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Scavenging by megabenthos and demersal fish on the South Georgia slope

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Abstract: The scavenging megafauna of the South Georgia and Shag Rocks slope in the south-west Atlantic (625–1519 m) were investigated using autonomous baited camera systems. Two surveys were conducted: the first in 1997 (13 deployments) used a conventional 35 mm stills camera with a 200 J flash, whilst the second in 2000 (15 deployments) used low-light digital video cameras. The scavenging community responded rapidly to the arrival of bait on the sea floor and was dominated by stone crabs (Lithodidae) and toothfish (*Dissostichus eleginoides*). Stone crabs took up residence around the bait until it was consumed, with a maximum number of 108 in the field of view after four hours. The most frequently observed crab species was *Paralomis formosa*. *Paralomis spinosissima, Neolithodes diomedea* and *Lithodes* sp., were also observed. Toothfish were the most frequently observed scavenging fish and were seen during all but one deployment, typically making brief visits (1–2 min) to the bait, but appeared startled by the flash in the 1997 survey. Labriform swimming (sculling with the pectoral fins) was the principal form of locomotion in toothfish (0.22 body lengths (BL) sec^{-1}), but they were capable of more rapid sub-carangiform (using caudal trunk and fin) motion (3 BL sec^{-1}) when startled. Other scavenging fish observed included the blue-hake *Antimora rostrata*, grenadiers (*Macrourus* spp.), skates, liparids and zoarcids.

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Key words: baited cameras, *Dissostichus eleginoides*, crabs, *Paralomis*, toothfish, south-west Atlantic

Introduction

The animals of the deep sea are almost entirely reliant on fall-out from the surface waters for the supply of food (Wells *et al.* 1931). A significant part of this fall-out comes in the form of phytodetritus, which at high latitudes comes in a strongly seasonal pulse following the spring plankton bloom (Lampitt 1985) and is immediately available to the benthic fauna. An alternative source of food is larger packages such as the carcasses of fish, squid and marine mammals, which arrive less predictably (Isaacs & Schwartzlose 1975, Jones *et al.* 1998, Smith 1986, Stockton & Delacca 1982), and may be supplemented by discards from commercial fishing vessels (Jennings & Kaiser 1998). These larger food-falls typically attract aggregations of mobile scavengers that disperse the organic material, making part of it available to the less mobile components of the benthic fauna (Collins *et al.* 1998). These mobile scavengers thus play a key role in food supply to many benthic groups.

Baited cameras have been used to study scavenging communities in the North (Desbruyeres *et al.* 1985, Jones *et al.* 1998, Priede *et al.* 1994) and South (Collins *et al.* 1999) Atlantic and Pacific (Priede & Smith 1986, Smith 1985, Smith 1986) Oceans and in the Arabian Sea (Janssen *et al.* 2000, Witte 1999). These studies indicate distinct bathymetric changes in the scavenging fauna, with hagfish and decapod crustacea dominant in shallow water whereas eels, morids and grenadiers were dominant at greater depths.

Around South Georgia, the shallow water fauna has been studied (e.g. White 1984, McKenna 1991) but the deep sea fauna remains largely unknown. Recent years have seen the development of a commercial deep water longline fishery for the Patagonian toothfish, *Dissostichus eleginoides* Smitt, 1898, in waters around South Georgia and other sub-Antarctic islands. There have also been investigations of other potential deep sea resources such as crabs (Otto & Macintosh 1996, Watters 1997). Such studies have highlighted the paucity of knowledge of the deep sea fauna in this area.

The development of the toothfish fishery and the need for a fishery independent assessment of abundance led to an initial baited camera survey in 1997 (Yau *et al.* 2001). Although the results were disappointing, they did highlight the presence of large numbers of crabs (Lithodidae) in the area. A further study was therefore undertaken in January 2000 using baited video cameras in an attempt to assess the abundance of both toothfish and stone crabs. Results of the crab assessment (Collins *et al.* in press) and the initial toothfish studies (Yau *et al.* 2001) have been presented elsewhere and here we report on the composition of the scavenging fauna of the South Georgia slope with observations on the behaviour of toothfish and crabs.

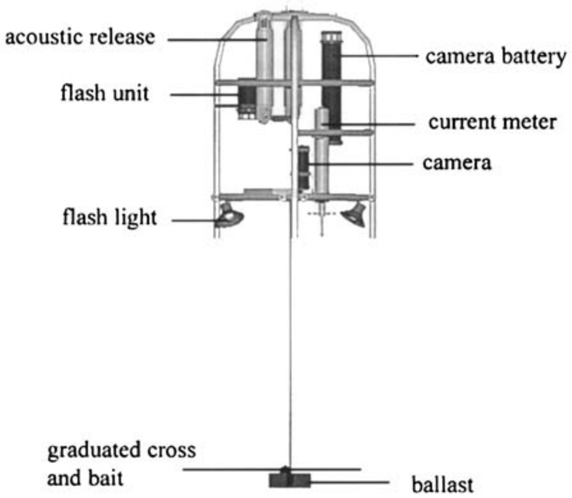

Fig. 1. The Aberdeen University Deep Ocean Submersible (AUDOS) as it was configured during the 1997 survey at South Georgia.

