Polar Biol (2003) 26: 157–165
DOI 10.1007/s00300-002-0463-y

ORIGINAL PAPER

R. Casaux · E. Barrera-Oro · A. Baroni · A. Ramón

Ecology of inshore notothenioid fish from the Danco Coast, Antarctic Peninsula

Received: 18 June 2002 / Accepted: 9 November 2002 / Published online: 14 January 2003

Abstract A total of 1,103 inshore notothenioid fish were caught by means of trammel-nets in 4 sites surrounding Cierva Point (Moss Island 1; Moss Island 2; Sterneck Island; Leopardo Island), Danco Coast, West Antarctic Peninsula, during February and March 2000. The families Nototheniidae, Channichthyidae and Bathydraconidae were represented in the samples, *Notothenia coriiceps* being the dominant fish of the area. *Gobionotothen gibberifrons* and *Trematomus newnesi* followed in importance. In general, the fish sampled agreed in terms of number and mass with those of the South Shetland Islands area, except for a marked higher occurrence of *G. gibberifrons* in the Danco Coast. This supports the hypothesis that the commercial fishery around the South Shetland Islands at the end of the 1970s was responsible for the decrease in the inshore population of *G. gibberifrons* in that area during the last 17 years. Information on morphometry, reproduction and diet of the fish species caught is provided.

Introduction

The role of fish in the Antarctic marine ecosystem is a very important ecological subject and, hence, has been the object of several studies during the last three decades. The ecological studies on coastal demersal fish from the South Shetland Islands and west Antarctic Peninsula waters (FAO Statistical Subarea 48.1) were done mainly in the first area (Bellisio 1967; Moreno and Bahamonde 1975; Tarverdiyeva and Pinskaya 1980; Linkowski et al. 1983; Kock 1989; Casaux et al. 1990; Gröhsler 1994; Kulesz 1994; Barrera-Oro 1996; among others) and a fewer number in the second area (Moreno et al. 1977; Daniels 1982; Daniels and Lipps 1982). In line with this, in 1983 the Ichthyology Project of the Instituto Antártico Argentino implemented a long-term research program focused on monitoring and ecological aspects of demersal fish in inshore sites of the South Shetland Islands, mainly in Potter Cove, King George Island, using trammel-nets (Barrera-Oro et al. 2000). This research program allowed the development of studies about the ecology of fish (e.g. populational aspects, trophic position, age and growth, predator-prey interactions), as well as about the impact of the offshore commercial fishery on inshore fish of the area (summarised in Barrera-Oro and Casaux 1998).

The substantial commercial activities in subarea 48.1 occurred throughout the South Shetland Islands offshore (>100 m depth) from 1977/1978 to 1989/1990, prior to closure by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) primarily west and northwest of Elephant Island and north of King George Island (Kock 1998). Besides the serious depletion of the target species in offshore waters, a diminution in the stocks of juvenile *Gobionotothen gibberifrons* and *Notothenia rossii* in inshore waters was demonstrated and explained as a reduction in recruitment due to heavy fishing suffered by the reproductive stock (Barrera-Oro and Marschoff 1991).

In 1997/1998, the scope of our research project was extended to the Danco Coast, a less investigated area of the Antarctic Peninsula, which has remained outside the influence of the commercial fishery. Thus, the aim of this study is to provide new data on occurrence, morphometry, reproduction and diet of demersal fish from this last region, by the analysis of samples obtained by trammel-nets at four sites during February and March 2000.

R. Casaux (✉) · E. Barrera-Oro
Instituto Antártico Argentino, Cerrito 1248,
(1010) Buenos Aires, Argentina
E-mail: pipocasaux@infovia.com.ar

R. Casaux · E. Barrera-Oro
Consejo Nacional de Investigaciones Científicas y Técnicas
(CONICET), Av. Rivadavia 1917, (1033)
Buenos Aires, Argentina

A. Baroni
Facultad de Farmacia y Bioquímica, Universidad de Buenos Aires,
Junín 956, (1113), Buenos Aires, Argentina

A. Ramón
Facultad de Medicina, Universidad de La Plata, Av. 60 s/nº,
1900 La Plata, Argentina

Materials and methods

A total of 1,103 fish were caught by means of trammel-nets in 4 sites surrounding Cierva Point (64°09'S; 60°57'W; Fig. 1) (Moss Island 1; Moss Island 2; Sterneck Island; Leopardo Island; Fig. 2), Danco Coast, Antarctic Peninsula, between 2 February and 31 March 2000. The distance between the farthest sampling sites, Leopardo Island and Moss Island 1, is 7.5 km. The nets (length 25 m; width 1.5 m; inner mesh 2.5 cm, outer mesh 12 cm) were fastened to rocks at the coast and laid on the bottom at depths from 20 to 70 m (Table 1). Stones and algae were often found in the nets at the four sampling sites. Although we have no information on the seabed topography in the sampling area, rocky bottoms with algae beds are likely constituents.

