

Distribution and diet of juvenile Patagonian toothfish on the South Georgia and Shag Rocks shelves (Southern Ocean)

Martin A. Collins, Katherine A. Ross, Mark Belchier, Keith Reid

British Antarctic Survey, Natural Environment Research Council, High Cross,
Madingley Road, Cambridge, CB3 0ET, UK.

Tel: 01223 221563

E-mail: macol@bas.ac.uk

Abstract The distribution and diet of juvenile (<750 mm) Patagonian toothfish are described from 4 annual trawl surveys (2003-06) around the island of South Georgia in the Atlantic sector of the Southern Ocean. Recruitment of toothfish varies inter-annually, and a single large cohort dominated during the four years surveyed. Most juveniles were caught on the Shag Rocks shelf to the NW of South Georgia, with fish subsequently dispersing to deeper water around both the South Georgia and Shag Rocks shelves. Mean size of juvenile toothfish increased with depth of capture. Stomach contents analysis was conducted on 795 fish that contained food remains and revealed that juvenile toothfish are essentially piscivorous, with the diet dominated by notothenid fish. The yellow-finned notothen, *Patagonotothen guntheri*, was the dominant prey at Shag Rocks whilst at South Georgia, where *P. guntheri* is absent, the dominant prey were Antarctic krill and notothenid fish. The diet changed with size, with an increase in myctophid fish and krill as toothfish grow and disperse. The size of prey also increased with fish size, with a greater range of prey sizes consumed by larger fish.

- 1 **Key words:** *Dissostichus; eleginoides*; diet; feeding; Southern Ocean;
- 2 *Patagonotothen guntheri*

1 **Introduction**

2
3 The Patagonian toothfish (*Dissostichus eleginoides*) belongs to the notothenioids or
4 Antarctic cods that are endemic to the southern hemisphere and dominate Antarctic
5 fish assemblages (Kock 1992). It is circumpolar in distribution, being found around
6 sub-Antarctic islands such as South Georgia, Heard Island and Kerguelen Island and
7 also extends north onto the Patagonian shelf. To the south it is replaced by the
8 congeneric Antarctic toothfish (*Dissostichus mawsoni*) which is found at high
9 latitudes around the Antarctic continent (Gon and Heemstra 1990).

10
11 Patagonian toothfish reach large size (> 2 m; > 100 kgs) and are long lived with adult
12 fish believed to reach 50 years old (Horn 2002). Growth is relatively quick for the
13 first 10 years, while the fish inhabit relatively shallow water, but following the onset
14 of maturity (700-800 mm total length (TL)) growth is very slow. Spawning is
15 thought to occur in deep-water, with both eggs and larvae pelagic (Evseenko et al.
16 1990).

17
18 The large size of toothfish, coupled with high quality flesh, led to the development, in
19 the mid 1980's, of a valuable long-line fishery, targeting large adult fish in deep water
20 (>500 m)(Agnew 2004). The fishery began in Chilean waters, but rapidly expanded
21 to cover the geographic range of toothfish (Agnew 2004). At South Georgia the
22 long-line fishery began in 1988, targeting large adult fish in deep-water although
23 toothfish had previously been taken in bottom trawls on the shelf. Since the mid
24 1990's the fishery has been managed under the auspices of the Commission for the
25 Conservation of Antarctic Marine Living Resources (CCAMLR), with mean annual
26 catches of around 4000 tonnes (Agnew 2004).

1

2 Ecologically sustainable management of a fishery requires an understanding of the
3 distribution and ecology of the exploited species throughout the life cycle and
4 interactions with other species in the ecosystem, and this underpins CCAMLR's
5 ecosystem approach to fisheries management (Constable et al. 2000). Whilst the
6 distribution and ecology of the adult part of the toothfish population has been
7 elucidated through the fishery (e.g. Pilling et al. 2001; Agnew 2004) and the use of
8 baited cameras (Yau et al. 2002; Collins et al. 2006), the distribution and ecology of
9 the pre-recruits or juveniles is poorly documented.

10

11 The diet of Patagonian toothfish has been studied across its geographic range
12 (Duhamel 1981; McKenna 1991; Garcia de la Rosa et al. 1997; Goldsworthy et al.
13 2001; Pilling et al. 2001; Goldsworthy et al. 2002; Arkhipkin et al. 2003; Barrera-Oro
14 et al. 2005), but most of these studies have focused on adult toothfish from the
15 fishery. At South Georgia adult toothfish (> 750 mm TL) are thought to be
16 opportunistic predators and scavengers (Pilling et al. 2001), but data on the diet of
17 fish prior to entering the fishery (TL ~ 750 mm) is limited to a study from a single
18 survey in March-April 1996 (Barrera-Oro et al. 2005).

19

20 Here we examine the distribution and diet of pre-recruit toothfish from trawl surveys
21 undertaken at South Georgia and Shag Rocks in four consecutive seasons and
22 consider the role of toothfish in the South Georgia ecosystem.

23

24

25 **Materials and methods**

26

1 During January 2003, 2004, 2005 & 2006 bottom trawl surveys were undertaken on
2 the FPRV *Dorada* in the area of South Georgia and Shag Rocks. South Georgia is
3 situated between the Polar Front and the Southern Antarctic Circumpolar Current
4 Front (SACCF), with circulation generally flowing from west to east in the Antarctic
5 Circumpolar Current (see Fig. 1). The surveys used a commercial sized otter trawl
6 (FP-120), which was fished, during daylight, for approximately 30 minutes at each
7 station. The trawl had a headline height of 4 m, and fished with a wingspread of 18-
8 20 m and a cod-end mesh of 40 mm. In January 2003 trawl stations were arranged in
9 a series of transects radiating away from the island and covering depths of 100-900 m.
10 In 2004-06 the trawl stations were arranged in a random, stratified design, to assess
11 the abundance of mackerel icefish and pre-recruit toothfish.

12

13 During all surveys, all captured toothfish were sampled, and were measured (to 10
14 mm category below), weighed and sexed. Except in 2003, when a subsample was
15 taken, all toothfish stomachs that contained any food items were carefully dissected
16 from the fish, and immediately frozen at -20°C .

17

18 In the laboratory stomachs were thawed and the total contents weighed prior to being
19 sorted into species or species groups. Contents were identified to the lowest
20 taxonomic level using published guides (Hulley 1981; Nesis 1987; Gon and Heemstra
21 1990) and reference collections. Partially digested fish were identified from sagittal
22 otoliths using reference material and published guides (Hecht 1987; Reid 1996).
23 Partially digested cephalopods were identified using reference collections of beaks.
24 Individual prey items were weighed and measured (total length (TL) for fish; mantle
25 length (ML) for cephalopods), with the size of highly digested prey estimated from

1 otolith to length relationships (Hecht 1987; Reid 1996). Items that were completely
2 undigested were considered to represent trawl feeding and were excluded from
3 subsequent analyses.

4

5 Diet was expressed using percent mass (% M), percent frequency of occurrence (%
6 F), percent number (% N) and percent index of relative importance (% IRI: see
7 (Cortes 1996)). Percent mass was based on the weight of the prey found in the
8 stomach and not on reconstituted mass.

9

10 Percent mass:
$$\%M_i = \frac{M_i}{\sum_{i=1}^n M_i} \times 100$$

11 Percent frequency of occurrence:
$$\%F_i = \frac{F_i}{S} \times 100$$

12 S = number of stomachs containing food remains

13 Percent number:
$$\%N_i = \frac{N_i}{\sum_{i=1}^n N_i} \times 100$$

14

15 Percent index of relative importance:
$$\%IRI_i = \frac{(\%N_i + \%M_i) \times \%F_i}{\sum_{i=1}^n (\%N_i + \%M_i) \times \%F_i} \times 100$$

16

17 Statistical analyses were undertaken using the statistical software MINITAB Release
18 14 and Sigma Plot 9.01. Inter-annual comparisons of stomach fullness (expressed as
19 % body weight) were investigated using a one-way ANOVA on arcsin-transformed
20 data. Regression analyses were undertaken to investigate the relationships between
21 depth (independent) and fish length and between toothfish size (independent) and prey

1 size. Assumptions about normality and constant variance were tested prior to
2 analyses.