Materials and methods

During September 1997 and January 2000 modified versions of the Aberdeen University Deep Ocean Submersible (AUDOS; see Fig. 1) were deployed on the South Georgia slope. The AUDOS system consists of an aluminium frame onto which are mounted a downward-facing camera, a battery, a light source, a current meter (Sensortec) and twin acoustic releases (Mors) (see Collins & Bagley 1999, Priede & Bagley 2000). Bait is attached to a 1 m aluminium cross, which is fixed to the ballast weight and suspended 2 m below the camera. On deployment, AUDOS freefalls under the weight of the ballast (100–120 kg of scrap iron chain), which holds the vehicle in position on the seafloor. At the end of each deployment, an acoustic signal is sent from the ship, triggering the acoustic releases to drop the ballast. AUDOS then surfaces from the buoyancy provided by a series of glass floats (Benthos Inc) attached to a mooring line. On the surface a dhan buoy, incorporating a VHF radio (Novatech) and a large flag, aid in the surface recovery procedure.

Table I. Details of AUDOS deployments around South Georgia and Shag Rocks in September 1997.

Station no.	Date	Latitude °S	Longitude °W	Depth (m)	Substratum type
97/01	07/09/97	53°19.13'	41°53.66'	1039	Sand/mud, some stones
97/02	08/09/97	53°31.24'	40°20.46'	1149	Sand/mud, stones
97/03	10/09/97	53°46.02'	41°59.07'	1000	Sand/mud
97/04	11/09/97	53°17.67'	42°12.03'	747	Sand/mud
97/05	13/09/97	53°35.20'	37°59.24'	1000	Sand/mud, small stones
97/06	17/09/97	53°45.08'	35°59.80'	1100	Sand/mud
97/07	18/09/97	54°14.94'	35°15.83'	775	Sand/mud
97/08	19/09/97	54°30.94'	35°06.12'	1487	Sand/mud
97/09	21/09/97	55°25.38'	34°55.27'	625	Sand/mud
97/10	22/09/97	55°09.11'	36°21.20'	1143	Sand/mud
97/11	23/09/97	55°02.62'	36°59.65'	1275	Sand/mud, small stones
97/12	24/09/97	54°52.67'	37°58.74'	1178	Sand/mud, small stones
97/13	27/09/97	53°44.39'	39°22.57'	872	Sand/mud, stones

In the 1997 survey a single AUDOS vehicle was used, which carried a 35 mm photographic camera (Ocean Instrumentation) loaded with Ektachrome 200 ASA colour reversal film which was set to operate at one minute intervals. Illumination was provided by twin flashlights (200 J). Bait consisted of squid (*Illex argentinus* (Castellanos)) and assorted fish (including icefish and myctophids) to a total of 800 g. Thirteen deployments were made at depths of 625–1487 m (Table I; Fig. 2). Following processing, the resulting films were assessed on a microfilm viewer. The field of view in each photograph covered an area of *c.* 4.3 m².

In the 2000 survey two AUDOS vehicles were deployed, each equipped with a digital video (DV) camera (JVC Colour Video Camera TK-C1380), with illumination provided by a pair of 50 W lights (Deep Sealites, Deep Sea Power & Light) and having a field of view of *c.* 4.9 m². The cameras were programmed to record a total of one hour of video footage in 45-second sequences every 2.5 min over hours 0–2; every 5 min over hours 2–4; and every 15 min over hours 4–6 of a deployment. The lights were set to activate one second before the cameras and brightened to full intensity gradually.

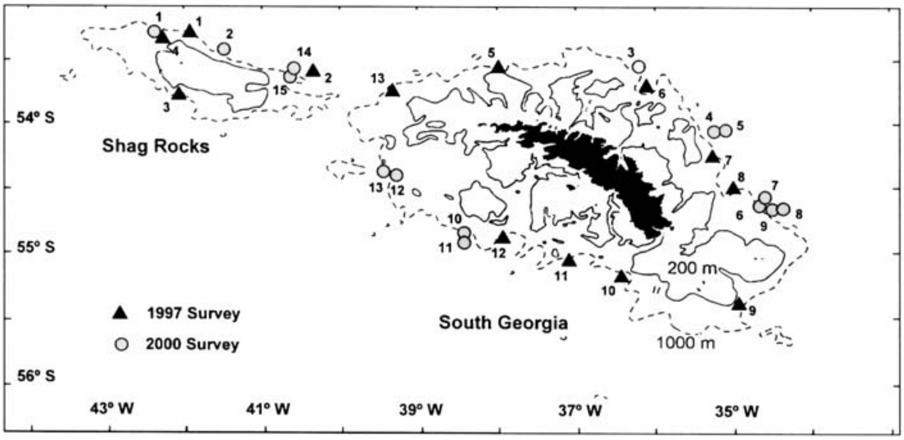

Fig. 2. Locations of AUDOS stations in the 1997 and 2000 surveys around Shag Rocks and South Georgia.

Table II. Details of AUDOS-I and II deployments around South Georgia and Shag Rocks in January 2000.

