Distribution and ecology of *Chaenocephalus aceratus* (Channichthyidae) around South Georgia and Shag Rocks (Southern Ocean)

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Abstract *Chaenocephalus aceratus* (Family Channicthyidae) is one of the dominant species of demersal fish living on the South Georgia shelf where it is caught in low numbers as by-catch in the mackerel icefish and Antarctic krill commercial fisheries. Data collected during 14 demersal fish surveys, from 1986 to 2006, are analysed to investigate biomass, distribution, growth and diet. Biomass estimates from a swept area method ranged from 4462 tonnes to 28740 tonnes on the South Georgia and Shag Rock shelves although few fish were caught at Shag Rocks. Analysis of length frequency data indicated that growth was fast in the first five years with males and females attaining lengths at first spawning of 440 mm TL and 520 mm TL. The diet was comprised of fish and crustaceans, with an ontogenetic shift in diet from *Euphausia superba* and mysids to benthic fish and decapods observed to begin at 250 mm TL. In larger fish (> 500 mm TL) the diet was dominated by fish. *C. aceratus* diet is sufficiently different from the other species of channichthyids around South Georgia to suggest that these species have undergone resource partitioning.

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Introduction

Demersal fish assemblages in the Southern Ocean are dominated by the perciform suborder Notothenioidae (Gon & Heemstra 1990; Eastman 2005). The notothenioids include 6 familes, one of which, the Family Channichthyidae, lacks the respiratory pigment haemoglobin and are known as the icefish (Everson 1984; Eastman 1991; Kock and Everson 1997; Koch 2005). The channnichthyids include 15 species, 3 of which (*Champsocephalus gunnari*, *Pseudochaenichthys georgianus* and *Chaenocephalus aceratus*) are abundant around South Georgia. The Scotia Sea or black-fin icefish, *Chaenocephalus aceratus* Lönnberg 1906, is found from South Georgia to the northern part of the Antarctic Peninsula in the Atlantic sector of the Southern Ocean and at Bouvetoya Island (Permitin 1977; Iwami and Kock 1990). It is predominately found in shelf waters to a depth of 450 m with a few individuals caught down to depths of 770 m (Iwami and Kock 1990; Kock 2005). Mature fish are believed to move inshore to spawn (Lisovenko 1988), in a seasonal migration that occurs from March to May at South Georgia and later further south (Kock and Kellermann 1991).

The seas around South Georgia are some of the most productive in the Southern Ocean (Atkinson et al. 2001) and support large populations of land-based predators and commercial fisheries for krill, mackerel icefish and Patagonian toothfish (Agnew 2004). Commercial fishing began at South Georgia in the mid-1960s and *C. aceratus* was caught as by-catch in the mackerel icefish (*Champsocephalus gunnari)* fishery (Sosinski and Szlakowski 1992; Kock at al. 2000). Early by-catch levels of *C. aceratus* are unknown because by-catches were incompletely reported or unreported

(Kock 2005), but in the late 1970s catches of *C. aceratus* reached over 2000 tonnes, peaking in 1977/78, when 2066 tonnes were caught in a targeted fishery (CCAMLR 1990). Biomass estimates in the 1980s suggested that the virgin stock of *C. aceratus* had declined by 40 % (Kock 1991). Since 1982 the fisheries at South Georgia have been managed under the auspices of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and following a poor season in 1990/91 commercial trawl fishing at South Georgia was prohibited. The mackerel icefish fishery resumed in 1992/3, but was restricted to pelagic trawling with strict by-catch limits set by CCAMLR. Under CCAMLR's ecosystem approach to management (Constable et al. 2000) stocks are managed conservatively, to ensure sustainability, but the impacts on non-target and dependent species are also taken into account in setting catch levels. As a by-catch in both the krill and mackerel icefish fisheries (Agnew 2004; Everson et al. 1992) *C. aceratus* is vulnerable to exploitation at different stages of its life cycle and developing a better understanding of its ecology will help underpin sustainable management.

Recent studies on the ecology of *C. aceratus* have focussed on age and growth (La Mesa et al. 2004) and diet (Flores et al. 2004) from samples collected around the South Shetland Islands. Earlier studies of the South Georgia population have focussed on growth (Kompowski 1990), reproduction (Lisovenko 1988) and diet (Target 1981; McKenna 1991), although sample sizes have been limited. The aim of this investigation is to synthesise biological data collected on *C. aceratus* during 14 demersal trawl surveys around South Georgia over a 19-year period. This long-term data set will be used to estimate growth and size at maturity and examine inter-annual variability in abundance. In addition data on diet was collected from the last two

surveys in the series. Knowledge of abundance, growth and diet are important in both fisheries management and in understanding the ecological role of this species.

Materials and methods

Sample collection

Research surveys around the South Georgia and Shag Rocks shelves are summarised in Table 1. A random stratified design, with three depth strata (<150 m; 151-250 m; >250 m) was used in all years except 2003. In 2003 trawls were made along radial transects away from South Georgia encompassing depths from 100 m to 900 m. Each trawl was fished for 30 minutes on the sea floor, at a speed of 4 knots with a commercial sized otter trawl (see Everson et al. 1999), with a headline height of 4-6 m, a wingspread of approximately 18 m and a cod-end mesh of 40 mm.