3
4
5

Results

Distribution of juvenile toothfish

Juvenile Patagonian toothfish (< 750 mm TL) were found throughout the South Georgia and Shag Rocks shelves, but the density of juvenile fish was considerably greater on the Shag Rocks shelf, where 84 % of the juveniles were caught (Table 1; Figs 2, 3). Toothfish comprised 2.8-9.1 % (by weight) of the fish catches at Shag Rocks and 0.7-6.7 % of catches at South Georgia (Table 2). No Antarctic toothfish (*Dissostichus mawsoni*) were caught during the surveys.

In each year the catch was dominated by a single cohort that was of size 200-250 mm in 2003 (putative 1+ yr old), 300-360 mm in 2004, 380-460 mm in 2005 and 430-530 mm in 2006 (Fig. 3). A second, numerically smaller, cohort was seen in 2003 at around 400 mm TL, which was present in small numbers in 2005 and 2006. A third cohort was detected in 2006 at size 260-340 mm (putative 2+ years old) that was not seen the previous year.

Juvenile fish were generally confined to the continental shelf areas, with the largest catches taken at depths of less than 300 m and larger fish were more frequently caught at South Georgia (Fig. 3). For trawls that caught 3 or more Patagonian toothfish, mean size increased significantly with depth of capture (regression: $F = 43.61$; $P < 0.001$; Fig. 4), and although large fish are occasionally caught in shallow water, smaller fish are restricted to shallow depths.

Diet of juvenile toothfish

1 Stomach fullness was generally high, and less than 25 % of stomachs were empty (23
2 % in 2004, 19% in 2005; 24% in 2006). Average stomach fullness (ratio of stomach
3 weight to body weight) was significantly higher in 2004 (2.52 % BW) than 2005 (1.86
4 %) and 2006 (2.12 %) (ANOVA: $F = 4.632$; $p < 0.01$) (2003 excluded as full set of
5 data not available). For stomachs containing food, contents weight averaged 2.78% of
6 body weight (range 0.01-12.6%). There was no relationship between stomach
7 fullness and time of day, but all trawls were conducted during daylight.

8

9 Stomach contents were examined from 795 toothfish that had full or partially full
10 stomachs, of which 636 were from fish caught at Shag Rocks and 159 from South
11 Georgia caught fish. The size distribution of sampled fish was approximately
12 proportional to the size range caught, with the exception of the small sized fish (200-
13 250 mm TL) caught in 2003, which were under-represented.

14

15 Juvenile toothfish (<750 mm) were predominantly ichthyophagous, with fish
16 accounting for 95 % of the diet by mass, 51 % numbers, 88 % frequency and 89 %
17 IRI (Table 3). The diet composition differed between South Georgia and Shag
18 Rocks (Table 3; Fig. 5), with more crustaceans taken at South Georgia, but this may
19 reflect the larger average size of fish caught off South Georgia compared to Shag
20 Rocks (see above). At South Georgia more krill (52 % by number) was taken, but
21 when the diet is considered in terms of percent mass fish prey accounted for 89 % of
22 the diet at South Georgia, compared to 97 % at Shag Rocks.

23

24 The fish component of the diet differed substantially between the two locations. At
25 Shag Rocks the yellow-finned notothen (*Patagonotothen guntheri*) dominated the diet

1 in each of the years (85 % by mass; 95 % IRI). Catches of both toothfish (Fig 2) and
2 *P. guntheri* (Fig 6) were highest at the eastern end of the Shag Rocks shelf, although
3 there was no significant correlation between catches of the two species at Shag Rocks.
4 On the South Georgia shelf the diet was more diverse with the notothenids
5 *Lepidonotothen larseni* (20 % mass; 21 % IRI) and *Trematomus hansonii* (23 % mass;
6 3.9 % IRI) the main fish prey species. Myctophid fish were also consumed, with
7 *Gymnoscopelus nicholsi* and *Protomyctophum bolini* the most common species taken.
8 There was a single incidence of southern blue whiting (*Micromesistius australis*),
9 which is rarely found at South Georgia and a single incidence of an undescribed
10 species of the Chiasmodontidae genus *Pseudoscopelus* (Marcelo Melo pers. comm.;
11 specimen lodged at the Natural History Museum, London: BMNH.2006.8.19.1).

12
13 The main crustacean prey species were Antarctic krill (*Euphausia superba*), the
14 mysids (*Antarctomysis ohlini* and *A. maxima*) and the pelagic amphipod (*Themisto*
15 *gaudichaudii*), with the decapod, *Notocrangon antarcticus*, and isopods of the genus
16 *Natanolana* (Family Cirolanidae) occasionally taken. Cephalopods were rare in the
17 diet, with the octopus *Adelieledone polymorpha* and the squid *Psychroteuthis glacialis*
18 the only species identified.

20 **Ontogenetic changes in diet**

21
22 The diet of toothfish changed with size at both Shag Rocks and South Georgia (Fig. 5:
23 note sample sizes were smaller for larger fish and at South Georgia). At Shag Rocks
24 the diet of fish size < 500 mm TL was dominated by the notothenioid,
25 *Patagonotothen guntheri*, which reflects the association with the Shag Rocks shelf. In

1 fish greater than 400 mm TL there was an increase in krill and myctophids. At South
2 Georgia, smaller fish consumed krill and other crustaceans, with larger fish taking
3 notothenioid fish.

4

5 Fish prey size increased significantly with toothfish size (Regression: $F= 83.571$;
6 $p<0.001$; $n= 832$; Fig. 7) but, more clearly, the range of prey sizes taken increased
7 with fish size. The main prey species, *Patagonotothen guntheri*, forms a cluster at
8 sizes 70-200 mm TL, consumed by toothfish of 200-600 mm TL, but the relationship
9 between predator size and prey size was still significant (Regression: $F= 49.706$;
10 $p<0.001$; $n= 546$). The larger prey items were other notothenioid fish, notably
11 *Trematomus hansonii* and *Champsocephalus gunnari*. The myctophid prey, with the
12 exception of a single large *Gymnoscopelus bolini* were of small size. The number of
13 prey items consumed also increased with predator size.

14

15 The length of *Patagonotothen guntheri* consumed by toothfish was generally slightly
16 smaller than that caught by the survey (not illustrated), the exception being in 2005,
17 when the survey caught relatively smaller *P. guntheri* than in the previous seasons.

18

19

20

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Discussion

Distribution

Whilst adult toothfish are distributed in deep-water all around South Georgia and Shag Rocks (Agnew et al. 1999; Agnew 2004), the data from this study suggest that the recruitment of juvenile toothfish occurs predominantly at Shag Rocks, with small numbers of juvenile fish caught on the South Georgia shelf, most notably at the SW edge. This is consistent with the data of Garcia de la Rosa et al. (1997), who only found small toothfish at Shag Rocks. Barrera-Oro et al. (2005) did catch some small fish on the South Georgia shelf, but the majority of fish < 600 mm TL were caught on the Shag Rocks shelf. The association between toothfish recruitment and Shag Rocks is not clear, but may be related to temperature and oceanography. Water temperatures at Shag Rocks are slightly warmer than on the South Georgia shelf (Collins, unpublished) and, as the Patagonian toothfish is at the southern edge of its range, and, unlike *D. mawsoni*, does not possess anti-freeze glycoproteins (Gon and Heemstra 1990), temperature may be a limiting factor.