Station no.	AUDOS no.	Date	Latitude °S	Longitude °W	Depth (m)	Mean current velocity (ms^{-1})	Bottom water temperature (°C)	Substrate type
00/01	I	17/01/00	53°16.90'	42°22.01'	719	0.062	2.2	Sand/mud, small stones
00/02	I	17/01/00	53°26.24'	41°35.61'	1085	0.031	1.8	Sand/mud, small stones
00/03	I	21/01/00	53°35.48'	36°20.87'	1035	0.048	1.6	Sand/mud
00/04	I	22/01/00	54°05.50'	35°20.93'	1114	0.063	1.6	Sand/mud, small stones
00/05	II	22/01/00	54°04.98'	35°20.09'	1294	-	-	Sand/mud
00/06	I	23/01/00	54°37.26'	34°47.64'	780	0.058	1.9	Sand/mud, small stones
00/07	II	23/01/00	54°36.80'	34°42.78'	1005	-	-	Sand/mud, small stones
00/08	I	24/01/00	54°38.09'	34°37.63'	1250	0.057	1.4	Sand/mud, small stones
00/09	II	24/01/00	54°38.08'	34°32.56'	1519	-	-	Sand/mud (steep slope)
00/10	I	26/01/00	54°50.66'	38°31.47'	1120	0.054	1.6	Sand/mud, small stones
00/11	II	26/01/00	54°50.98'	38°31.46'	1335	-	-	Boulders, patches of sand
00/12	I	27/01/00	54°23.65'	39°28.65'	946	0.037	1.7	Sand/mud
00/13	II	27/01/00	54°23.90'	39°23.62'	1202	-	-	Sand/mud
00/14	I	29/01/00	53°36.09'	40°44.90'	1283	0.054	1.7	Sand/mud, small stones
00/15	II	29/01/00	53°36.22'	40°45.73'	1140	-	-	Sand/mud, small stones

Approximately 800 g of bait was used in each deployment, consisting of squid (*I. argentinus*) with sardines inserted into their mantle cavities. The squid baits were wired onto the cross and additional sardines attached to the ballast weight. The DV tapes were reviewed on board immediately after each experiment. AUDOS-I was fitted with a current meter and dual acoustic releases; AUDOS-II carried no current meter and a single acoustic release. In total 15 deployments were made (9 using AUDOS-I, 6 using AUDOS-II) in water depths of 719–1519 m (Fig. 2, Table II). The AUDOS-I and AUDOS-II were generally deployed in paired configuration, so that the current meter data could be applied to both deployments.

The observed fauna were identified using relevant texts (Andriashev & Stein 1998, Gon & Heemstra 1990, Macpherson 1988, Norman 1937, Peden & Anderson 1978). Total lengths (TL) of fish were estimated using the 1 m cross as a reference scale. Swimming velocities of Patagonian toothfish were calculated from the video sequences. The standard measurement of size for lithodid crabs is carapace length, measured from the orbital margin to the mid-posterior edge of the carapace. However, the eyes of the crabs are not discernible on either the photographs or video footage, consequently carapace width (CW), the maximum width of carapace including marginal spines, was recorded.

Results

Details of each AUDOS deployment are shown in Fig. 2 and Tables I & II. In the 1997 survey the mean current velocity during the first four deployments around Shag Rocks was 0.089 ms^{-1}. However, the current meter was subsequently damaged so no further current speeds were obtained. From the 2000 survey the current velocities around Shag Rocks and South Georgia were low (overall mean 0.051 ms^{-1}), with bottom water temperatures relatively stable at a mean of 1.74°C (Table II).

From a visual assessment of the photographs and video footage the substratum appeared to be comprized mainly of sand or mud and small stones (Tables I & II). There was little evidence of any epifauna except for a few echinoderms (asteroids and ophiuroids), colonial hydroids and small sponges. Hard ground was restricted to one station (Stn. 00/11) where the substrate comprized loose boulders with patches of sand or mud.

In most of the deployments the bait was consumed within 4–8 h. Bait consumption was generally quicker during the 2000 survey, when part of the bait was placed close to the sea floor and thus was more accessible to the crabs. Toothfish were also seen to remove whole squid during the 2000 survey.

Scavenging fauna

Lithodid crabs

The most frequently observed scavenging species were stone crabs of the family Lithodidae (Crustacea: Anomura). Three species were distinguished based mainly on the pattern of spines on the dorsal carapace (see Macpherson 1988): *Paralomis formosa* (Henderson, 1888), *P. spinosissima* (Birshteyn & Vinogradov, 1972), and *Neolithodes diomedeae* (Benedict, 1895). Small specimens (< 80 mm CW) were impossible to differentiate to species and only the larger *N. diomedeae* (> 80 mm CW) could be distinguished from *Paralomis* spp. on the lower resolution digital video footage from the 2000 survey. A fourth species of lithodid (*Lithodes* sp.) was identifiable from a few photographic frames in the 1997 survey, but was extremely difficult to distinguish from the other stone crab species. The identifications of *P. formosa* and *P. spinosissima* were confirmed from trawl specimens obtained during the 2000 survey.

The numbers of stone crabs observed at each station are given in Tables III & IV. By far the most common species was *P. formosa* (Fig. 3a), which was recorded during all deployments. This species has a pentagonal carapace ornamented with a few spines, thus giving the appearance of a relatively smooth dorsal surface (Fig. 3b). It is the smallest

Table III. Fauna identified from photographs taken by the AUDOS in the 1997 survey around South Georgia and Shag Rocks.

