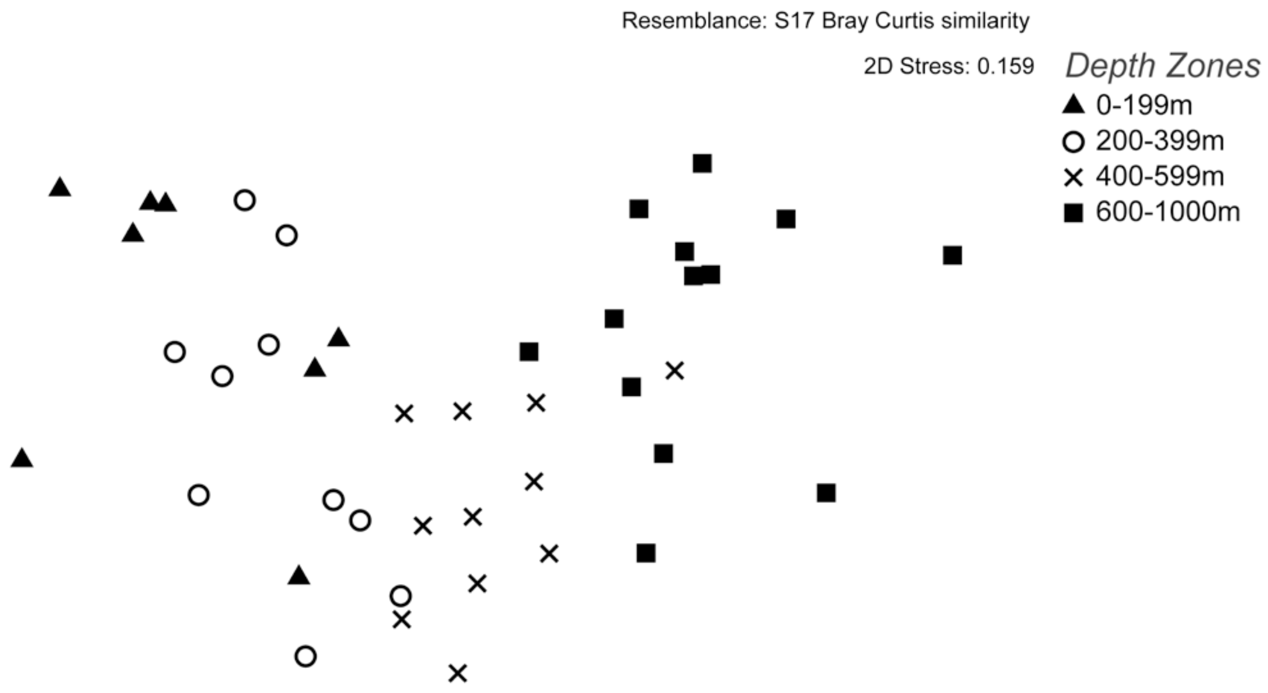