From the fish, the following data were obtained: total (TL) and standard (SL) lengths to 0.1 cm (in the text, size measurements are expressed as TL), weight (in grammes) and sex. The otoliths were removed and the gonad stage was determined according to the scale in Kock and Kellermann (1991). In this scale, stage I indicates immature ovaries and testis, stage II ovaries maturing virgin or resting and testis developing or resting, stage III ovaries developing and testis developed, stage IV ovaries gravid and testis ripe, and stage V ovaries and testis spent.

Nine hundred and twenty-five stomach contents were examined according to the mixed method of Hureau (1970). Data are expressed in terms of the dietary coefficient (Q), which is the product of the percentage by number and the percentage by mass of each prey type. According to this index, the prey items are separated into the following categories: $Q > 200$ main preys, $200 > Q > 20$ secondary preys and $20 > Q$ occasional preys. To estimate the percentage by number of algae, the number of algae species present in each stomach content was considered as the number of specimens represented in the sample. The stomach fullness was evaluated according to a 5-point scale: 0 (empty), 1 (1/4 full), 2 (1/2 full), 3 (3/4 full), 4 (full).

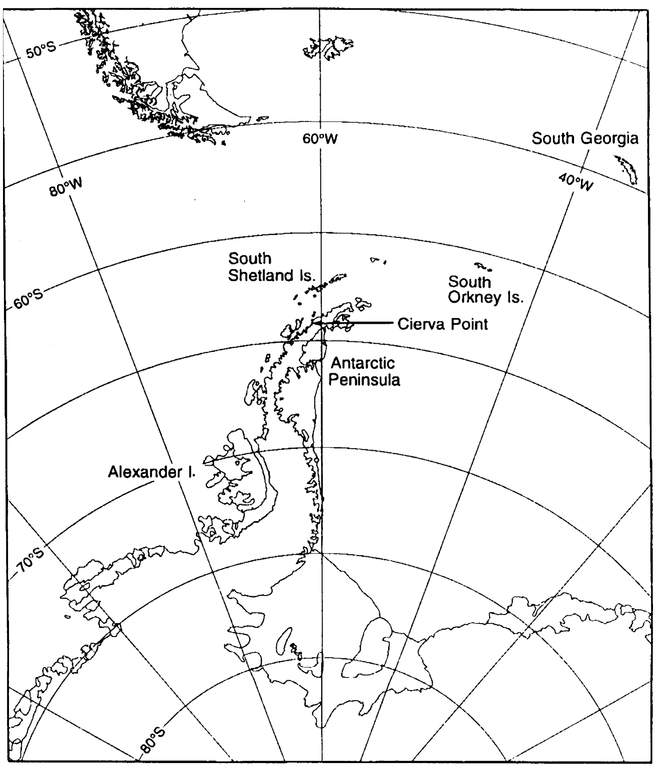

Fig. 1 Location of Cierva Point at the Danco Coast, Antarctic Peninsula

The fish species are identified following the nomenclature given in Gon and Heemstra (1990).

Results

There were no statistical differences in the number of fish caught per net between sampling sites (ANOVA, $F_{3,1103} = 0.23$; ns) (Table 1).

Nototheniid species (471 *N. coriiceps*; 265 *Trematomus newnesi*; 215 *G. gibberifrons*; 45 *T. bernacchii*; 28 Lepidonotothen nudifrons; 3 *N. rossii* and 3 *Trematomus hansoni*) dominated in the samples whereas the families Bathydraconidae (12 *Parachaenichthys charcoti*) and Channichthyidae (8 *Chaenocephalus aceratus*) were scarcely represented.

Several specimens were not assigned to species because their soft tissues were eaten by amphipods and only unidentifiable parts were recovered. Most of these fish belonged to the genus *Trematomus*, since they exhibited the scapular foramen enclosed within scapula.