Species	97/01	97/02	97/03	97/04	97/05	97/06	97/07	97/08	97/09	97/10	97/11	97/12	97/13
	Numbers of individuals/encounters												
Dissostichus eleginoides	1	2	3	9	1	4	0	1	6	4	5	1	3
Macrourus spp.	0	0	23	0	0	0	0	0	0	2	0	0	0
Antimora rostrata	0	0	1	0	3	0	0	0	0	2	3	0	1
Lycodapus cf. *antarcticus*	40	11	29	15	9	3	0	4	2	1	34	55	4
Careproctus sp.	0	7	5	12	5	14	2	5	2	2	0	0	0
Unidentified benthic zoarcid	0	0	1	0	3	2	1	6	0	0	2	0	0
	Maximum numbers in any frame												
Paralomis formosa	3	18	4	43	27	44	33	28	24	37	20	26	21
Paralomis spinosissima	0	0	0	0	4	0	3	0	0	0	0	0	2
Neolithodes diomedeae	0	0	1	1	0	0	0	1	4	1	3	1	0
Thymops birsteini	0	0	0	0	0	0	0	1	0	1	0	0	0

species of stone crab recorded during this study with a narrow size range of 50–90 mm CW. The maximum number of *P. formosa* recorded was > 100 individuals (Stn. 00/12) as the crabs took up residence at the bait. *Paralomis spinosissima* was identified from the high resolution photographs of the 1997 survey by the numerous dense spines covering its carapace and legs (Fig. 3d), but this species could not easily be differentiated from *P. formosa* in the digital video footage of the 2000 survey. From the 1997 survey data, *P. spinosissima* had a size range of 70–110 mm CW and was restricted to water depths < 1000 m. *Neolithodes diomedeae* was the largest lithodid species recorded during the study, ranging in size from 70–150 mm CW. This species is characterized by the long, robust spines on the posterior portion of its pear-shaped carapace (Fig. 3c). The numbers of *N. diomedeae* observed were low, with typically only 1–3 individuals present at any time.

The number of stone crabs observed was highly variable, although they were usually more numerous in areas of sand and mud and less common on stony or rocky ground (e.g. Stations 97/01 & 00/11). During the 1997 survey, the numbers of *P. formosa* observed fluctuated over the duration of a deployment, with periodic peaks in numbers as individuals accumulated at the bait and then dispersed rapidly, possibly influenced by changes in the current velocity and direction (e.g. Stn. 97/04; Fig. 4). However, the addition of bait to the ballast during the 2000 survey resulted in stone crabs taking up residence at the bait, i.e. the crabs stayed at the bait for the duration of the deployment or until the bait had been consumed. Crab numbers therefore increased over time with little or no dispersal (e.g. Stn. 00/12; Fig. 5).

Other invertebrates

The decapod prawn, *Thymops birsteini* (Zarenkov & Semonov), was observed at several stations but never in high numbers (max. number 7; Stn. 00/07) (Tables III & IV). The preferred substrate for this species appeared to be muddy sediments as it was absent from stony ground. Nine burrow openings (*c.* 20–25 mm in diameter) were visible around the AUDOS ballast at Stn. 00/07, and the prawns could be seen entering and leaving some of these openings. Individuals observed ranged in size from 100–170 mm TL.

Octopods of the genus *Pareledone* were observed during two deployments, but did not appear attracted to the bait.

Table IV. Fauna identified from digital videos recorded by the AUDOS systems in the 2000 survey around South Georgia and Shag Rocks.

Species	00/01	00/02	00/03	00/04	00/05	00/06	00/07	00/08	00/09	00/10	00/11	00/12	00/13	00/14	00/15
	Numbers of individuals/encounters														
Dissostichus eleginoides	7	8	24	38	44	14	10	32	21	7	16	3	18	18	18
Macrourus spp.	-	-	-	-	1	-	-	-	-	30	-	-	9	1	14
Antimora rostrata	-	-	11	-	-	13	10	4	-	8	-	13	10	1	-
Lycodapus cf. *antarcticus*	-	3	3	-	5	1	4	4	-	9	25	8	1	5	2
Careproctus/Paraliparis spp.	-	-	4	-	3	1	3	3	1	-	-	-	1	-	1
Raja georgiana (?)	3	1	-	-	3	1	1	1	1	-	-	-	-	-	-
Bathyraja meridionalis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Unidentified benthic zoarcid	-	-	-	2	1	-	-	-	-	-	-	3	-	-	-
	Maximum numbers in any sequence														
Paralomis spp.*	40	22	74	17	27	39	22	12	15	24	3	108	30	21	20
Neolithodes diomedeae	-	-	1	-	1	1	1	2	1	-	-	-	1	-	1
Thymops birsteini	-	-	-	-	-	2	7	2	1	-	-	-	3		