Although two other cohorts were detected, this study essentially monitored a dominant cohort through four consecutive seasons. The cohort, first detected at size 200-250 mm TL, were probably 1+ years old in 2003 and would therefore be 4+ in 2006 (Belchier, unpublished). The dominance of a single cohort through four years of sampling suggests strong interannual variability in recruitment. Toothfish are thought to spawn in winter in deep-water around South Georgia and Shag Rocks (Agnew et al. 1999). The eggs and larvae are both pelagic, with developmental stages thought to last 3 and 6 months respectively (Evseenko et al. 1995), and successful recruitment will be dependent on transport in near surface currents. The

1 oceanography of the Scotia Sea is highly complex (Fig. 1) and subject to inter-annual
2 variability, which may be the main factor driving recruitment variability. A detailed
3 analysis of variability in growth and recruitment in Patagonian toothfish from 14
4 surveys from 1987-2006 is in progress (Belchier & Collins in prep).

5

6 In common with other species that scavenge as adults (see Collins et al. (2005)), the
7 Patagonian toothfish has a bigger-deeper trend (Arkhipkin et al. 2003; Laptikhovsky
8 et al. 2006), and although this study was largely focussed in shallow areas it showed a
9 distinct pattern, which is supported by evidence from the fishery (Agnew et al. 1999).

10 Larger fish do occasionally occur in shallow water and fish over a metre in length
11 have been caught in trammel nets in < 200 m depth in Cumberland Bay (pers. obs).

12

13 **Diet**

14 Although this study only gives a summer snapshot of toothfish diet, it is clear that pre-
15 recruit toothfish in the South Georgia/Shag Rocks area are essentially piscivorous,
16 which is largely consistent with previous studies in the area (Zhivov and Krivoruchko
17 1990; Barrera-Oro et al. 2005) and dietary studies of similar sized toothfish in other
18 parts of the range (Duhamel 1981; Garcia de la Rosa et al. 1997; Goldsworthy et al.
19 2002; Arkhipkin et al. 2003).

20

21 The difference in the specific composition of the toothfish diet between Shag Rocks
22 and South Georgia is largely a consequence of distinct differences in the ichthyofauna
23 between the two areas. The Shag Rocks and South Georgia shelves are separated by a
24 deep (~1500 m) channel, and many of the notothenids and channichthyids that are
25 common on the South Georgia shelf are rare or absent at Shag Rocks (see Table 2). At

1 Shag Rocks the demersal fauna is less diverse and dominated by *Lepidonotothen*
2 *squamifrons*, mackerel icefish and *Patagonotothen guntheri*, with the latter being
3 absent from South Georgia (Gon and Heemstra 1990). *Lepidonotothen squamifrons*
4 are, in some years, abundant at Shag Rocks and were the main fish prey identified by
5 Barrera-Oro *et al.* (2005), however they are usually large fish and maybe too large for
6 a juvenile toothfish to consume. Hence the most abundant fish species of suitable size
7 is usually *P. guntheri* and the dominance of this species in toothfish diet may simply
8 be a consequence of the distribution of the two species, with conditions that favour
9 toothfish recruitment also favouring *P. guntheri*. Both species are abundant at the
10 eastern end of the Shag Rocks shelf, which may be more productive than other parts
11 of the Shag Rocks shelf. Interestingly, on the Falkland shelf the congeneric
12 *Patagonotothen ramsayi* is the main prey of pre-recruit toothfish of sizes < 600 mm
13 TL (Arkhipkin *et al.* 2003).

14
15 The specific composition of the toothfish diet in this study differs from that identified
16 from sampling in March-April 1996 by Barrera-Oro *et al.* (2005) and from 1985-86
17 by Zhivov and Krivoruchko (1990). The Barrera-Oro *et al.* (2005) study found
18 *Lepidonotothen kempfi* (= *L. squamifrons*) to be the main toothfish prey at South
19 Georgia and Shag Rocks and neither study found *Patagonotothen guntheri* to be so
20 dominant (10 % occurrence in Zhivov and Krivoruchko (1990) and not recorded by
21 Barrera-Oro *et al.* (2005)). Differences between the studies may reflect seasonal or
22 inter-annual variability in prey availability, but in both of the other studies a large part
23 of the fish diet was unidentified (49 % unidentified in Barrera-Oro *et al.* (2005)).

1 *Patagonotothen guntheri*, the dominant prey species at Shag Rocks, is a semi-pelagic
2 notothenid that is one of the most abundant species caught during trawl surveys at
3 Shag Rocks (Table 2), but is at the southern end of its range (Gon and Heemstra
4 1990). It is a pelagic feeder, consuming large copepods (e.g. *Rhincalanus gigas*),
5 pelagic amphipods (e.g. *Themisto gaudichaudii*) and krill (Collins, unpublished). On
6 the South Georgia shelf the most important prey species were *Lepidonotothen larseni*
7 and *Trematomus hansonii*, which also feed on macro-zooplankton. The mackerel
8 icefish (*Champsocephalus gunnari*), which is abundant at both South Georgia and
9 Shag Rocks (Table 2) and is commercially fished, was only occasionally found in
10 toothfish stomachs in this study.

11

12 Even within the limited size range studied here, a change in diet with size of toothfish
13 was detected. The shift from *Patagonotothen guntheri* to other notothenioids is
14 associated with dispersion of fish from Shag Rocks to the South Georgia shelf. There
15 is also an increase in krill consumption and, to a lesser extent, myctophid fish
16 (particularly at Shag Rocks) with increased size. The principal myctophid species
17 taken was *Gymnoscopelus nicholsi*, which is a relatively large species (upto 180 mm
18 TL) abundant on the slope (300-1000 m) around South Georgia and Shag Rocks, and
19 although it is a pelagic species it is frequently caught in bottom trawls. This dietary
20 change is associated with the ontogenetic migration into deeper water, where the
21 available prey will differ, for instance *Patagonotothen guntheri* are rarely caught in
22 depths greater than 300m.

23

24 The migration to deep water is probably accompanied by changes in foraging
25 behaviour as well as diet with large adults scavenging as well as taking live prey

(Garcia de la Rosa et al. 1997; Pilling et al. 2001; Arkhipkin et al. 2003), making them susceptible to baited long-lines and attracted to baited cameras (Collins et al. 1999, 2006; Yau et al. 2002). Arkhipkin et al. (2003) suggested that larger toothfish generally take less active prey than small toothfish, although adult fish are capable of bursts of high speed swimming (Yau et al. 2002), and consequently the diet of the larger toothfish is considerably different from that of the juveniles. At South Georgia the diet of adult fish appears more diverse than juveniles, with more cephalopods (Onychoteuthidae, Gonatidae, Chiroteuthidae and octopods) and crustaceans (krill, the decapod *Nauticaris* sp. and isopods) taken (Garcia de la Rosa et al. 1997; Pilling et al. 2001). The main fish families consumed were Myctophidae, Moridae and Zoarcidae, but in both studies over half the fish were not identified.

Although the size of prey increased with size of toothfish, it is clear that it is the range of prey size that increases, with the larger toothfish taking small prey as well as large prey items. The size of *P. guntheri* taken by toothfish was generally slightly smaller than that taken by the trawl survey and this is likely to be a consequence of both selectivity of the trawl and selectivity by the toothfish.

The diet of juvenile toothfish comprised a mixture of both pelagic and demersal species, and it is not known how much time toothfish spend foraging above the sea-floor. For instance the main prey species *P. guntheri* feeds pelagically, but is also caught in bottom trawls. Time spent foraging above the sea-floor will clearly impact their catchability in a bottom trawl, but potentially make toothfish more susceptible to diving predators (see below).