Catch sorting and processing

Fish caught in demersal trawls were sorted into species, with total catch of each species determined using spring balances (pre 2000) or motion compensated scales. Random sub-samples (~200) of *Chaenocephalus aceratus* were collected from trawl catches and were measured to the nearest 10 mm total length (TL) below. Fish weight was measured to the nearest gram, sex was determined and maturity stage assigned (following Kock and Kellermann 1991). In 2005 and 2006 stomachs were removed, placed in zip lock bags and frozen at -20°C for later processing.

Stomach analysis

Stomachs were defrosted before analysis. Stomach contents were separated into different species or species groups. Prey items were identified to the lowest

taxonomic level using relevant literature (Gon and Heemstra 1990; Reid 1996) and reference specimens. Heavily digested fish were identified by their sagittal otoliths. Each prey item was weighed to the nearest 0.01 g and measured using electronic callipers or a ruler. The TL of highly digested fish was estimated using otolith-length relationships (Reid 1996).

Data analysis

For each catch fish density was estimated using the mass of the catch, distance trawled and horizontal opening of the net. Biomass estimates were obtained using the TrawlCI programme, which uses Aitchison's delta distribution to generate unbiased estimates of abundance with confidence intervals (de al Mare 1994). The input data were the individual densities for each trawl, stratified by depth zone and the sea-floor area for each depth strata, which was taken from Everson & Campbell (1991).

Length frequency analysis was undertaken using the software "MIX" (Macdonald and Green 1979), implemented in "R" as "RMIX" (Du 2002). For each year's data the number of components (cohorts) and initial estimates of component means were estimated from length-frequency plots and used as input parameters. "RMIX" outputs were constrained to have a constant co-efficient of variation (standard deviation proportional to the mean) and were run from different starting parameters to find the optimal solution (minimising chi-squared). The resultant means were assigned an age relating to the length frequency distribution assuming that the larvae hatched on 1st September (BAS, unpublished data). To provide information on younger age classes, the mean size of larval and juvenile *C. aceratus* caught from plankton sampling around South Georgia were included. Larvae came from two sources: sampling in

Cumberland East Bay, South Georgia during September and October (2001 to 2006) and from RRS James Clark Ross samples (March 2004) collected to the north west of South Georgia. A von Bertalanffy growth curve was fitted (using Sigma Plot 9.0) to the mean sizes of each cohort by following cohort progression and assuming similar sized fish in different years were the same age.

Length-mass relationships and length at first spawning were examined. The relationship between length and mass was calculated for each sex independently and for both sexes combined. The length at which 50 % of the population spawns for the first time (L_{50}) was estimated by fitting a logistic curve to the cumulative frequency of individuals of maturity stage 3 and greater. L_{50} was estimated for both sexes.

Diet was expressed as percentage number (%N), mass (%M), frequency (%F) and percent index of relative importance (%IRI) following Cortes (1996). Curve fitting routines and regression analyses were undertaken in Sigma Plot 9.0.

Results

Biomass and distribution

Chaenocephalus aceratus was caught in 88.6 % of trawls on the South Georgia shelf compared to 7.5 % of trawls at Shag Rocks (Figure 1), and estimates of biomass of *C. aceratus* were considerably higher on the South Georgia shelf than around Shag Rocks (Table 2). In many surveys *C. aceratus* was absent in trawls around Shag Rocks. The confidence intervals associated with biomass estimates were particularly large in 1997/98 and 1998/90, due to some large catches and zero catches in the sane depth strata. Biomass estimates in the late 1980s and through the 1990s were

generally higher than the 2000s. From 2000 onwards estimated biomass has not exceeded 10 000 tonnes. The greatest biomass around South Georgia is found between 150 m to 250 m.

Length composition and growth parameters

A total of 28342 *Chaenocephalus aceratus* were measured ranging from 120 mm to 760 mm TL. Not all these individuals were sexed. Females attained a larger size (760 mm TL, $n = 5939$) than males (610 mm TL, $n = 4812$).

Discrete size modes can be seen within the population in each survey (Figure 2). The first three modes were clearly visible in most surveys at approximately 170 mm, 260 mm and 350 mm TL. A fourth and fifth mode were observed at 420 mm and 490 mm TL in some of the surveys, but at greater sizes it became difficult to distinguish size classes. In most surveys "RMIX" picked out the first four or five modes successfully but could not differentiate year classes beyond that point (Table 3). Larvae were caught in September-October (TL~20 mm) and March (TL~70 mm).

The growth parameters, estimated by fitting a von Bertalanffy growth curve to the mean size at age data (Figure 3) were K = 0.152, t_0 = -0.069 and L_∞ = 841. Annual growth was fast up to five years varying from 61 mm yr^{-1} to 119 mm yr^{-1} (Figure 3). By extrapolating the von Bertalanffy growth curve, the maximum size of fish caught in this study (760 mm) was estimated to be 15 years old.

Length-mass relationship

Mass of males ranged from 10 g to 2000 g ($n = 1953$) and females ranged from 10 g to 3970 g ($n = 2146$). The relationship between length (L) and mass (M) is summarised by the following equations below:

Males: $M = 0.0004\ TL^{3.7045}$ $r^2 = 0.98, p < 0.0001$

Females: $M = 0.0003\ TL^{3.8238}$ $r^2 = 0.97, p < 0.0001$

Sexes combined: $M = 0.0004\ TL^{3.7422}$ $r^2 = 0.97, p < 0.0001$

These relationships indicate that females weigh more for a given length than males.