* *Paralomis* spp. were mostly *P. formosa*. - -

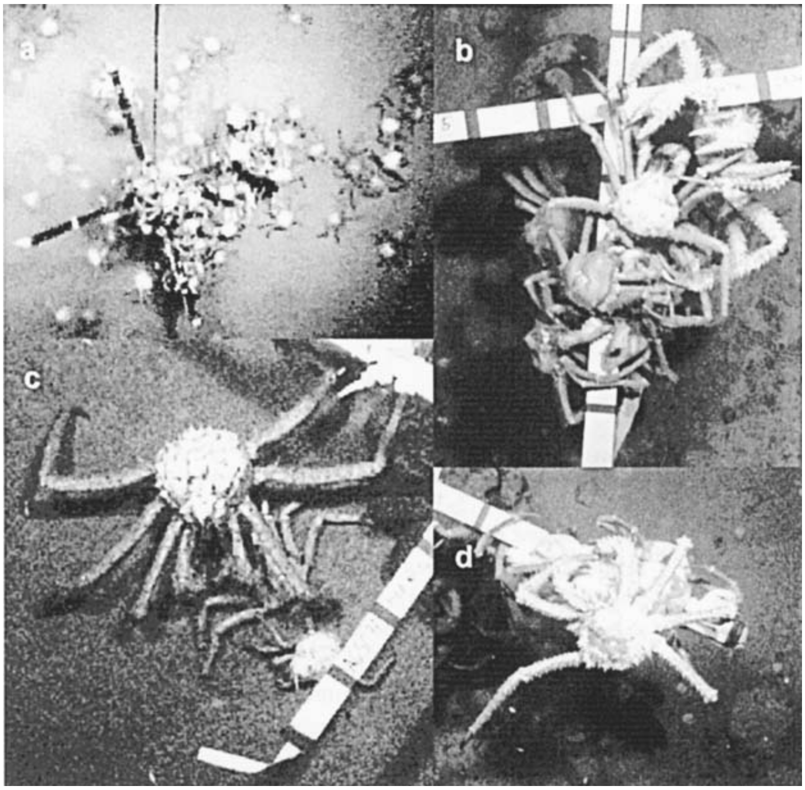

Fig. 3. Stone crabs attracted to bait on the South Georgia slope. **a.** Large numbers of the stone crab, *Paralomis formosa*, accumulating and feeding at the bait (video still), **b.** *P. formosa* on the reference cross, with a larger *P. spinosissima* visible on the underside of the cross (top right), **c.** a large *Neolithodes diomedeae*, with two smaller *P. formosa* also visible, **d.** *Paralomis spinosissima*.

Amphipods were seen around the bait but could not be identified or quantified.

Patagonian toothfish

The Patagonian toothfish, *D. eleginoides,* (Fig. 6a–c) was observed in every deployment except Stn. 97/07. During the 1997 survey, a total of 39 toothfish were recorded but only 19 individuals could be measured from the photographs as individual fish were seldom entirely within the field of view. A mean TL of 650 mm was obtained (s d ± 135 mm; range 430–930 mm; Fig. 7a). Although toothfish were obviously attracted to the bait, they appeared to show little or no further

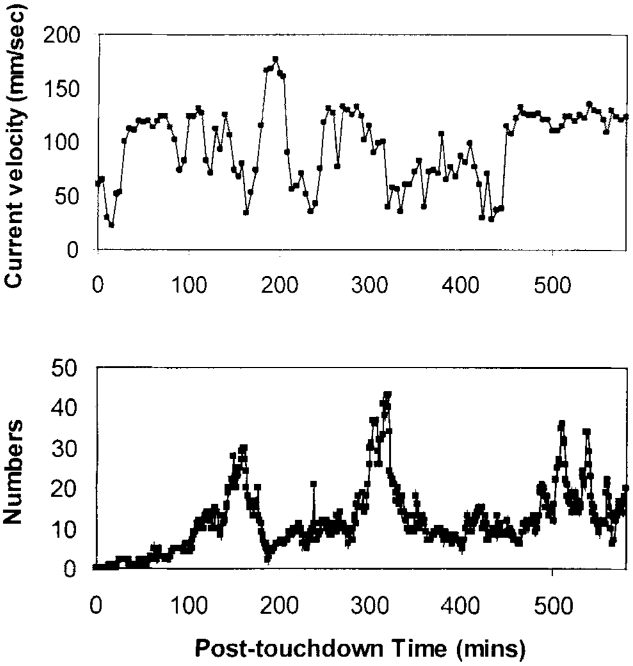

Fig. 4. AUDOS Deployment 97/04. **a.** Current velocity, **b.** numbers of the stone crab, *Paralomis formosa* at bait.

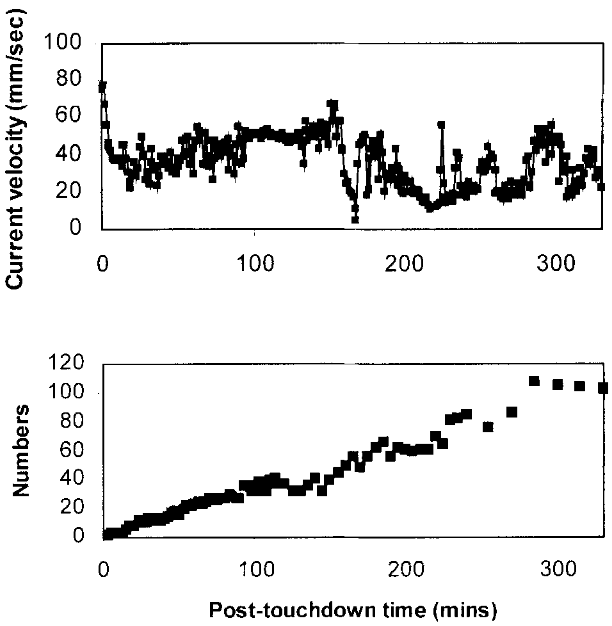

Fig. 5. AUDOS Deployment 00/12. **a.** Current velocity, **b.** numbers of the stone crab, *Paralomis formosa* at bait.