1 Given the importance of *P. guntheri* in the diet of toothfish recruits and the co-
2 occurrence of the two species, it is likely that any exploitation of *P. guntheri* would
3 impact on toothfish populations. Fishing for *P. guntheri* at Shag Rocks is likely to
4 have a by-catch of small toothfish, and the removal of a large biomass of *P. guntheri*
5 would reduce the available food for toothfish. Whilst there is currently no fishery for
6 *P. guntheri* it has been estimated that around 170 000 tonnes were fished from the
7 Shag Rocks area between 1969 and 1990 (Anon 1990a, b; Kock 1992). Currently a
8 relatively small pelagic trawl fishery, targeting mackerel icefish (*Champscephalus*
9 *gunnari*), operates on the South Georgia and Shag Rocks shelves, which does have the
10 potential to catch juvenile toothfish.

11

12 **The role of toothfish in the South Georgia marine ecosystem**

13 In order to have an ecologically sustainable fishery it is important to have knowledge
14 of the diet of a target species and of potential predators that may be competing with
15 the fishery. Whilst knowledge of the diet of toothfish is now substantial, little is
16 known about the predators of toothfish. In shallow water, potential predators of
17 juveniles include king and gentoo penguins, fur and elephant seals, but with increased
18 size and habitat depth the range of potential predators is likely to decline (Table 4).
19 From studies undertaken at on South Georgia, toothfish are rarely taken in the diets of
20 fur seals or penguins, and only are occasionally taken by these species elsewhere (see
21 Table 4). Toothfish have been reported in the diet of Weddell seals, of which there is
22 a small population at South Georgia, and these are a potential predator. Albatross and
23 white-chinned petrels are known to take toothfish, but these are, almost certainly, fish
24 that escape from hooks or discards from fishing vessels. In deeper water, the only
25 likely predators are elephant seals, sperm whales and large squid such as the Antarctic

giant squid, *Mesonychoteuthis hamiltoni*. Both sperm and killer whales are known to take toothfish from longlines during hauling (Ashford et al. 1996; Kock et al. 2006; Purves et al. 2004), but toothfish habitat is beyond the normal diving capabilities of killer whales. Little is know about the ecology of *Mesonychoteuthis hamiltoni*, but these large squid are probably capable of catching and consuming large toothfish, and are occasionally caught on long-line hooks at South Georgia (Collins, unpublished). Although cannibalism was not recorded in this study it has been recorded in larger toothfish (Arkhipkin et al. 2003) and may occur between cohorts. Overall the evidence from predators indicates low levels of predation, which is a consequence of the depth distribution and size of the toothfish.

Acknowledgements Thanks to Len Featherstone (Master) and the crew of the FPRV Dorada for their efforts during the surveys in 2003 and 2004. Sarah Clark, Terese Cope, Mike Endicott, Inigo Everson, Suzi Hawkins, Tom Marlow, Richard Mitchell, Tony North, Martin Purves, Jacek Szlakowski, Jamie Watts & Will Reid assisted with sorting trawl catches. Thanks to Geraint Tarling for assistance in identification of crustacean prey, Peter Rothery for statistics advice and to Claire Waluda & Sally Thorpe for help with the figures.

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Figures

Fig. 1: The location of South Georgia and Shag Rocks in relation to the main fronts and currents in the Scotia Sea. SACCF = Southern Antarctic Circumpolar Current Front; SB = Southern Boundary of Antarctic Circumpolar Current.

Fig. 2: Distribution of juvenile Patagonian toothfish (*Dissostichus eleginoides*) (<750 mm TL) around South Georgia & Shag Rocks from surveys in 2003, 2004, 2005 & 2006.

Fig. 3: Length frequency distribution of Patagonian toothfish (*Dissostichus eleginoides*) from each survey showing the size of fish sampled (excludes trawls that targeted toothfish for tagging).

Fig. 4: Mean length of Patagonian toothfish (*Dissostichus eleginoides*) in relation to depth of capture from the four surveys. Error bars show standard deviations of length, only trawls with 3 or more fish included.

Fig. 5: Diet of juvenile toothfish by size category from Shag Rocks (a) and South Georgia (b).

Fig. 6: Distribution of catches of the yellow-finned notothen (*Patagonotothen guntheri*) from surveys in 2003, 2004, 2005 & 2006.

Fig. 7. Relationship between prey size and predator size in Patagonian toothfish (*Dissostichus eleginoides*).

Table 1: Numbers of trawl stations undertaken in each depth zone at Shag Rocks and South Georgia during each of the surveys, with the numbers of toothfish caught (excludes hauls that targeted toothfish for tagging).

Depth	Shag Rocks						South Georgia					
	100-200	200-300	300-400	>400	100-200	200-300	300-400	>400	100-200	200-300	300-400	>400
January 2003	Haul 1 Fish 218	Haul 1 Fish 10	Haul 2 Fish 13	Haul 6 Fish 25	Haul 8 Fish 0	Haul 3 Fish 0	Haul 3 Fish 5	Haul 15 Fish 63	Haul 0 Fish 0	Haul 3 Fish 0	Haul 3 Fish 5	Haul 15 Fish 63
January 2004	6 24	10 10	4 237	2 88	15 4	18 32	8 9	2 0	48 127	51 40	30 44	20 68
January 2005	3 108	5 114	3 35	1 9	12 0	11 55	5 10	3 5	13 40	19 40	14 20	0 0
January 2006	5 133	10 308	2 11	0 0	13 9	19 40	14 20	0 0	48 127	51 40	30 44	20 68
TOTAL	15 483	26 669	11 147	9 44	48 13	51 127	30 44	20 68	48 127	51 40	30 44	20 68

Table 2. Percentage composition (of mass) of the main fish species caught in non-target trawls (mean depth <400 m) on the South Georgia and Shag Rocks shelves. Total catch is given in kg.

	South Georgia				Shag Rocks			
	2003	2004	2005	2006	2003	2004	2005	2006
<i>Champscephalus gunnari</i>	59.43	63.46	12.79	68.44	10.82	50.72	4.94	35.01
<i>Gobionotothen gibberifrons</i>	19.47	10.67	20.94	9.45	0.55	0.49	0.70	0.86
<i>Notothenia rossii</i>	2.44	6.25	26.15	8.61	0.00	0.01	0.00	0.22
<i>Chanocephalus aceratus</i>	8.27	6.50	8.72	5.33	0.07	0.00	0.05	0.13
<i>Pseudochaenichthys georgianus</i>	4.37	8.58	9.26	5.31	0.00	0.00	0.00	0.00
<i>Lepidonotothen squamifrons</i>	0.77	0.28	1.58	0.38	2.42	4.00	47.69	25.91
<i>Dissostichus eleginoides</i>	0.83	0.74	6.70	0.65	2.81	9.07	5.09	5.79
<i>Patagonotothen guntheri</i>	0.00	0.00	0.00	0.00	82.57	33.29	40.17	31.83
Other	4.43	3.51	13.85	1.83	0.77	2.42	1.36	0.25
Total catch (kg)	1225	9040	1830	13895	2258	2282	3966	7898