Maturity

Stage 1 males and females were caught in the highest numbers followed by stage 2. Together these stages made up 90 % of males and 78 % of females sampled ($n = 8534$). Only a small percentage of the population had begun to develop gonads for spawning within a given year. L_{50} for males and females were estimated as 440 mm TL and 520 mm TL, respectively (Figure 4), which means male and female *C. aceratus* reach sexual maturity at approximately 72 % and 68 % of their maximum TL.

The greatest proportion of stage 1 males and females were caught in the north east region of South Georgia (Figure 5). In this region the first three year classes were stronger than in other areas. However, the numbers of 1+ individuals were highest in the south east and west of the island. The greatest numbers of stage 3 individuals were along the east coast of the island. Within this maturity class there were a greater proportion of females than males. No males were found at stage 4 and less than 1 % of females were in this category.

Diet

A total of 38 and 110 full or partially full stomachs were analysed from *C. aceratus* (170-690 mm TL) collected during bottom trawling around South Georgia in 2005 and 2006, respectively.

The diet of *C. aceratus* was pooled for the two years, as the sample size in 2005 was low and comprised similar species to the 2006 sample (Table 4). Fish dominated the prey by percentage mass (96 %), with nototheniids and channichthyids comprising the majority of the fish diet. Crustaceans were found more frequently in stomachs (71 %), with euphausids, the decapod *Notocrangon antarcticus* and the mysid *Antarctomysis* spp. being the most common. The importance of each prey item was calculated by combining %N, %F and % W to produce a %IRI.

Distinct ontogenetic changes were evident in the diet (Figure 6). Up to 250 mm TL the diet was dominated by krill with *Antarctomysis* sp. also consumed. At 250 mm TL a shift in prey species began with benthic decapods and fish appearing in the diet, and by 350 mm TL approximately 60 % of the prey was fish and benthic decapods (Figure 6). By 450 mm TL fish dominated the stomach contents. Mackerel icefish were the primary fish prey from 450 to 650 mm TL, and were replaced by Nototheniidae (*Dissostichus eleginoides, Notothenia gibberifrons and Lepidonotothen larseni*) in fish > 650 mm TL. *Antarctomysis* spp. did not appear in stomach contents of fish greater than 450 mm TL.

Predator prey relationships

Only one modal length of krill and mysids were found within the stomach of *C. aceratus* at any time. The length of krill and mysids ranged from 32-57 mm and 30-45 mm, respectively. Size of fish ingested increased significantly with the size of predator (Pearson's correlation: $r^2 = 0.415$, d.f. 29, $p < 0.001$). Ingested fish ranged in size from 60- 490 mm TL (Figure 7). *C. aceratus* was found to consume fish up to 93 % of its own body length.

Discussion

Information on the groundfish stocks around South Georgia has been collected through scientific research since the 1980s (Sosinski and Szlakowski 1992; Everson et al. 1999). Biomass estimates of *C. aceratus* have shown interannual variability since the late 1980s. This could be caused by a variety of sources including sampling variability as a result of differences in vessel and gear type (Sosinski and Szlakowski 1992; Pilling and Parks 1995), natural variability within the ecosystem and fishing pressure (McKenna and Saila 1991). Direct fishing on *C. aceratus* was prohibited in 1989/90 (Kock 1991) and since 1988 less than five tonnes per year has been taken as by-catch in the mackerel icefish fishery (CCAMLR 1992; CCAMLR 2006), so direct fishing pressure is unlikely to be the cause. Biomass estimates in the late 1980s suggested that the stock was 40 % of its original size (Kock 1991) and the data presented here indicate that the population has not recovered to pre-exploitation levels. This would suggest that factors other than commercial fishing are controlling the population size of *C. aceratus*.

Adult *C. aceratus* are benthic predators with fish, particularly *C. gunnari,* as their main food source. The biomass of *C. gunnari* fluctuates dramatically between years

(Everson et al. 1999) and may therefore affect food availability for adult *C. aceratus* and may limit energy for reproduction. Changes in *C. gunnari* abundance have been linked to variability in its primary prey, Antarctic krill (Everson et al. 1999), which are also important in the diet of juvenile and sub-adult *C. aceratus* (this study; Kompowski 1980). The abundance of Antarctic krill at South Georgia is subject to considerable interannual variability (Brierley et al. 1999), and poor krill years may significantly reduce the survival of juvenile *C. aceratus*. *Chaenocephalus aceratus* are also competing with land-based predators such as Antarctic fur seals and gentoo penguins for Antarctic krill and mackerel icefish (Everson et al. 1999). The dramatic increase in the fur seal population since the 1970's has probably increased that competition and may, in part, be responsible for the lack of recovery in the *C. aceratus* stock.

Recruitment variability is high within *C. aceratus*. Some recruitment, however, is seen each year but there are noticeable years in which the number of individuals recruiting to the population is much higher. Sea surface temperature (SST) has been linked to recruitment in mackerel icefish around South Georgia (Hill et al. 2005) and Patagonian toothfish on the Shag Rocks shelf (Collins et al. in press). Hill et al. (2005) found that the abundance of juvenile mackerel icefish in the diet of gentoo penguins was positively correlated to temperature at the putative spawning time. *C. aceratus* and mackerel icefish are both channichthyids that cover a similar latitudinal range and have very similar life history strategies, which could suggest spawning temperatures may play a role in the determination of year class strength of *C. aceratus*.