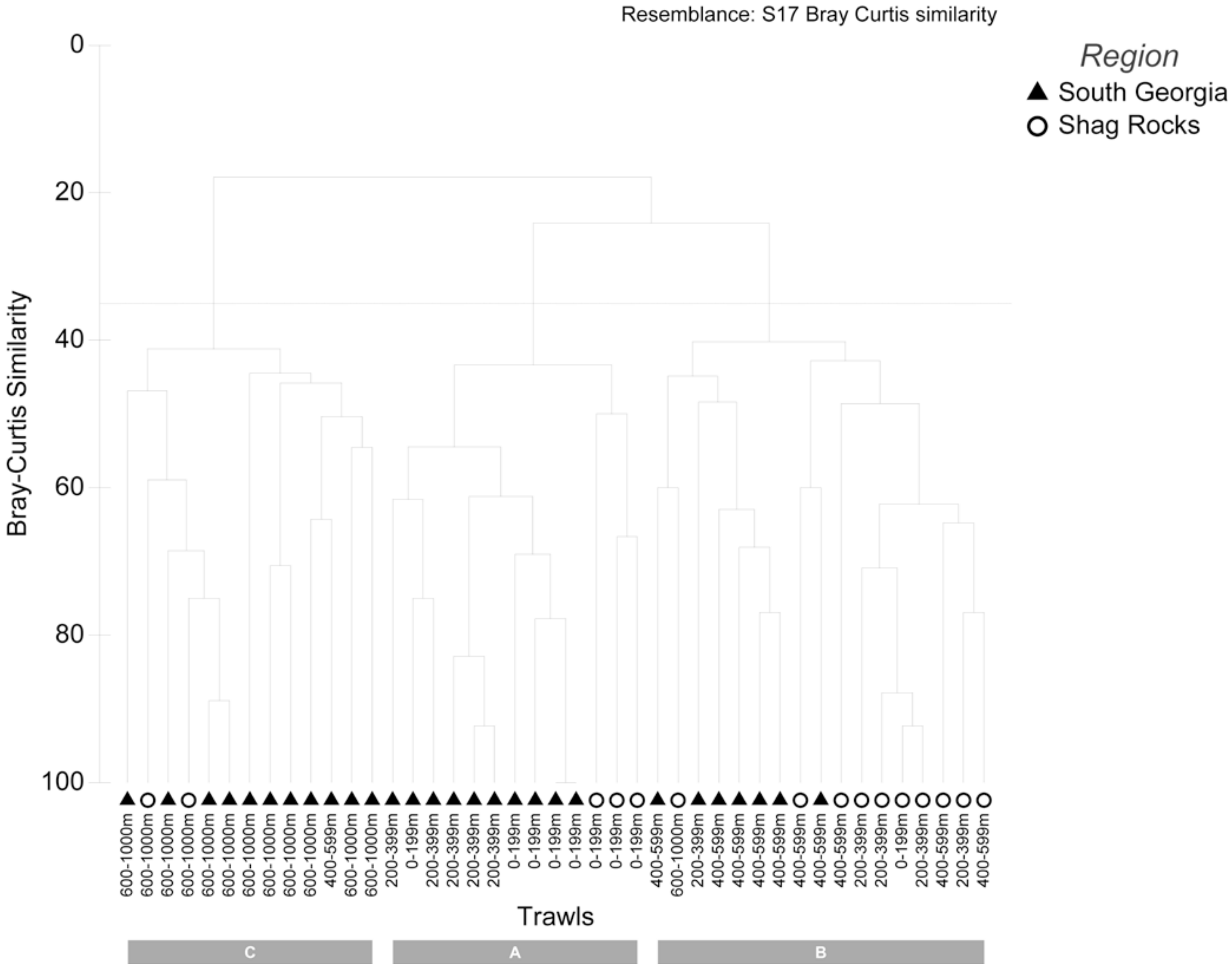