Overall, *N. coriiceps* was always present in the catches and was the dominant fish by number and mass in all of the sampling sites, except at Sterneck Island where *G. gibberifrons* was the most abundant fish (Table 2). In the other sites, this last species and *T. newnesi* followed in importance. The relative abundance of *N. coriiceps* decreased (Spearman test, $r = -0.90$, $P < 0.01$) and that of *G. gibberifrons* increased with depth ($r = 0.93$, $P < 0.001$).

The total length ranges observed in *N. coriiceps*, *T. newnesi* and *G. gibberifrons* are plotted in Fig. 3. The size frequency distribution of *T. newnesi* was unimodal whereas those of *N. coriiceps* and *G. gibberifrons* showed polymodality. The size of *N. coriiceps* (ANOVA, $F_{3,471} = 25.6$; $P < 0.00001$), *T. newnesi* (ANOVA, $F_{3,265} = 5.7$; $P < 0.001$) and *G. gibberifrons* (ANOVA, $F_{3,215} = 5.5$; $P < 0.01$) specimens caught at the different sites differed statistically (Table 3). The largest (mean length) *N. coriiceps*, *T. newnesi* and *G. gibberifrons* specimens were caught at Leopardo Island, Moss Island 2 and Sterneck Island, respectively. The sizes of *G. gibberifrons* ($r = -0.96$, $P < 0.001$) and *N. coriiceps* (Spearman test, $r = 0.70$, $P < 0.05$) decreased and increased along the depth sampling range, respectively.

For the study of the predator-prey interactions between seabirds/seals and fish of the area, based on the analysis of otoliths recovered from faeces, regurgitated casts and stomach contents, we have estimated the otolith length-standard/total fish length relationships according to the equations presented in Table 4.

The total length-standard length relationship was estimated applying the equation $TL = a * SL$, where a is a constant. The results are presented in Table 5.

Length-weight relationships were estimated applying the equation $W = a * TL^k$ where W is the weight in grammes (the mass of the stomach contents was excluded), TL is the total length in centimetres, and a and k are constants (Table 6). Except in *T. newnesi*, at similar lengths males were heavier than females.