Larval retention on the continental shelf may also play an important role in the recruitment of this species. Interannual variability in the direction of flow and the velocity of the shelf break front or transitional zone could have profound effects on larval distribution and egg transport (Meredith et al. 2005). *C. aceratus* make inshore migrations to spawn on the continental shelf (Lisovenko 1988) and there is evidence that they lay benthic eggs (Detrich et al. 2005). It is therefore likely that pelagic larval stages will be more affected by variability in oceanographic currents than eggs. Length frequency analysis shows a high proportion of 1+ individuals recruiting to the south of the island and this area may be an important nursery ground before fish migrate to the north east of the island, where there is greater biomass and hence an increased risk of predation by cannibalism.

There are differences between this study and others in relation to estimates of age structure and growth rate. Analysis of length frequency distributions by Kompowski (1990) on *C. aceratus,* caught around South Georgia between April and May, found modal lengths of 100 mm, 200 mm, 270 mm, 340 mm and 400 mm. These were believed to equate to one to five years old (Kompowski 1990) and, given the different sampling months, are consistent with those observed in this study, indicating that *C. aceratus* grows quickly in its first 4-5 years (Kompowski 1990). Similar modes were also apparent in the length frequency data from the South Shetlands (La Mesa et al 2004), with modes at 150, 250, 310 and 400 mm TL, but interpretation of growth rings in otoliths from these fish were not consistent with these modes representing year classes.

Our estimate of the growth parameter K, that describes growth rate, is similar to Kompowski's (1990) otolith based estimate, but is more than double that of La Mesa et al. (2004), which was derived from otolith analysis of South Shetlands fish. La Mesa et al. (2004) suggested that, if the differences in growth rate (compared to Kompowski 1990) were real, it could be a consequence of different environmental conditions such as temperature or food availability. Otoliths were examined from fish caught in this study, but no consistent growth pattern was detected (Reid & Belchier unpublished), and otoliths of the channichthyids are notoriously difficult to age. To date no validation of the annual deposition of growth rings in *C. aceratus* otoliths has been achieved, a problem highlighted by La Mesa et al. (2004). Clearly a growth estimate that combined validated otoliths readings and length frequency analysis would give greater confidence in growth estimates. However, in a highly seasonal environment, the clear modes consistently detected in the first three size classes (in all three studies) supports the hypothesis that these are year classes and indicates relatively rapid growth.

The diet data presented here provide a snapshot of the diet of *C. aceratus* in two austral summers, but do not take into account any inter-annual or seasonal variability in the diet as observed by Koslov et al. (1988). Overall the results are consistent with other diet studies on *C. aceratus* and demonstrate that this species eats a wide range of prey items (Targett 1981; Koslov et al. 1988; McKenna 1991; Flores et al. 2004). Focussing on one or two forms of analyses can produce misleading results in relation to the importance of specific prey items. Calculation of either a dietary coefficient (Flores et al. 2004) or using a combination of percentage mass, frequency and number of prey items to produce a %IRI (Cortes, 1996) makes studies easier to compare. This

study agrees with Flores et al. (2004) that *C. aceratus* starts life as a planktivorous predator, becoming an opportunistic benthic predator as it grows. At South Georgia a change in diet begins to appear at 250 to 350 mm TL when *C. aceratus* are more prevalent in demersal trawls. This change is manifested by a shift in diet from euphausids and mysids to benthic fish and decapods. Together this would suggest a change in foraging behaviour or habitat utilization and will reduce competition for food and decrease the risk of cannibalism between adults and juveniles.

Diet studies aid our understanding of resource partitioning within the ecosystem and the magnitude of the links between different species within the food web (Collins et al. in press). The diet and morphology of *C. aceratus* and *C. gunnari* are consistent with different feeding behaviours and habitats (Eastman 1993). Behavioural and morphology studies have shown that the Scotia Sea icefish is an ambush predator that sits on its heavy first pelvic fin rays and waits for moving prey (Fanta et al. 2003). Daily vertical feeding migrations have been observed in mackerel icefish (Trunov et al. 2000), which is more streamlined in shape (Iwami and Kock 1990) and lighter than *C. aceratus* (Eastman and Sidell 2002). The daily migrations of *C. gunnari* and *N. larseni* (Trunov et al. 2000), another important prey species, occur at the peak activity of adult *C. aceratus* (Fanta et al. 2003). *C. aceratus* use visual and chemical senses to target moving prey and ignore stationary targets (Fanta et al. 2003). *C. aceratus* benthic foraging strategy allows resources to be partitioned vertically between species of icefish (Gröhsler 1994) as well as potentially bringing it into contact with its major prey after *C. gunnari* and *Lepidonotothen larseni* have been foraging. *C. aceratus* has been observed to guard nests at Bouvetoya Island (Dietrich et al. 2005). A benthic

foraging strategy could be more appropriate as they may not leave the nest site for long periods of time to forage in the pelagic realm.