Resemblance: S17 Bray Curtis similarity
2D Stress: 0.159
Depth Zones
0-199m
200-399m
400-599m
600-1000m

Figure 5



Resemblance: S17 Bray Curtis similarity
Region
South Georgia
Shag Rocks
Bray-Curtis Similarity
0
20
40
60
80
100
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
600-1000m
400-599m
600-1000m
600-1000m
200-399m
0-199m
200-399m
200-399m
200-399m
200-399m
0-199m
0-199m
0-199m
0-199m
0-199m
0-199m
0-199m
400-599m
600-1000m
200-399m
400-599m
400-599m
400-599m
400-599m
400-599m
400-599m
400-599m
200-399m
200-399m
0-199m
200-399m
400-599m
200-399m
400-599m
Trawls
C
A
B

Figure 6a

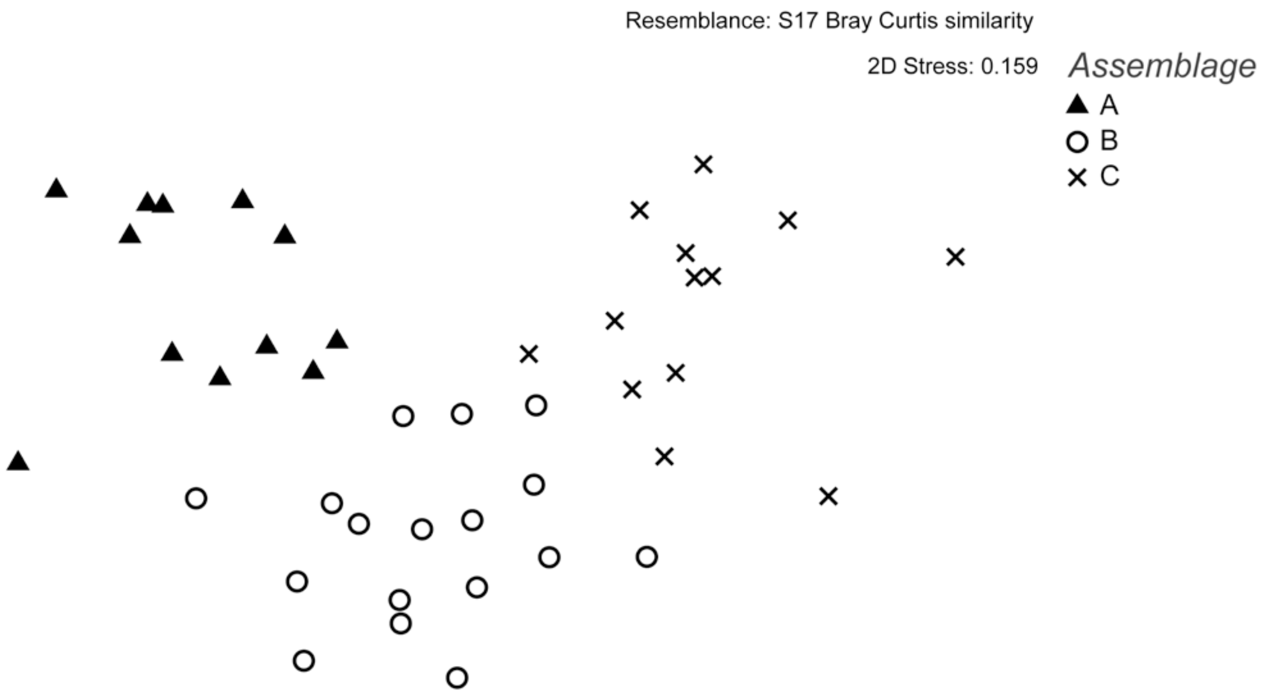

Resemblance: S17 Bray Curtis similarity
2D Stress: 0.159
Assemblage
A
B
C

Figure 6b

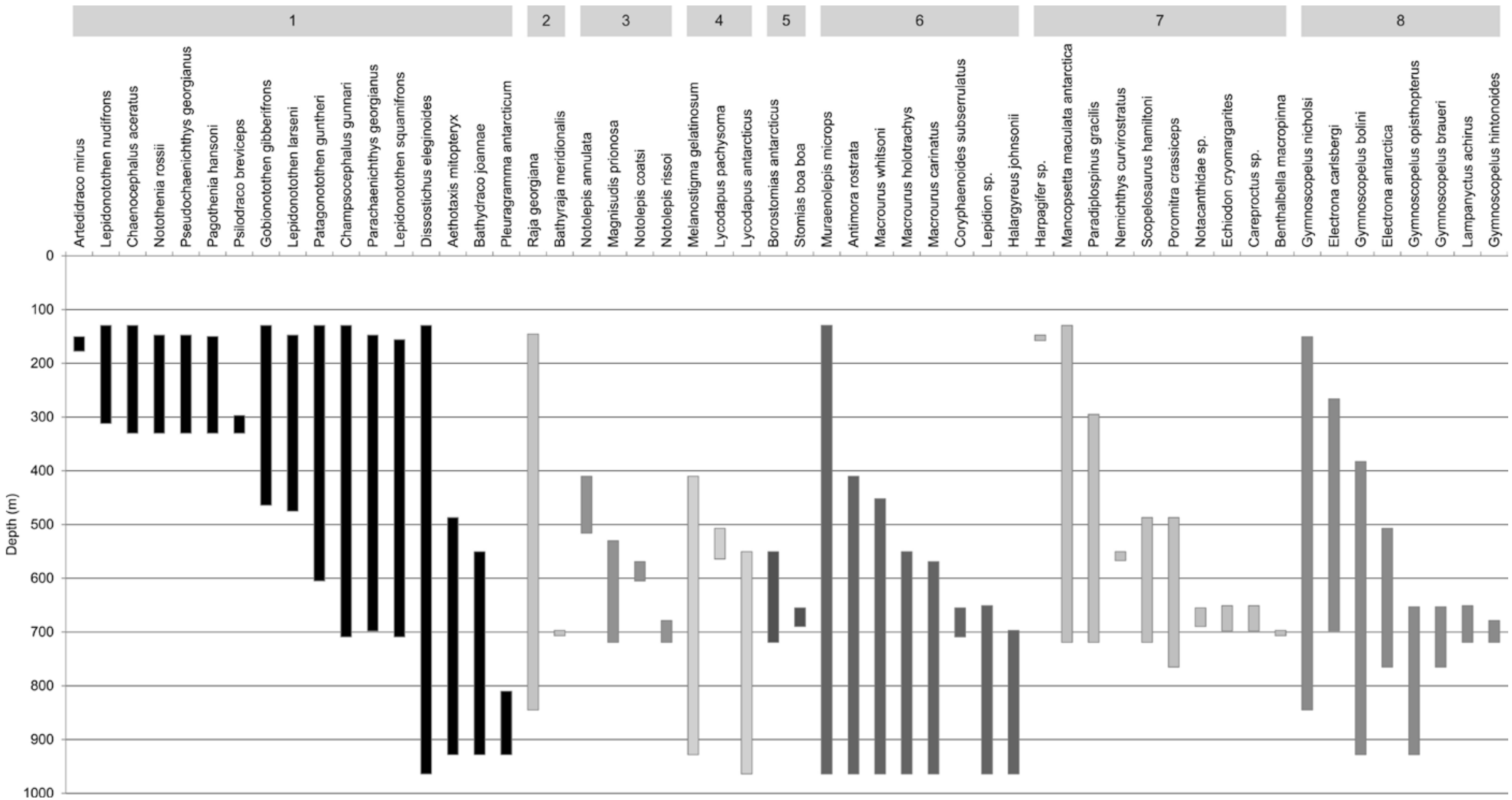

1
2
3
4
5
6
7
8
Artedidraco mirus
Lepidonotothen nudifrons
Chaenocephalus aceratus
Notothenia rossii
Pseudochaenichthys georgianus
Pagothenia hansoni
Psilodraco breviceps
Gobionotothen gibberifrons
Lepidonotothen larseni
Patagonotothen guntheri