	% Mass		% Numbers			% Occurrence			% IRI				
Prey	SR	SG	All	SR	SG	All	SR	SG	All	SR	SG	All	Rank
<i>Antarctomysis</i> sp.	0.00	1.05	0.26	0.07	20.08	7.37	0.16	8.18	1.76	0.00	4.39	0.23	6
<i>Euphausia triacantha</i>	0.00	0.00	0.00	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
<i>Euphausia superba</i>	1.75	8.10	3.34	21.12	52.07	32.42	10.69	39.62	16.48	2.70	60.56	10.27	
Eusiridae	0.00	0.00	0.00	0.00	0.13	0.05	0.00	0.63	0.13	0.00	0.00	0.00	2
Notocrangon	0.00	1.05	0.26	0.00	2.63	0.96	0.00	9.43	1.89	0.00	0.88	0.04	
<i>Natatolana</i> sp. (Isopoda)	0.03	0.00	0.03	0.43	0.00	0.27	0.63	0.00	0.50	0.00	0.00	0.00	
Isopoda indet.	0.01	0.00	0.01	0.14	0.00	0.09	0.31	0.00	0.25	0.00	0.00	0.00	5
<i>Themisto gaudichaudii</i>	0.10	0.08	0.09	9.16	2.13	6.59	2.67	4.40	3.02	0.27	0.25	0.35	
<i>Vibilia antarctica</i>	0.00	0.00	0.00	0.29	0.00	0.18	0.63	0.00	0.50	0.00	0.00	0.00	
Copepoda (parasitic)	0.00	0.00	0.00	0.22	0.00	0.14	0.47	0.00	0.38	0.00	0.00	0.00	1
Crustacea indet.	0.13	0.02	0.10	0.58	0.38	0.50	1.26	1.26	1.26	0.01	0.01	0.01	
Crustacea Total	2.04	10.30	4.10	32.08	77.42	48.63	15.25	47.17	21.64	2.99	66.09	10.92	
Gastropoda	0.01	0.00	0.01	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	1
<i>Adelieledone polymorpha</i>	0.00	1.02	0.25	0.00	0.25	0.09	0.00	1.26	0.25	0.00	0.04	0.00	
Octopoda	0.00	0.00	0.00	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
<i>Psychroteuthis glacialis</i>	0.22	0.00	0.16	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	1
<i>Cephalopoda</i> indet.	0.01	0.00	0.01	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
Mollusca Total	0.25	1.02	0.44	0.29	0.25	0.27	0.63	1.26	0.75	0.00	0.04	0.00	
<i>Electrona antarctica</i>	0.32	0.19	0.28	1.37	0.38	1.01	1.89	0.63	1.64	0.04	0.01	0.04	1
<i>Electrona carlsbergi</i>	0.26	0.00	0.20	0.79	0.00	0.50	1.42	0.00	1.13	0.02	0.00	0.01	
<i>Gymnoscopelus bolini</i>	1.11	0.00	0.84	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
<i>Gymnoscopelus braueri</i>	0.07	0.04	0.06	0.14	0.13	0.14	0.31	0.63	0.38	0.00	0.00	0.00	1
<i>Gymnoscopelus fraseri</i>	0.26	0.33	0.28	0.43	0.25	0.37	0.94	1.26	1.01	0.01	0.02	0.01	
<i>Gymnoscopelus hintonoides</i>	0.10	0.00	0.08	0.29	0.00	0.18	0.63	0.00	0.50	0.00	0.00	0.00	
<i>Gymnoscopelus nicholsi</i>	3.82	0.31	2.94	3.39	0.13	2.20	6.29	0.63	5.16	0.50	0.01	0.46	4
<i>Gymnoscopelus</i> sp.	0.54	0.00	0.41	0.72	0.00	0.46	1.42	0.00	1.13	0.02	0.00	0.02	
<i>Krefflichthys andersonni</i>	0.02	0.00	0.02	0.65	0.00	0.41	0.94	0.00	0.75	0.01	0.00	0.01	
<i>Protomyctophum bolini</i>	0.82	0.00	0.62	3.82	0.00	2.43	3.62	0.00	2.89	0.19	0.00	0.15	7=
<i>Protomyctophum choriodon</i>	0.29	0.00	0.22	1.01	0.00	0.64	1.57	0.00	1.26	0.02	0.00	0.02	
<i>Protomyctophum parallellum</i>	0.03	0.00	0.02	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
Myctophidae indet.	0.51	0.41	0.48	1.23	0.50	0.96	2.04	1.89	2.01	0.04	0.04	0.05	1
Myctophidae Total	8.16	1.27	6.44	13.99	1.38	9.39	17.92	3.77	15.09	0.84	0.08	0.78	
<i>Chaenocephalus aceratus</i>	0.00	1.62	0.41	0.00	0.13	0.05	0.00	0.63	0.13	0.00	0.03	0.00	
<i>Chaenodraco wilsoni</i>	0.00	0.11	0.03	0.00	0.13	0.05	0.00	0.63	0.13	0.00	0.00	0.00	7=
<i>Champsocephalus gunnari</i>	0.76	12.94	3.80	0.22	1.51	0.69	0.47	7.55	1.89	0.01	2.77	0.15	
Channychthyidae	0.01	0.04	0.02	0.07	0.13	0.09	0.16	0.63	0.25	0.00	0.00	0.00	
<i>Gobionotothen gibberifrons</i>	0.00	2.88	0.72	0.00	0.25	0.09	0.00	1.26	0.25	0.00	0.10	0.00	1
<i>Gobionotothen marionensis</i>	0.23	0.00	0.17	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
<i>Lepidonotothen larseni</i>	0.00	20.22	5.05	0.00	7.78	2.84	0.00	28.93	5.79	0.00	20.57	0.80	
<i>Lepidonotothen nudifrons</i>	0.06	0.00	0.04	0.14	0.00	0.09	0.31	0.00	0.25	0.00	0.00	0.00	1
<i>Lepidonotothen squamifrons</i>	0.00	9.91	2.48	0.00	0.13	0.05	0.00	0.63	0.13	0.00	0.16	0.01	
<i>Patagonotothen guntheri</i>	85.19	0.00	63.90	46.58	0.00	29.58	65.72	0.00	52.58	95.47	0.00	85.68	
<i>Pseudochaenichthys georgianus</i>	0.00	7.79	1.95	0.00	0.63	0.23	0.00	2.52	0.50	0.00	0.54	0.02	9
<i>Trematomus hansonii</i>	0.00	22.80	5.70	0.00	1.63	0.60	0.00	6.29	1.26	0.00	3.90	0.14	
Notothenioid indet.	0.65	2.29	1.06	1.80	2.38	2.01	3.93	11.95	5.53	0.11	1.42	0.30	
Notothenioid Total	86.90	80.61	85.33	48.88	14.68	36.40	70.60	54.09	67.30	95.59	29.50	87.08	10
<i>Pseudoscopelus</i> sp. (Chiasmodontidae)	0.14	0.00	0.11	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
Macrouridae	0.00	0.67	0.17	0.00	0.13	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
<i>Micromesistius australis</i>	0.09	0.00	0.07	0.07	0.00	0.05	0.00	0.63	0.13	0.00	0.00	0.00	3
<i>Muraenolepis</i> sp.	0.28	1.89	0.69	0.36	2.89	1.28	0.79	10.69	2.77	0.01	1.30	0.09	
<i>Paradiplospinosus gracilis</i>	0.36	0.00	0.27	0.07	0.00	0.05	0.16	0.00	0.13	0.00	0.00	0.00	
Fish indet.	1.78	4.24	2.39	4.11	3.26	3.80	8.96	15.72	10.31	0.58	3.00	1.11	3
Other Fish Total	2.65	6.80	3.69	4.69	6.27	5.27	10.06	25.79	13.21	0.70	3.50	1.22	

Table 3. Diet composition of Patagonian toothfish (*Dissostichus eleginoides*) expressed as percent mass, percent numbers, percent frequency of occurrence and percent IRI for the South Georgia and Shag Rocks shelves and the two areas combined. The ten main prey items are ranked by % IRI in the right hand column.

Table 4. Potential predators of Patagonian toothfish (*Dissostichus eleginoides*) on the South Georgia and Shag Rocks shelf.