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Table 1 Season, vessel, dates and number of demersal trawls conducted on the South Georgia and the Shag Rocks groundfish survey between 1986 and 2006.

Season	Survey Vessel	Start Date	End Date	Shag Rocks	South Georgia
1986/87	Profesor Siedlecki	29-Nov-86	17-Dec-86	11	93
1987/88	Profesor Siedlecki	19-Dec-87	12-Jan-88	4	109
1988/89	Profesor Siedlecki	01-Feb-89	14-Feb-89	0	55
1989/90	Hill Cove	06-Jan-90	26-Jan-90	9	59
1990/91	Falklands Protector	22-Jan-91	11-Feb-91	12	66
1991/92	Falklands Protector	03-Jan-92	26-Jan-92	13	67
1993/94	Cordella	04-Jan-94	08-Feb-94	13	65
1997/98	Argos Galicia	02-Sep-97	29-Sep-97	12	45
1999/2000	Argos Galicia	16-Jan-01	30-Jan-01	11	30
2001/02	Dorada	05-Jan-02	01-Feb-02	19	44
2002/03	Dorada	07-Jan-03	31-Jan-03	8	11
2003/04	Dorada	07-Jan-04	05-Feb-04	21	44
2004/05	Dorada	07-Jan-05	25-Jan-05	14	24
2005/06	Dorada	03-Jan-06	01-Feb-06	17	46

Table 2 Biomass estimates (tonnes) calculated by TrawlCI for *Chaenocephalus aceratus* caught in bottom trawls on the South Georgia and Shag Rocks shelves. No trawls were conducted at Shag Rocks in 1989 (ND = no data); * only one tow in this depth zone caught *C. aceratus*.

	Sea-floor area (km^{-2})	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1993/94	1997/98	1999/00	2001/02	2003/04	2004/05	2005/06
South Georgia < 150 m	8861	645	998	2089	3030	4155	1312	1048	105	476	1973	2383	*	1175
South Georgia 150-250 m	19205	8769	6513	6913	23900	9632	10220	11208	12356	3343	5253	4531	3740	8166
South Georgia >250 m	7974	4145	641	757	1810	898	6461	565	2093	881	1774	1116	722	1420
SR	4981	0	0	ND	0	0	0	0	0	17	0	0	0	46
Total		13561	8152	9759	28740	14690	17990	12821	14554	4717	9000	8030	4462	10807
L 95% CI		9284	6030	6850	9781	10600	11299	7542	4639	2869	5923	5289	2360	6780
U 95% CI		23709	12200	16869	192246	23100	47624	29650	173459	11807	17153	27560	44139	23168

Table 3 Mean total length of each cohort estimated by the "RMIX" analysis. Standard error is in parenthesis, - denotes no mean length for year class.

Survey season	Mean total length of cohort (SE mean) (mm)				
	1+	2+	3+	4+	5+
1986/87	149.9 (1.4)	248.7 (1.3)	329.6 (2.8)	411.0 (5.4)	496.4 (6.6)
1987/88	161.0 (0.8)	241.8 (1.3)	320.8 (0.9)	410.3 (3.4)	489.7 (3.5)
1988/89	169.7 (1.3)	256.7 (1.4)	327.4 (3.6)	398 (1.7)	494.9 (3.0)
1989/90	173.3 (0.7)	264.0 (0.9)	342.8 (2.3)	438.6 (8.4)	492.0 (9.8)
1990/91	177.0 (0.6)	268.2 (0.7)	335.1 (1.1)	413.8 (2.4)	497.0 (3.7)
1991/92	177.0 (0.4)	261.2 (0.3)	341.2 (1.2)	-	-
1993/94	161.9 (0.9)	248.1 (0.8)	332.0 (1.2)	409.8 (2.8)	494.5 (2.2)
1997/98	158.3 (1.5)	259.5 (1.1)	325.8 (2.6)	-	-
1999/00	171.5 (1.4)	247.3 (0.8)	326.3 (2.4)	419.7 (5.2)	500.9 (5.8)
2001/02	175.9 (0.7)	264.5 (0.8)	316.2 (1.3)	389.5 (3.3)	444.2 (5.4)
2002/03	182.5 (0.9)	270.2 (2.1)	343.5 (4.5)	395.2 (10.5)	481.9 (6.2)
2003/04	183.9 (1.8)	276.7 (1.0)	360.2 (2.0)	431.9 (3.8)	490.6 (6.2)
2004/05	187.4 (0.7)	269.0 (1.7)	353.7 (2.9)	429.2 (10.0)	467.0 (16.9)
2005/06	183.2 (0.8)	268.8 (4.8)	345.0 (1.7)	425.0 (2.4)	496.9 (5.9)

Table 4 Summary of the prey items found within the stomach of *Chaenocephalus aceratus* caught around South Georgia in 2005 and 2006 with the number of partial and full stomachs examined in parenthesis. The prey composition is expressed as % number (N), % frequency (F), % mass (M) and has then been combined to form a % index of relative importance (IRI).