Champsocephalus gunnari
Parachaenichthys georgianus
Lepidonotothen squamifrons
Dissostichus eleginoides
Aethotaxis mitopteryx
Bathydraco joannae
Pleuragramma antarcticum
Raja georgiana
Bathyraja meridionalis
Notolepis annulata
Magnisudis prionosa
Notolepis coatsi
Notolepis rissoi
Melanostigma gelatinosum
Lycodapus pachysoma
Lycodapus antarcticus
Borostomias antarcticus
Stomias boa boa
Muraenolepis microps
Antimora rostrata
Macrourus whitsoni
Macrourus holotrachys
Macrourus carinatus
Coryphaenoides subserrulatus
Lepidion sp.
Halargyreus johnsonii
Harpagifer sp.
Mancopsetta maculata antarctica
Paradiplospinus gracilis
Nemichthys curvirostratus
Scopelosaurus hamiltoni
Poromitra crassiceps
Notacanthidae sp.
Echiodon cryomargarites
Careproctus sp.
Benthalbella macropinna
Gymnoscopelus nicholsi
Electrona carlsbergi
Gymnoscopelus bolini
Electrona antarctica
Gymnoscopelus opisthopterus
Gymnoscopelus braueri
Lampanyctus achirus
Gymnoscopelus hintonoides
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000

Figure 7