Potential predator	Maximum depth	Comments	Sources
Southern elephant seal <i>Mirounga leonina</i>	Dive to > 2000 m.	Have been reported taking toothfish. Population size at South Georgia: potentially significant predator	Slip et al. 1994; Reid and Nevitt 1998
Antarctic fur seal <i>Arctocephalus gazella</i>	Dive to 300 m	Toothfish otoliths occasionally in scats at South Georgia and Heard Island; unlikely to be a significant predator.	Green et al. 1989; Reid 1995; Reid and Arnould 1996
Weddell seal <i>Leptonychotes weddelli</i>	Dive to 450 m	Know to take <i>D. mawsoni</i> in Weddell Sea; small South Georgia population may take <i>D. eleginoides</i> .	Calhaem and Christoffel 1969; Testa et al. 1985; Plotz 1986; Lake et al. 2003
Sperm whale <i>Physeter macrocephalus</i>	Dive in excess of 2000 m	Known to consume toothfish; take toothfish from longlines; population size at South Georgia is unknown.	Korabelnikov 1959; Clarke 1980; Abe and Iwami 1989; Watkins et al. 1993; Ashford et al. 1996; Purves et al. 2004; Kock et al. 2006
Killer whale <i>Orcinus orca</i>	Dive to 200 m	Take toothfish off long-lines, but do not dive deep enough to catch adults	Ashford et al. 1996; Purves et al. 2004; Kock et al. 2006
King penguin <i>Aptenodytes patagonicus</i>	Dive to 300 m	Piscivorous, but pelagic feeders generally taking small fish (myctophids) and squid; no toothfish reported in diet at South Georgia, but reported in diet at Crozet (n=2, 4.3 % occurrence).	Kooyman et al. 1992; Cherel et al. 1996; Olsson and North 1997
Gentoo penguin <i>Pygoscelis papua</i>	Dive to 150 m	Not known to take toothfish in South Georgia area, but toothfish recorded in diet at Macquarie Is (0.1-1.2 % occurrence) and Kerguelen (2.5 % occurrence)	Adams and Klages 1989; Robinson and Hindell 1996; Goldsworthy et al. 2001; Lescroel et al. 2004
Macaroni penguin <i>Eudyptes chrysolophus</i>	Dive to 120 m	Single incidence of toothfish in diet at Marion Is., never recorded at South Georgia	Brown and Klages 1987
Black-browed albatross <i>Thalassarche melanophris</i>	Surface feeders	Toothfish in stomachs probably from hooks and/ or discards from fishing vessels	Cherel et al. 2000; Cherel et al. 2002
Grey-headed albatross <i>Thalassarche chrysostoma</i>	Surface feeders	Toothfish in stomachs probably from hooks and/ or discards from fishing vessels	Cherel et al. 2002; Xavier et al. 2003
White chinned petrels <i>Procellaria aequinoctialis</i>	10 m	Toothfish in stomachs probably from hooks and/ or discards from fishing vessels	Catard et al. 2000
Patagonian toothfish <i>Dissostichus eleginoides</i>	2500 m	Some cannibalism likely, with large fish taking smaller cohorts, but will be limited by the size-depth distribution pattern.	Arkhipkin et al. 2003
Sleeper sharks <i>Somniosus</i> sp.	2000 m	Toothfish recorded in stomachs, but may be net feeding and scavenging on discarded heads.	Cherel and Duhamel 2004
Giant Antarctic squid <i>Mesonychoteuthis hamiltoni</i>	Unknown	Reach large size (>100 kg); incidentally caught on longline hooks targeting toothfish. Possible predator, abundance unknown.	Young 2003; Collins unpublished