	January 2005 (n = 38)							January 2006 (n = 110)							Pooled data (n = 148)						
	M %	M (g)	F%	F	N%	N	IRI%	M %	M (g)	F %	F	N %	N	IRI%	M%	M (g)	F %	F	N%	N	IRI %
Crustaceans																					
Amphipoda																					
Themisto gaudichaudi	0.02	0.45	5.26	2	5.60	7	0.79	0.03	2.42	5.45	6	3.53	12	0.83	0.03	2.87	5.41	8	4.09	19	0.82
Decapoda																					
Notocrangon antarcticus	0.31	6.36	10.53	4	3.20	4	0.99	1.17	83.76	26.36	29	16.76	57	31.85	0.98	90.12	22.30	33	13.15	61	15.99
Euphausiacea																					
Euphausia superba	6.42	133.10	39.47	15	57.60	72	67.80	0.78	55.73	22.73	25	27.94	95	44.78	2.05	188.83	27.03	40	35.99	167	48.80
Thysanoessa spp.	0.00	0.00	0.00	0	0.00	0	0.00	0.00	0.26	0.91	1	0.29	1	0.01	0.00	0.26	0.68	1	0.22	1	0.01
Unidentified euphausid	0.00	0.00	0.00	0	0.00	0	0.00	0.01	0.76	2.73	3	0.00	0	0.00	0.01	0.76	2.03	3	0.00	0	0.00
Isopoda																					
Unidentified isopods	0.01	0.12	2.63	1	0.80	1	0.06	0.01	0.95	0.91	1	1.47	5	0.06	0.01	1.07	1.35	2	1.29	6	0.07
Mysidacea																					
Antarctomysis ohlinii	0.24	4.98	0.07	3	11.20	14	2.42	0.48	33.66	24.50	27	37.06	126	4.98	0.42	38.64	20.20	30	30.17	140	1.23
Unidentified Crustacean	0.02	0.38	5.26	2	1.60	2	0.23	0.00	0.09	0.91	1	0.29	1	0.01	0.01	0.47	2.03	3	0.65	3	0.05
Crustacea Total	7.01	145.39	71.05	27	80.00	100	47.56	2.49	177.63	82.73	91	87.35	297	62.15	3.51	323.02	79.73	118	85.56	397	64.56
Other Invertebrates																					
Bivalve	0.00	0.00	0.00	0	0.00	0	0.00	0.01	0.64	0.91	1	0.29	1	0.01	0.01	0.64	0.68	1	0.22	1	0.01
Ophiuroid	0.00	0.00	0.00	0	0.00	0	0.00	0.01	0.54	0.91	1	0.29	1	0.01	0.01	0.54	0.68	1	0.22	1	0.01
Sea urchin	0.00	0.00	0.00	0	0.00	0	0.00	0.54	38.38	0.91	1	0.29	1	0.04	0.42	38.38	0.68	1	0.22	1	0.02
Fish																					
Atredidraconidae																					
Artedidraco sp.	0.00	0.00	0.00	0	0.00	0	0.00	0.03	2.15	0.91	1	0.29	1	0.01	0.02	2.15	0.68	1	0.22	1	0.01
Bathydraconidae																					
Parachaenichthys georgianus	7.53	156.12	2.63	1	0.80	1	0.59	1.98	141.26	1.82	2	0.59	2	0.22	3.23	297.38	2.03	3	0.65	3	0.29
Channichthyidae																					
Chaenocephalus aceratus	6.91	143.20	2.63	1	0.80	1	0.54	6.80	485.00	0.91	1	0.29	1	0.31	6.82	628.20	1.35	2	0.43	2	0.36
Champsocephalus gunnari	45.57	944.60	13.16	5	4.00	5	17.50	32.41	2312.18	9.09	10	2.94	10	15.31	35.37	3256.78	10.14	15	3.23	15	14.46
Channichthyid sp	0.00	0.00	0.00	0	0.00	0	0.00	1.23	87.68	1.82	2	0.59	2	0.16	0.95	87.68	1.35	2	0.43	2	0.07
Nototheniidae																					
Dissostichus eleginoides	15.42	319.70	2.63	1	0.80	1	1.15	16.75	1195.00	0.91	1	0.29	1	0.74	12.98	1195.00	0.68	1	0.22	1	0.33
Gobionotothen gibberifrons	0.00	0.00	0.00	0	0.00	0	0.00	13.67	975.00	0.91	1	0.29	1	0.60	14.06	1294.70	1.35	2	0.43	2	0.72
Gobionotothen marionensis	0.00	0.00	0.00	0	0.00	0	0.00	0.47	33.31	0.91	1	0.29	1	0.03	0.36	33.31	0.68	1	0.22	1	0.01
Lepidonotothen larseni	7.01	145.21	10.53	4	3.20	4	2.88	2.96	211.15	6.36	7	2.65	9	1.70	3.87	356.36	7.43	11	2.80	13	1.84
Notothenia rossii	0.00	0.00	0.00	0	0.00	0	0.00	18.23	1301.00	1.82	2	0.59	2	1.63	14.13	1301.00	1.35	2	0.43	2	0.73
Nototheniid sp	0.68	14.06	10.53	4	3.20	4	1.10	2.39	170.64	7.27	8	2.35	8	1.64	2.01	184.70	8.11	12	2.59	12	1.38
Muraenolepididae																					
Muraenolepis spp.	7.78	161.23	5.26	2	1.60	1	1.32	0.05	3.22	0.91	1	0.29	1	0.01	1.79	164.45	2.03	3	0.65	3	0.18
Myctophidae																					
Myctophid sp	0.01	0.30	2.63	1	0.80	1	0.06	0.00	0.00	0.00	0	0.00	0	0.00	0.00	0.30	0.68	1	0.22	1	0.01
Unidentified Fish	2.07	42.99	15.79	6	4.00	5	2.57	0.00	0.02	0.91	1	0.29	1	0.01	0.47	43.01	4.73	7	1.29	6	0.31
Total Fish	92.99	1927.41	47.37	18	19.20	24	52.43	96.96	6917.61	34.55	38	11.76	40	37.84	96.06	8845.02	37.84	56	13.79	64	35.43