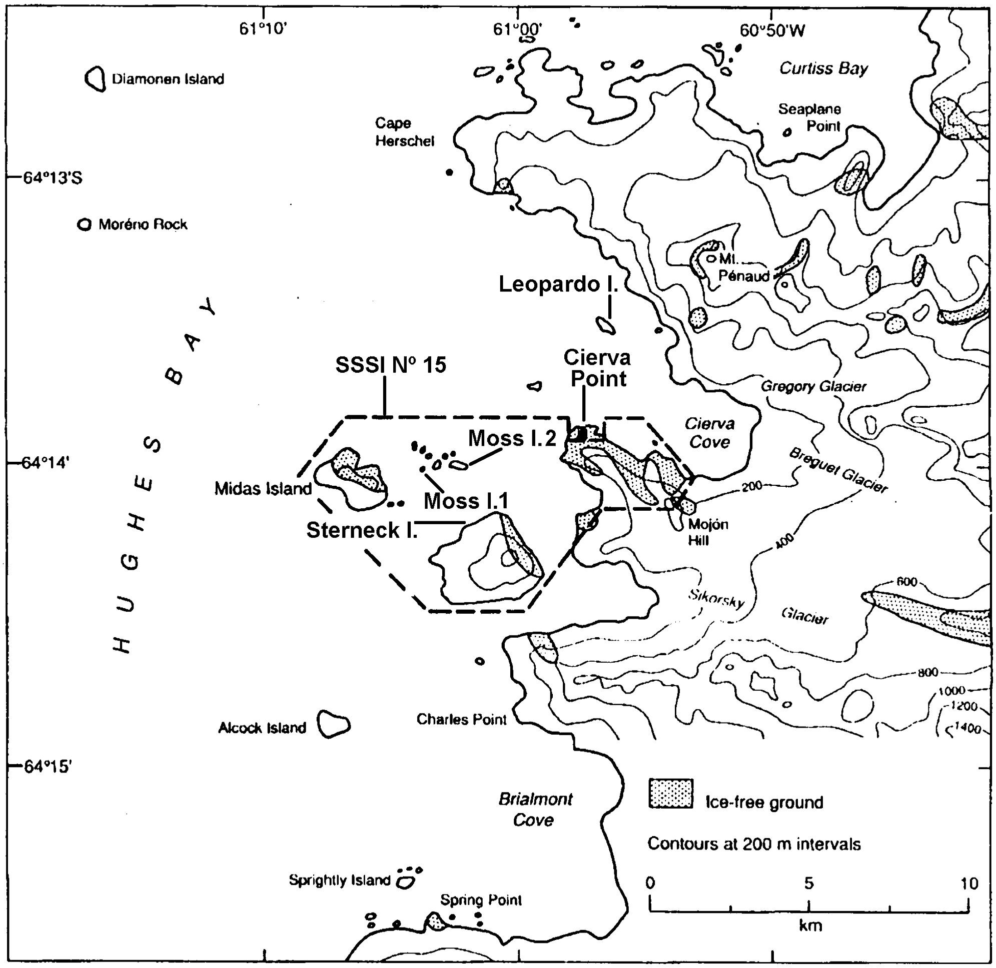

Fig. 2 Location of the sampling ites in the proximity of Cierva Point, Danco Coast, Antarctic Peninsula

Table 1 Characteristics of the sampling

	Moss I. 1	Moss I. 2	Sterneck I.	Leopardo I.
Location	64°10'S,61°03'W	64°10'S,61°02'W	64°11'S,61°02'W	64°08'S,60°56'W
Number of nets	4	15	8	8
Mean depth(m)	22.5	45.9	49.4	45.0
Depthrange (m)	20–30	35–55	20–55	35–70
No. of fish caught	119	437	242	305
No. of fish per net	29.8	29.1	30.3	38.1
SD	8.3	18.1	24.3	21.6
Range	18–37	10–81	2–82	8–66

Table 2 Fish caught in trammel-nets at the Danco Coast. The frequency of occurrence (*F*) and the importance by number (*N*) and mass (*M*) are expressed in percentage

	Total			Moss I. 1			Moss I. 2			Sterneck I.			Leopardo I.		
	F %	*N* %	*M* %	*F* %	*N* %	*M* %	*F* %	*N* %	*M* %	*F* %	*N* %	*M* %	*F* %	*N* %	*M* %
G. gibberifrons	74.3	19.5	11.6	25.0	0.8	0.9	100	27.0	13.9	87.5	38.5	24.7	37.5	1.0	1.0
L. nudifrons	42.9	2.5	0.4	–	–	–	60.0	3.2	0.5	50.0	5.0	0.9	25.0	0.7	***
N. coriiceps	100	42.7	74.2	100	97.5	97.7	100	32.3	67.6	100	28.1	61.0	100	47.9	85.9
N. rossii	5.7	0.3	0.5	25.0	0.8	1.1	–	–	–	12.5	0.8	1.5	–	–	–
T. bernacchii	48.6	4.1	1.5	–	–	–	53.3	3.9	1.3	62.5	2.9	2.1	50.0	6.9	2.3
T. hansoni	8.6	0.3	0.2	–	–	–	6.7	0.2	0.3	12.5	0.4	0.3	12.5	0.3	0.3
T. newnesi	80.0	24.1	7.7	25.0	0.8	0.3	100	27.5	7.9	87.5	24.0	9.5	75.0	28.2	10.1
C. aceratus	20.0	0.7	2.1	–	–	–	40.0	1.6	4.7	–	–	–	12.5	0.3	***
P. charcoti	20.0	1.1	1.8	–	–	–	40.0	2.5	3.8	–	–	–	12.5	0.3	0.4
Unidentified	22.9	4.7	–	–	–	–	13.3	1.8	–	12.5	0.4	–	62.5	14.1	–