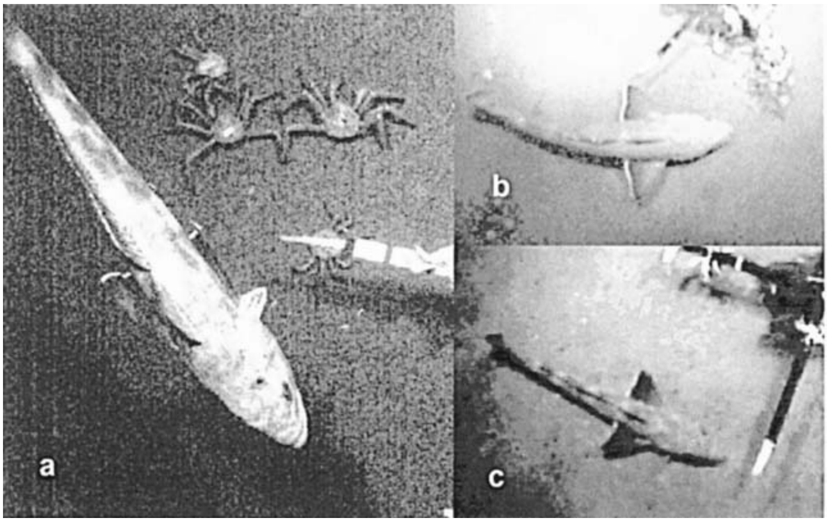

Fig. 6. Patagonian toothfish *Dissostichus eleginoides*, **a.** arriving at bait as photographed in the 1997 survey, **b.** circling around the bait and avoiding the area of brightest illumination during the 2000 survey (video still), **c.** settling onto the seafloor (video still).

interest after arrival and usually departed within minutes. No successful attempts to take the squid bait were observed. Some individuals could be recognized from distinguishing marks and scars but were not observed to return to the bait after initial departure.

During the 2000 survey, a total of 278 toothfish encounters were recorded. However, distinguishing individuals was difficult given the lower resolution of the video images. It was not clear whether the same fish made repeated visits to the bait. The overall mean size of *D. eleginoides* was 770 mm TL (s d ± 168 mm; range 490–1640 mm $n = 276$; Fig 7b). There was no correlation between toothfish size and depth of deployment.

Toothfish typically arrived singly and departed after a few minutes, though up to four fish were observed together at one time. The fish were often at the bait at the start of each video sequence and, where determinable, the direction of arrival was usually from down current. The activation of the video lights may have startled some fish into immediate departure and toothfish that remained were observed circling just outside the area of brightest illumination (Fig. 6b). Active 'interest' was shown in the bait, though most of the toothfish had difficulty in locating the squid attached to the cross, and some swam underneath the squid bait without appearing to detect it. Toothfish either continued circling the cross for a period before departing, or settled on the seafloor (Fig. 6c) before eventually leaving prior to the next video sequence.

Labriform swimming (using sculling motions of the large pectoral fins) was the principal mode of locomotion employed by toothfish and produced relatively slow cruising speeds (mean 0.17 ms^{-1} or *c.* 0.22 BL s^{-1}). The pectoral fins were also used in a gliding motion where toothfish swam close to the seafloor, rarely venturing any distance into the water column. Sub-carangiform swimming (using the caudal trunk and fin) was only observed during turning or rapid acceleration. The maximum swimming speed recorded was 2.23 ms^{-1} for an individual of 0.72 cm TL (3.1 BL s^{-1}) when the fish was in 'panic flight'.

Only two successful attempts at removing the bait were observed on the video sequences. Toothfish bit and pulled the squid off the cross and then swallowed it. One toothfish tugged the bait off the cross with rapid spins of the body (6–7 rotations). Other successful attempts had apparently taken place during periods when the camera was not recording. Since individual toothfish did not take up residence at the bait, there was no accumulation of numbers over time. Toothfish appeared to be solitary and generally avoided each other. Any accidental contact between conspecifics resulted in sudden departure in different directions; similarly unintended contact with the stone crabs also led to the rapid departure of the toothfish. Toothfish made no attempt to approach the bait if large numbers of stone crabs were clustered around it.

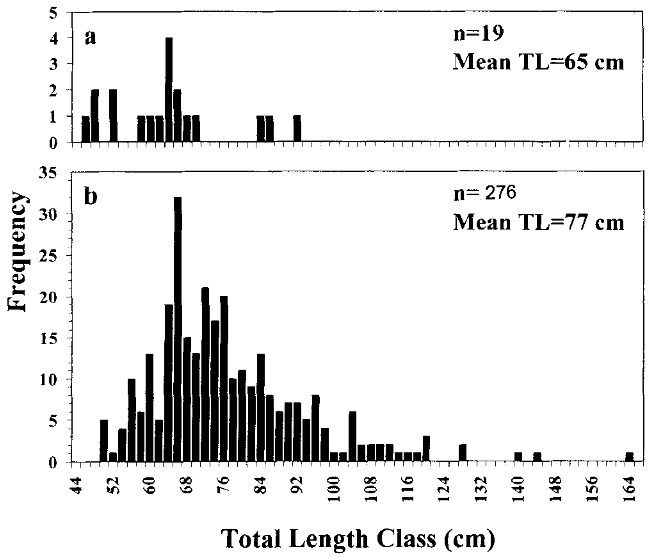

Fig. 7. Length-frequency distributions showing the size range of the Patagonian toothfish, *Dissostichus eleginoides*, **a.** during the 1997 photographic survey, **b.** during the 2000 digital video camera survey.