Legends to Figures

Fig. 1 Catches of *Chaenocephalus aceratus* on the South Georgia and Shag Rocks shelves from demersal trawl surveys between 1987 and 2006. The 200 m and 1000 m isobaths are shown.

Fig. 2 Length-frequency distributions of *Chaenocephalus aceratus* from the South Georgia shelf between 1987 and 2006 caught during demersal trawls. Arrows represent the mean lengths of each cohort estimated by "RMIX".
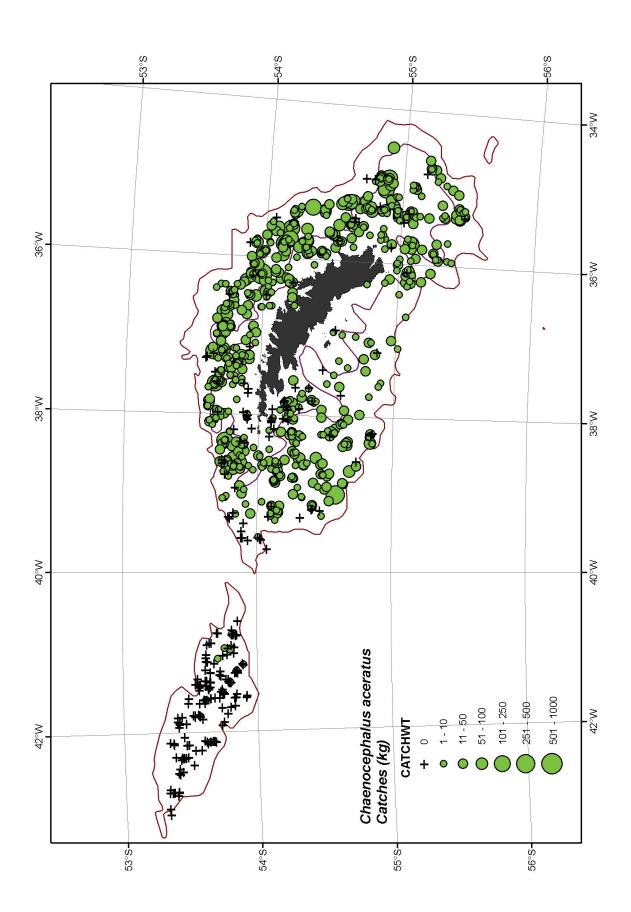
Fig. 3 von Bertalanffy growth curve for *C. aceratus*, derived from mean lengths of each cohort (sexes combined) estimated by "RMIX" collected by demersal trawls on the South Georgia shelf (1987-2006). Larval length data was obtained from pelagic trawls to the north west of South Georgia in March (total length 64 to 94 mm TL) and larvae collected in Cumberland East Bay between September and October (< 60 mm TL).
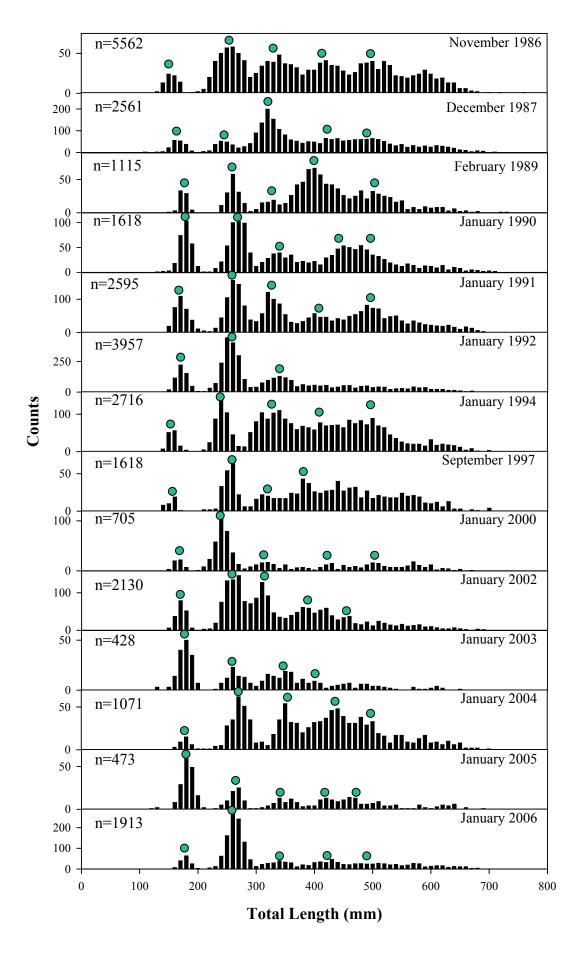