*** Specimens not weighed that were partially eaten by amphipods

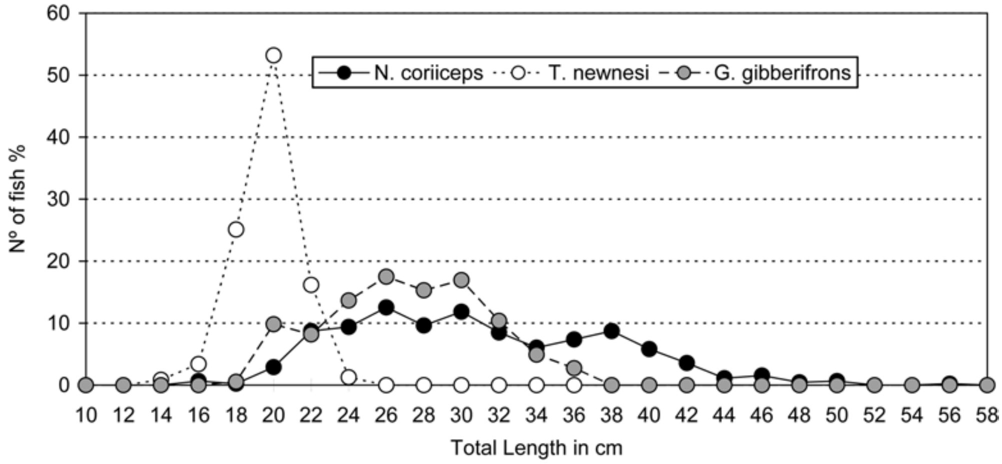

Fig. 3 Length-frequency distributions of *Notothenia coriiceps*, *Gobionotothen gibberifrons* and *Trematomus newnesi* caught in the proximity of Cierva Point, Danco Coast, Antarctic Peninsula

Table 3 Size measurements (cm) of the fish caught at the Danco Coast, Antarctic Peninsula: mean total length, standard deviation and range (*in parentheses*)

	Moss I. 1	Moss I. 2	Sterneck I.	Leopardo I.
G. gibberifrons	33.8	28.7 ± 3.9 (20.4–36.7)	27.1 ± 4.2 (19.5–37.8)	33.4 ± 4.0 (30.6–36.2)
L. nudifrons	–	16.7 ± 0.9 (15.8–18.7)	16.5 ± 1.4 (14.4–19.4)	–
N. coriiceps	27.7 ± 5.9 (17.0–56.1)	34.5 ± 6.6 (21.8–48.5)	33.2 ± 6.4 (21.8–50.5)	31.7 ± 6.5 (17.2–50.6)
N. rossii	33.2	–	33.4 ± 0.5 (33.0–33.7)	–
T. bernacchii	–	22.0 ± 4.9 (11.2–31.3)	23.6 ± 3.5 (20.0–30.8)	21.3 ± 3.2 (17.7–27.0)
T. hansoni	–	33.2	25.0	26.0
T. newnesi	20.2	20.2 ± 1.7 (14.4–24.3)	21.2 ± 1.4 (18.2–24.3)	20.7 ± 1.2 (18.0–23.4)
C. aceratus	–	54.9 ± 4.1 (49.8–60.5)	–	–
P. charcoti	–	43.8 ± 5.4 (33.0–52.2)	–	37.3
Overall	27.7 ± 6.0 (17.0–56.1)	28.5 ± 8.7 (11.2–60.5)	27.0 ± 6.7 (14.4–50.5)	27.4 ± 7.4 (17.2–50.6)

Table 4 Standard (*SL*)/total (*TL*) length-otolith length (*OL*) relationships for the fish species caught at the Danco Coast, Antarctic Peninsula

	SL-OL	TL-OL
G. gibberifrons	$SL = 1.9248*OL^{1.3312}$, $n = 154$, $r = 0.92$	$TL = 2.67956*OL^{1.24451}$, $n = 156$, $r = 0.91$
L. nudifrons	$SL = 2.2594*OL^{1.30482}$, $n = 40$, $r = 0.90$	$TL = 4.43772*OL^{0.929417}$, $n = 25$, $r = 0.75$
N. coriiceps	$SL = 3.70009*OL^{1.5381}$, $n = 116$, $r = 0.91$	$TL = 4.69259*OL^{1.46818}$, $n = 170$, $r = 0.89$
T. bernacchii	$SL = 3.27818*OL^{1.2356}$, $n = 30$, $r = 0.88$	$TL = 3.86225*OL^{1.21206}$, $n = 36$, $r = 0.88$
T. newnesi	$SL = 6.9155*OL^{0.9857}$, $n = 168$, $r = 0.88$	$TL = 9.0365*OL^{0.8575}$, $n = 162$, $r = 0.76$
P. charcoti	$SL = 5.11345*OL^{1.47965}$, $n = 9$, $r = 0.99$	$TL = 6.61066*OL^{1.35235}$, $n = 12$, $r = 0.97$

The sex ratio of the fish species is presented in Table 7. Female *L. nudifrons* and female *T. bernacchii* predominated largely in the sampling sites where these species occurred. Except for *N. rossii*, all the species caught were represented in the samples by reproductive specimens (gonad stages III and IV) (Table 8). Fish with spent gonads (stage V) were absent from the samples.