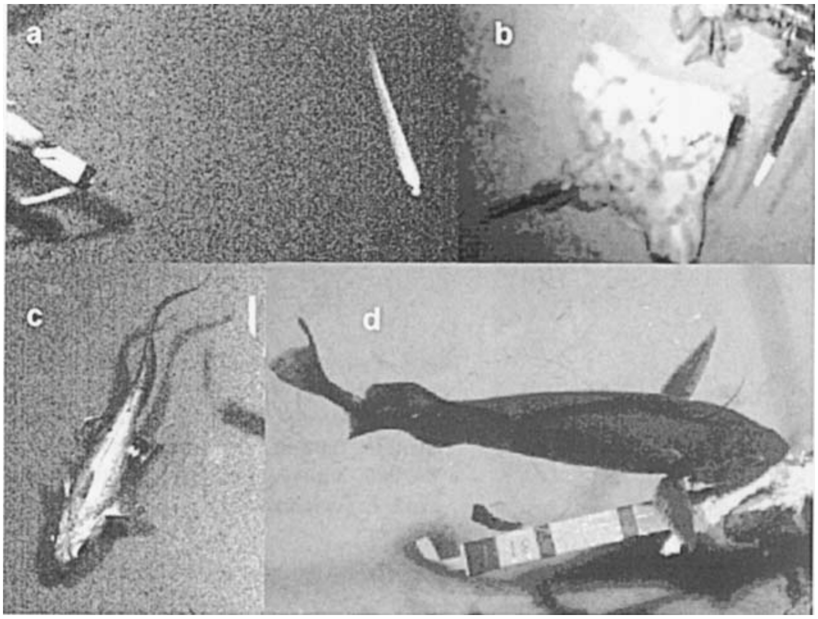

Fig. 8. Photographs of fish seen during AUDOS deployments on the South Georgia slope, **a.** the benthopelagic zoarcid *Lycodapus* cf. *antarcticus* drifting past (ca. 200 mm total length), **b.** video still of the skate, *Raja* cf. *georgiana*, **c.** the grenadier, *Macrourus* sp., **d.** the blue hake, *Antimora rostrata*.

Other fish species

The most frequently observed fish was a benthopelagic zoarcid tentatively identified as *Lycodapus antarcticus* Tomo, 1981 (Tables III & IV; Fig. 8a). A maximum of 55 encounters was observed at Stn. 97/12, and a maximum of three *L. antarcticus* were observed together at any one time. A size range of 35–200 mm TL was recorded from the 1997 survey. The fish typically adopted a rigid, straight, posture in the water column with its body axis perpendicular to the current flow. They drifted with the current unless startled by the camera lights, when they would perform "C-starts" and swim away with rapid anguilliform motion. This species was never observed feeding directly on the bait and may therefore not, strictly, be a scavenging species.

A species of benthic zoarcid was observed lying on the seafloor in some deployments, e.g. Stn. 97/08 (Tables III & IV). Definitive identification from photographs and video stills was impossible, though it superficially resembled a *Lycenchelys*-type zoarcid. Specimens were of the size range 83–314 mm TL (mean 179 mm TL). This type of zoarcid often remained motionless for considerable periods of time, moving only when disturbed by stone crabs. They appeared to aggregate near the bait although feeding was not observed.

Two species of skate were observed during the 2000 survey (none were photographed in the 1997 survey), which have been tentatively identified as *Bathyraja meridionalis* Stehmann, 1987 and *Raja georgiana* Norman, 1938 (Table IV; Fig. 8b). Positive identification of the Rajiidae relies on the flexibility of the rostral snout and the patterns of spines on the dorsal body and tail, thus positive identification was not possible. The skates were clearly interested in the bait but were never observed taking it.

The grenadiers (Family Macrouridae) observed were probably *Macrourus holotrachys* Gunther, 1878 and/or *M. whitsoni* (Regan, 1913)(Fig. 8c). The species are difficult to distinguish in the absence of collected specimens. The 23 encounters recorded at Stn. 97/03 (Table III) probably represent a few individuals that were making repeated visits to the bait. Although the grenadiers were attracted to the bait only the larger individuals attempted to consume it. The blue hake, *Antimora rostrata* (Gunther, 1878) (Moridae) was also observed trying to consume the bait (Fig. 8d). Relatively large numbers of small *A. rostrata* (mean TL 376 mm) were observed in the 2000 survey (e.g. Stns. 00/06, 00/12), often immediately after touchdown, though they usually dispersed rapidly.

Snailfishes (Family Liparidae) were often observed accompanying or even attached to *Paralomis formosa* and *Neolithodes diomedeae* (Tables III & IV). This liparid was assumed to belong to the genus *Careproctus*, which possesses a ventral sucking disc. However, identification cannot be confirmed in the absence of reference specimens. Interspecific association was not, however, observed with *P. spinosissima*, probably because the dense spines of this lithodid preclude attachment by the fish. Other liparid species were also observed swimming across the seafloor and around the bait, but did not associate with the lithodid crabs. These probably belonged to the genus *Paraliparis*, a common snailfish genus that lacks a sucking disk.

Discussion

In general, the scavenging community of the South Georgia slope responded rapidly to the arrival of bait on the sea floor, and in most of the deployments the bait was quickly consumed by a combination of lithodid crabs and toothfish. Smaller scavengers, such as amphipods, may have contributed to the bait consumption, but they could not be quantified from the still photographs or video sequences. In most cases the bait was consumed within 5 h, at a rate of approximately 100 g h^{-1}, which is similar to other experiments in the deep sea (Collins *et al.* 1999, Janssen *et al.* 2000, Jones *et al.* 1998). The scavenging fauna was similar all around the island of South Georgia and over the bathymetric range assessed (*c.* 600–1500 m). The most notable variant was that on rocky ground the scavengers were slower in responding to the bait. The composition of the scavenging fauna was similar to that found at slope depths around the Falkland Islands (600 miles north-west), but there was less variation between deployments at South Georgia. The principal difference was that hagfish (*Myxine* sp.), which were the dominant scavenger at depths of 900–1100 m on the Patagonian slope (Collins *et al.* 1999), were entirely absent from the South Georgia slope. Although hagfish are regarded as cold-water species, there are few records of hagfish south of the Antarctic convergence and Collins *et al.* (1999) suggested that the Patagonian species did not tolerate temperatures below 2.5°C.