Fig. 4 Logistic curve of the size at sexual maturity for male and female *Chaenocephalus aceratus* from South Georgia. Solid line indicates the estimated size at, which 50% of the population reach maturity.
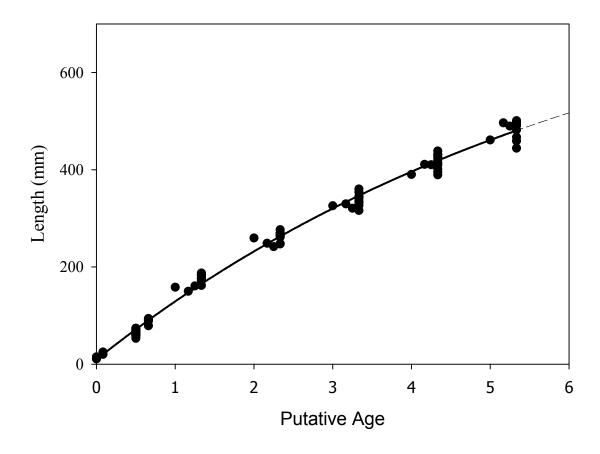
Fig. 5 The distribution of the maturity stages 1 to 5 and length frequency distribution of *Chaenocephalus aceratus* caught in demersal trawls on the continental shelf of South Georgia in the northwest (NW), northeast (NE), southeast (SE) and southwest (SW).
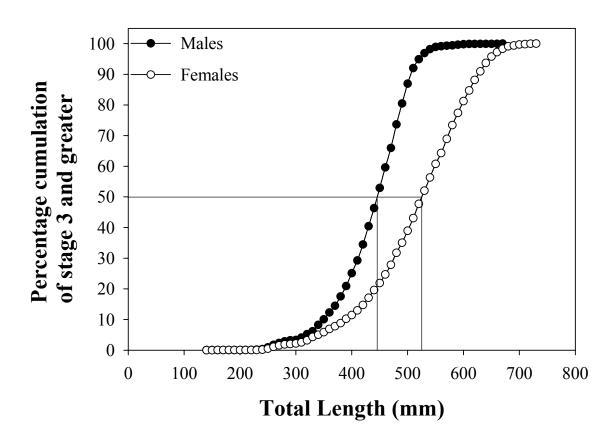
Fig. 6 Index of relative importance (%) of prey items split into separate size classes for *Chaenocephalus aceratus* caught around South Georgia.
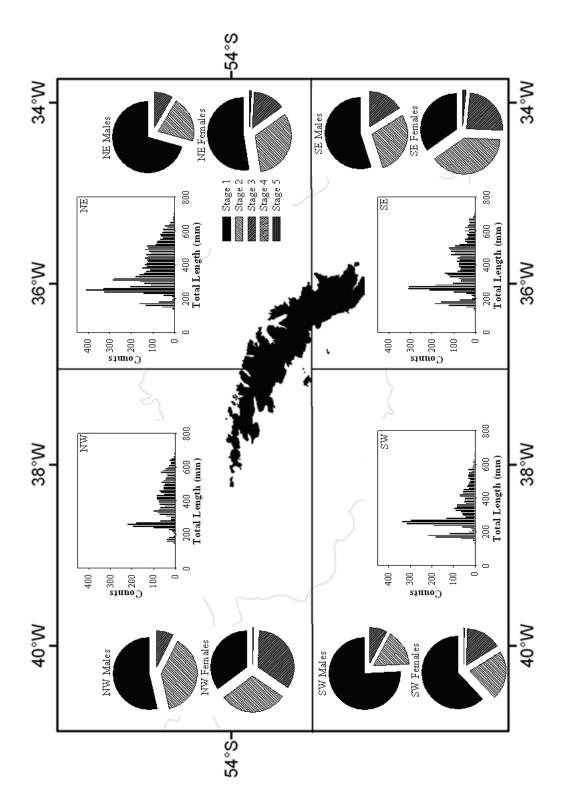
Fig. 7 The length of prey in the diet of *Chaenocephalus aceratus* from stomachs collected in demersal trawls around South Georgia.
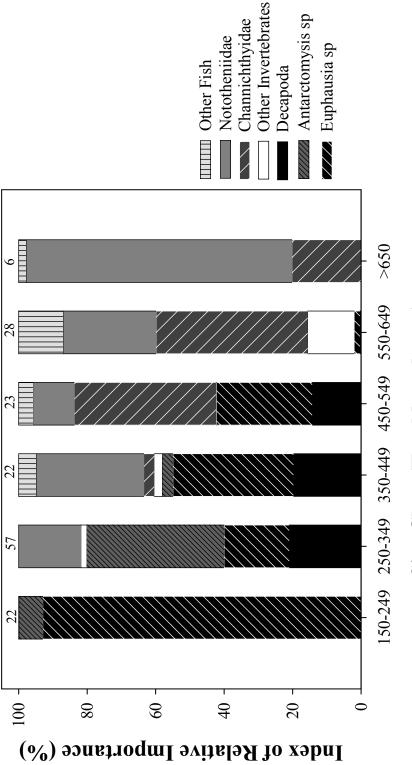
Chaenocephalus aceratus
Catches (kg)

CATCHWT
+ 0
· 1 - 10
· 11 - 50
● 51 - 100
● 101 - 250
● 251 - 500
● 501 - 1000