All *T. hansoni* and *C. aceratus* specimens showed empty stomachs (Table 9). This stage predominated also in *T. bernacchii* and *T. newnesi*. In contrast, full stomachs was the commonest stage in the two most important species by mass, *N. coriiceps* and *G. gibberifrons*.

The diet composition was diverse in *N. coriiceps* and *G. gibberifrons* (mainly at Moss Island 2 and Sterneck Island) but was limited in the remaining species (Tables 10, 11). *N. coriiceps* ate mainly algae and gammarid amphipods. This last prey predominated in the diet of *G. gibberifrons*, *L. nudifrons* and *T. bernacchii*.

Table 5 Total length (*TL*)-standard length (*SL*) relationships for the fish species caught at the Danco Coast, AntarcticPeninsula (*N* number of specimens; *r* correlation coefficient)

	TL-SL relationship	*N*	*r*
G. gibberifrons	TL = 1.17638*SL	174	0.99
L. nudifrons	TL = 1.14354*SL	21	0.98
N. coriiceps	TL = 1.15742*SL	271	0.99
T. bernacchii	TL = 1.14530*SL	27	0.99
T. newnesi	TL = 1.15156*SL	207	0.98
C. aceratus	TL = 1.12576*SL	5	0.99
P. charcoti	TL = 1.10805*SL	8	0.99

Table 6 Length-weight relationships for the fish species caught at the Danco Coast, Antarctic Peninsula (*N* number of specimens; *r* correlation coefficient)

	Sex	Length-weight relationship	*N*	*r*
G. gibberifrons	Mixed	$W = 0.00088*TL^{3.679096}$	176	0.98
	Female	$W = 0.000824*TL^{3.700443}$	79	0.99
	Male	$W = 0.00165*TL^{3.49172}$	90	0.98
L. nudifrons	Mixed	$W = 0.004397*TL^{3.35572}$	23	0.91
N. coriiceps	Mixed	$W = 0.007513*TL^{3.19103}$	441	0.99
	Female	$W = 0.007704*TL^{3.18482}$	217	0.99
	Male	$W = 0.010926*TL^{3.08257}$	211	0.99
T. bernacchii	Mixed	$W = 0.000877*TL^{3.85892}$	32	0.99
	Female	$W = 0.000647*TL^{3.95136}$	23	0.98
	Male	$W = 0.002673*TL^{3.50987}$	8	0.93
T. newnesi	Mixed	$W = 0.005532*TL^{3.26198}$	228	0.95
	Female	$W = 0.00552*TL^{3.25521}$	123	0.96
	Male	$W = 0.001695*TL^{3.66248}$	102	0.95
C. aceratus	Mixed	$W = 0.00000025*TL^{5.577918}$	5	0.96
P. charcoti	Mixed	$W = 0.000037*TL^{4.33102}$	11	0.99
	Female	$W = 0.000013*TL^{4.60391}$	6	0.99
	Male	$W = 0.000089*TL^{4.10803}$	5	0.99

Table 7 Sex proportion (%) in the fish species caught at the Danco Coast, Antarctic Peninsula (*M* males; *F* females; *N* number of specimens)

	Moss I. 1			Moss I. 2			Sterneck I.			Leopardo I.		
	M	*F*	*N*	*M*	*F*	*N*	*M*	*F*	*N*	*M*	*F*	*N*
G. gibberifrons	0.0	100	1	44.0	56.0	84	61.9	38.1	84	100	0.0	2
L. nudifrons	–	–	–	7.7	92.3	13	9.1	90.9	11	–	–	–
N. coriiceps	49.1	50.9	116	43.9	56.1	132	58.7	41.3	63	50.8	49.2	118
N. rossii	100	0.0	1	–	–	–	0.0	100	2	–	–	–
T. bernacchii	–	–	–	29.6	71.4	14	14.3	85.7	7	30.8	69.2	13
T. hansoni	–	–	–	0.0	100	1	–	–	–	100	0.0	1
T. newnesi	100	0.0	1	50.5	49.5	109	44.2	55.8	52	35.8	64.2	67
C. aceratus	–	–	–	20.0	80.0	5	–	–	–	–	–	–
P.charcoti	–	–	–	40.0	60.0	10	–	–	–	100	0.0	1

Krill was the main prey of *N. rossii* and *T. newnesi*, whereas *P. charcoti* ingested mainly fish.