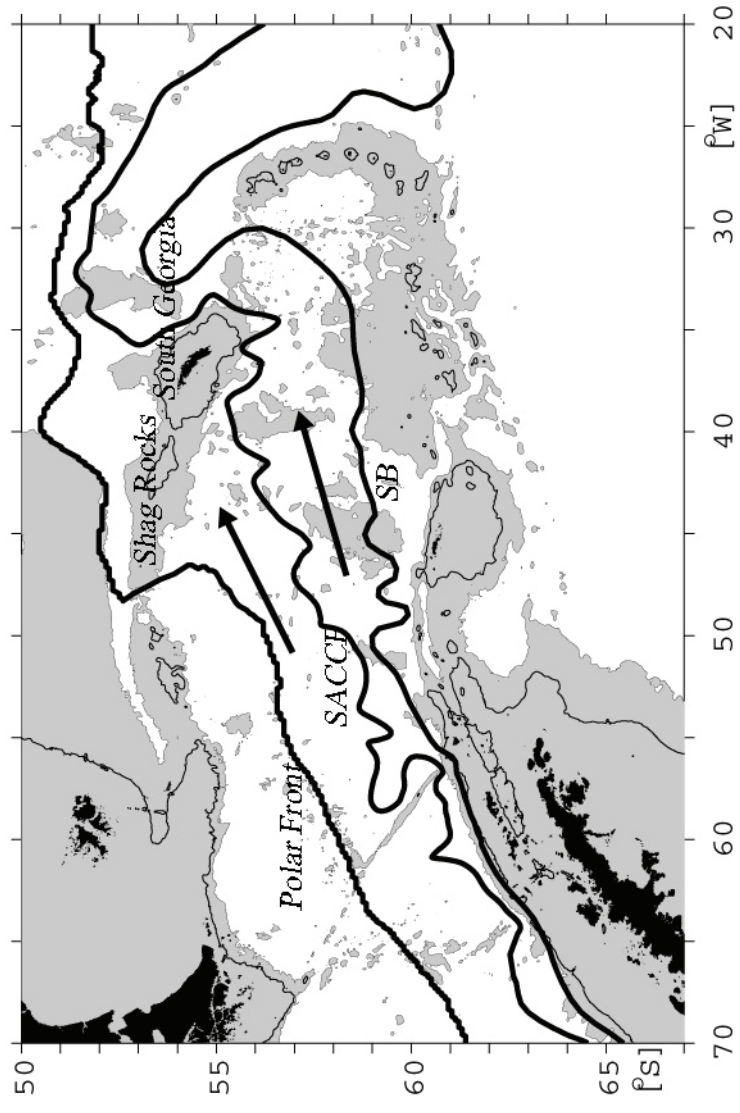


Fig. 1

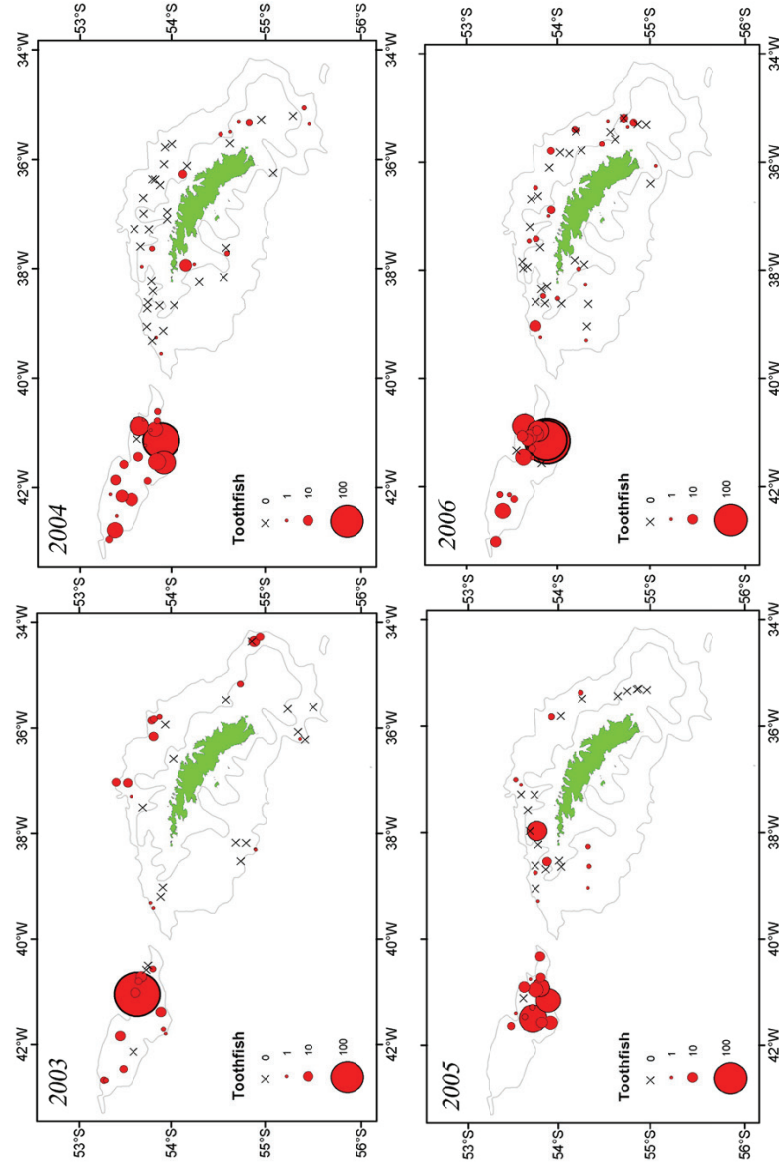


Fig 2

Fig. 3

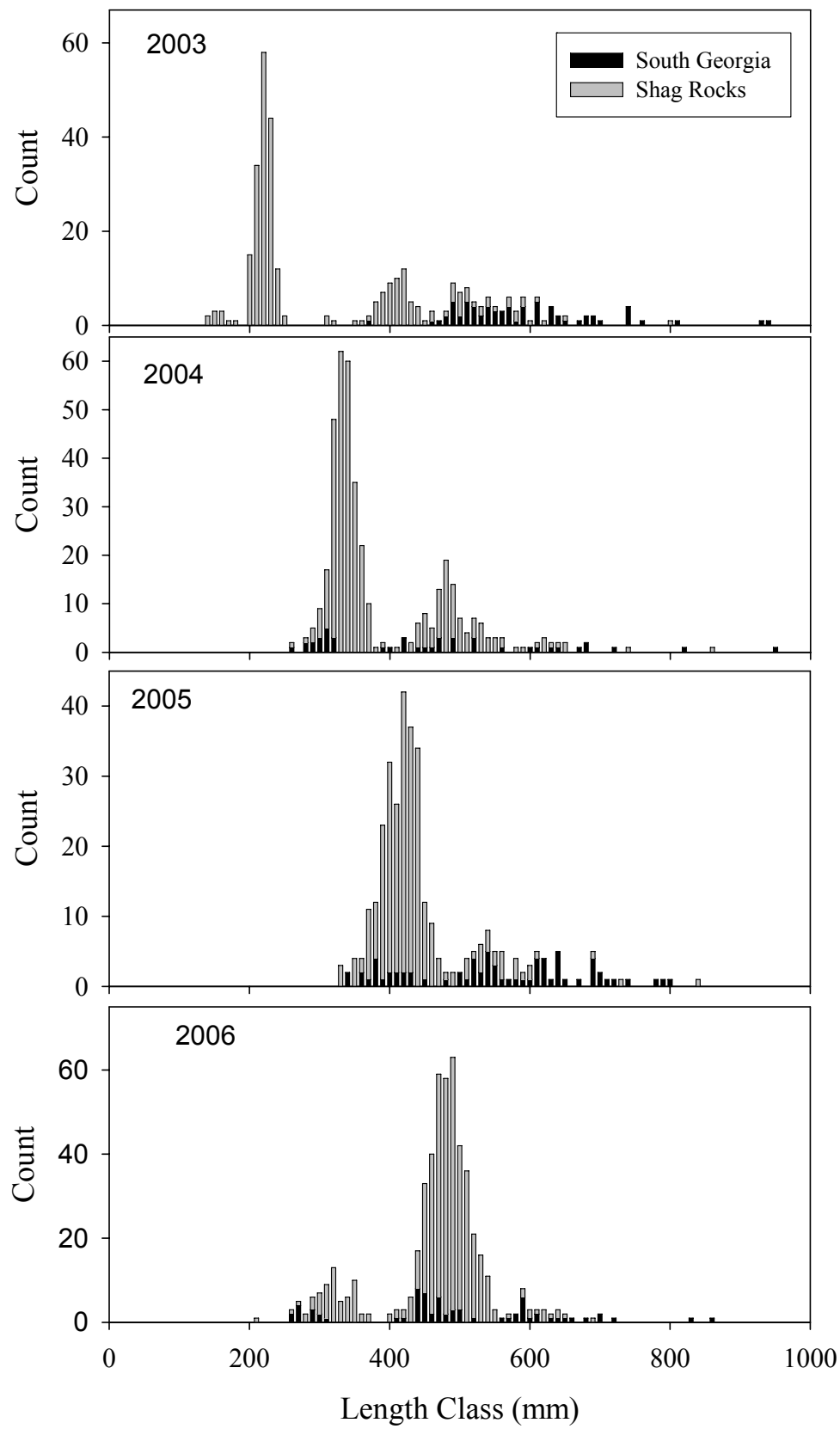
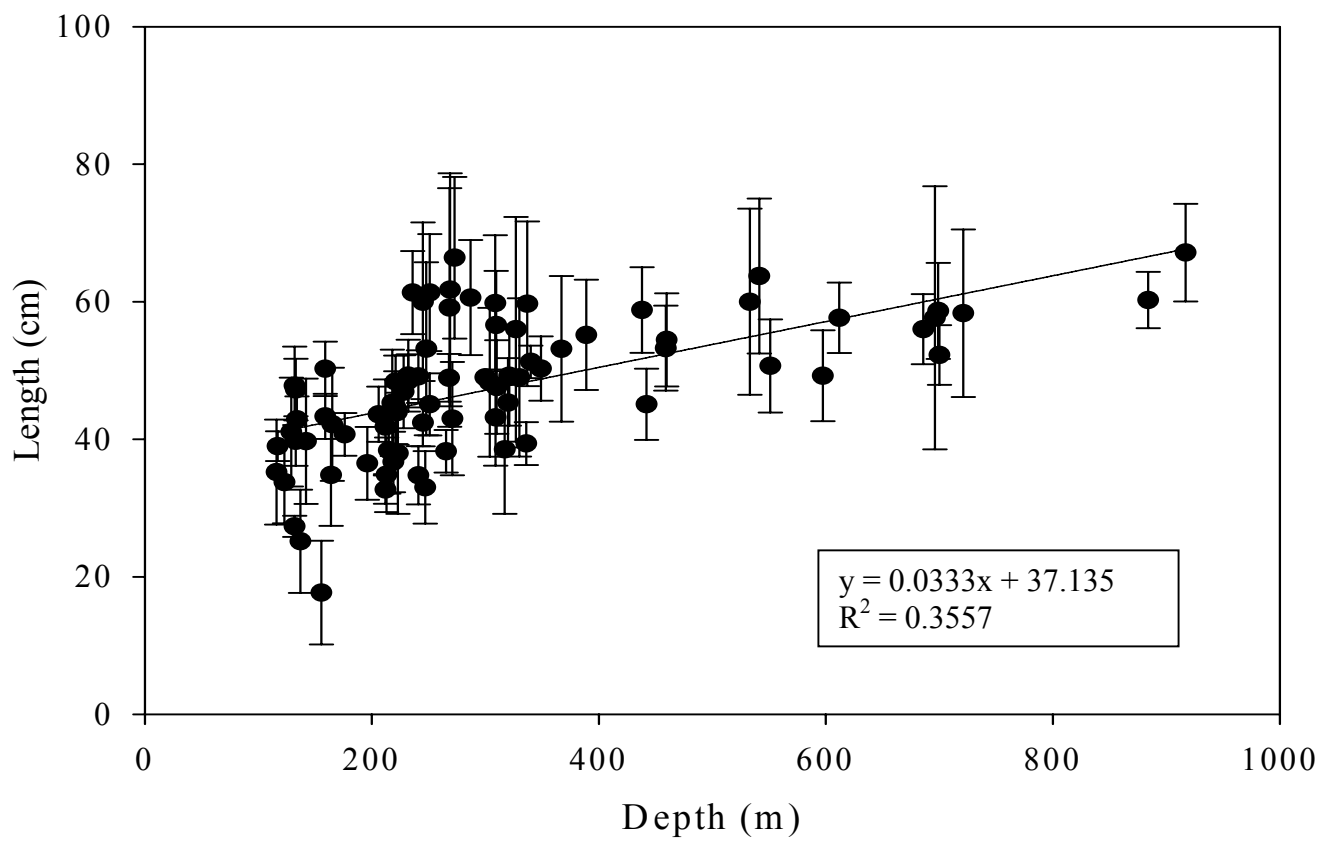