Stone crabs were the numerically dominant scavengers; they arrived rapidly at the bait and frequently took up residence in the area. The differences in stone crab numbers between the two surveys may have been a result of the difference in season (September 1997 and January 2000 respectively), but was probably a consequence of the addition of more bait onto the ballast (i.e. close to the sea floor). This ensured that the crabs could get access to the bait and hence remained in the area for longer, allowing the total number of crabs attracted to be counted, and hence the density of crabs to be estimated (Collins *et al.* in press). The most abundant species of crab was *Paralomis formosa*, which is a deep-water species, rarely taken in trawls at less than 300 m. Conversely, the congeneric *P. spinosissima* was only seen at the shallow stations and is frequently taken in shallow-water trawls. Both species of crab were attracted to baits at similar depths on the Patagonian slope (Collins *et al.* 1999). An exploratory fishing survey for stone crabs was undertaken around South Georgia by the *Antartida* during the 1986/87 season, but only low numbers of mainly *P. spinosissima* were caught (López-Abellán & Balguerías 1994). In 1992, the American National Marine Fisheries Service (NMFS), under license to CCAMLR, initiated an experimental crab fishing trial around South Georgia using baited pots and concluded that *P. spinosissima* and *P. formosa* were present in sufficient numbers for a viable fishery (Otto & Macintosh 1996). An experimental harvest regime was subsequently adopted for a proposed period of three fishing seasons, but only the 1994/95 and 95/96 seasons were completed (Watters 1997). No further fishing has taken place following limitations on the fishery set by CCAMLR in order to protect the stocks.

The interspecific association between *P. formosa* and the snailfish *Careproctus* sp. has been documented and described as a commensal relationship (Yau *et al.* 2000). However, further studies are required to determine whether the same *Careproctus* sp. is associated with *N. diomedeae*, and whether the stone crabs benefit from the relationship. Any harm inflicted on the crabs by the snailfish may have significant consequences for a potential stone crab fishery where yield is important.

The primary aim of the initial baited camera survey was to estimate the abundance of toothfish (Yau *et al.* 2001), but this had limited success due to the behaviour of the toothfish. Toothfish were seen in all but one experiment (97/07), but were seen much more frequently in the 2000 survey than in 1997. This is attributed to the longer viewing time afforded by the use of the video system and absence of powerful flashlights during the 2000 survey (see also Collins *et al.* 1999). Nevertheless, during the 2000 survey there was evidence that toothfish were affected by the video camera lights. Individual toothfish never remained long at the bait, making it difficult to determine the total number attracted. First arrival time at bait can be used to estimate scavenger abundance (Priede & Merrett 1996), but requires accurate estimates of fish swimming speed as well as current speed. Mean first arrival time during the 2000 survey was 66 min (range 20–153 min), which with a mean current speed of 0.05 ms^{-1} and estimated swimming speed of 0.17 ms^{-1} gives a density estimate of 16.4 ind. km^{-2}. This is likely to be an underestimate, since fish may have arrived and departed earlier, whilst the camera was off, but may be a more realistic estimate than the 0.4 ind. km^{-2} obtained from the 1997 data (Yau *et al.* 2001).

The video footage from the 2000 survey gave some interesting insights into the behaviour of toothfish. The slow labriform swimming of *D. eleginoides* appears to be a relatively energy efficient mode of locomotion, and by staying close to the seafloor, the fish may take advantage of the boundary layer effect to further conserve energy. The toothfish are, however, capable of more rapid activity as illustrated by their rotation to remove the squid bait and by one fish that attained a speed of 3.1 BL s^{-1} across the field of view. This speed is remarkable, considering that a similar sized cod may only be capable of about 2 BL s^{-1} at the same ambient temperature (Videler & Wardle 1991). The frequent inability of toothfish to locate the bait on the arms of the cross is puzzling, given that squid and sardines are also the bait used in the longline fishery. Toothfish may initially locate carrion by olfaction but close to the bait they may be saturated with odour and therefore unable pinpoint its precise position. The lights on AUDOS were clearly affecting the toothfish and may have contributed to abnormal behaviour, or perhaps some movement of the bait is necessary for precise location (e.g. by use of the lateral line system). There was no evidence from the video sequences of toothfish preying on other species attracted to baits, and in fact they seemed to actively avoid contact with the stone crabs. The diet of toothfish has not been well documented, but McKenna (1991) found it to be dominated by other fish species including *Notothenia larseni* Lönnberg, *Pseudochaenichthys georgianus* Norman and its own young.

It is clear from this study that any carcasses, whether natural or discarded by fishing vessels, will be rapidly consumed by the benthic scavenging community. Across the bathymetric and geographic range studied, the composition of the macroscavenging community of the South Georgia slope was similar, with lithodid crabs and toothfish dominant, but to what extent these species rely on scavenging for food remains unknown.

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