Fig. 4



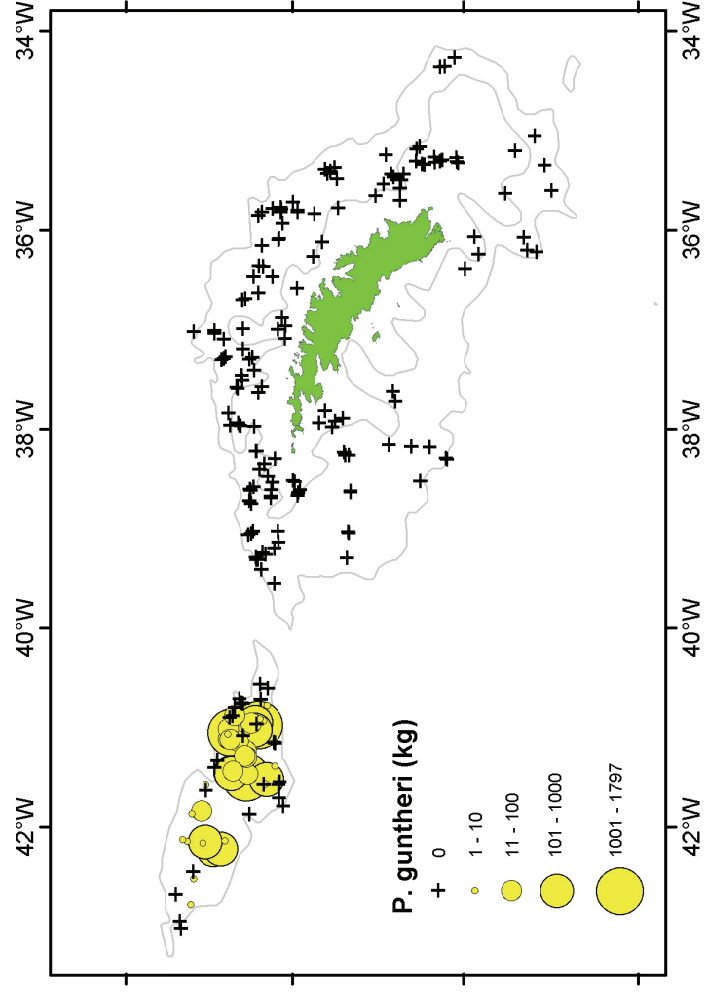
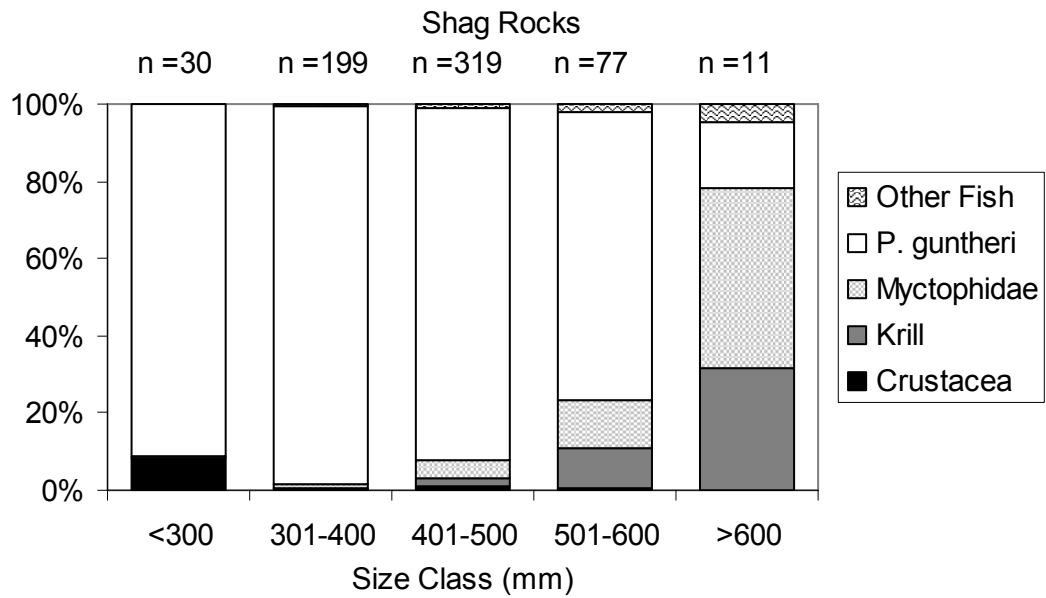


Fig. 6

Fig. 5
(a)



(b)

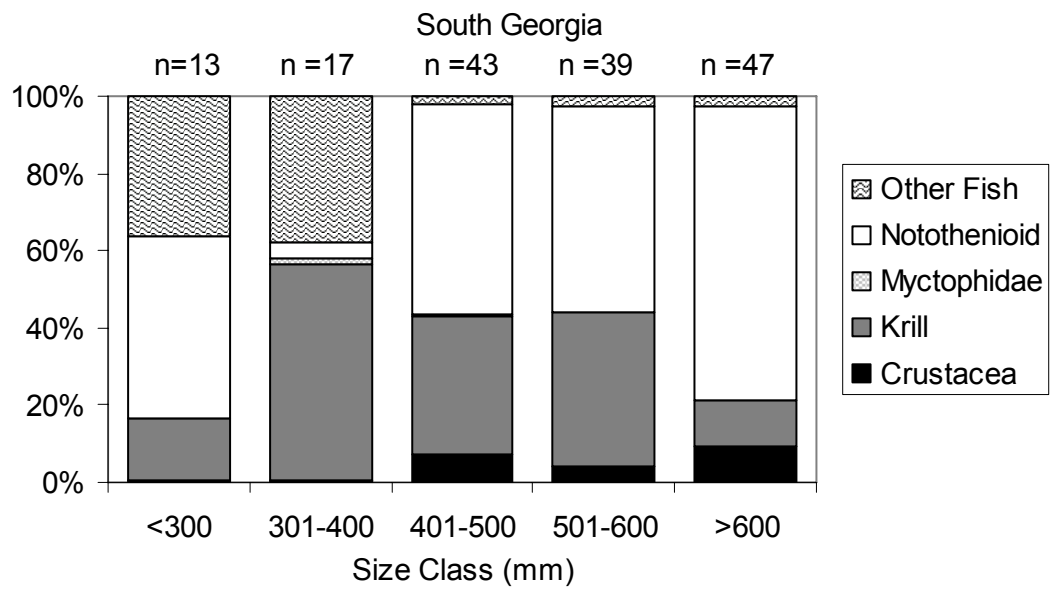


Fig. 7