The separate diet analysis of fish from the different sampling sites showed the same pattern, except for *N. coriiceps* at Sterneck and Leopardo Islands where gammarid amphipods and krill were the main preys, respectively (Fig. 4a); *G. gibberifrons* at Leopardo Island where polychaetes dominated in the diet (Fig. 4b); and *P. charcoti* at Leopardo Island where decapods constituted the main food item in the only stomach analysed.

Thirty-three percent of the fish ingested were identified to species but only a few could be measured. *N. coriiceps* preyed on *L. nudifrons* (14 specimens; 2 of them of 8.7 and 13.0 cm), *T. newnesi* (4 specimens; 1 of 13 cm), *G. gibberifrons* (4 specimens; 1 of 11.0 cm), *Electrona antarctica* (3) and *P. charcoti* (1 specimen of 19.2 cm). *P. charcoti* ate *T. newnesi* (2 specimens of 14.5 and 15.0 cm) and *G. gibberifrons* (1 specimen of 24.0 cm).

Eighty-seven *Euphausia superba* specimens ingested by *T. newnesi* averaged 4.63 cm in length (SD 0.48) and ranged from 3.67 to 5.89 cm.

Discussion

The fish species caught at the Danco Coast in the present study have been previously reported for neritic waters of the Antarctic Peninsula, and agree in terms of composition with those sampled also with trammel-nets in the South Shetland Islands area (Daniels and Lipps 1982; Fischer and Hureau 1985; Casaux et al. 1990; Barrera-Oro 1996). *N. coriiceps* was the dominant fish in number and mass in the sampling sites, except at Sterneck Island where *G. gibberifrons* was the most abundant. Given that the relative abundance of *N. coriiceps* and *G. gibberifrons* decreased and increased with depth respectively, this might be related to the fact that at Sterneck Island the nets were laid down deeper than at the remaining sites.

The total length ranges observed in *N. coriiceps*, *T. newnesi* and *G. gibberifrons* (Table 3, Fig. 3) coincide with those reported by Casaux et al. (1990) for fish caught with similar trammel-nets at Potter Cove, South Shetland Islands. The size-frequency distribution of *T. newnesi* was unimodal indicating the presence of one age class. In contrast, the size-frequency distributions of *N. coriiceps* and *G. gibberifrons* showed polymodality, reflecting the existence of different age classes. Although it is likely that several age classes are masked in the length distribution, *N. coriiceps* and *G. gibberifrons* specimens of 3–13 and 5–12 years of age (Casaux et al. 1990), respectively, seem to be represented in the whole sample.

It is known that *G. gibberifrons* displays a positive length stratification as a function of depth (Barrera-Oro

Table 8 Number (*N*) and total length in centimetres (mean ± standard deviation and range) of individuals of each sex at different gonad stages belonging to the fish species caught at the Danco Coast, Antarctic Peninsula

	Stage I			Stage II			Stage III			Stage IV		
	Mean ± SD	Range	*N*	Mean ± SD	Range	*N*	Mean ± SD	Range	*N*	Mean ± SD	Range	*N*
G. gibberifrons												
Males	24.5 ± 2.5	19.5–29.0	52	28.5 ± 2.0	25.7–32.0	12	31.4 ± 1.9	27.7–36.2	27	–	–	–
Females	27.5 ± 3.5	20.2–34.4	46	33.0 ± 2.2	29.0–37.8	33	–	–	–	–	–	–
L. nudifrons												
Males	–	–	–	16.0	–	1	15.8	–	1	–	–	0
Females	–	–	–	–	–	–	17.7	–	1	16.7 ± 1.2	14.4–19.4	21
N. coriiceps												
Males	25.8 ± 3,4	17.0–33.5	94	30.3 ± 2.9	22.3–37.0	66	36.9 ± 3.6	30.0–44.5	50	38.1 ± 2.3	35.6–40.2	2
Females	27.2 ± 3.8	19.7–37.3	109	35.0 ± 4.2	25.0–42.2	37	40.9 ± 3.9	35.3–56.0	62	42.5 ± 4.4	36.3–50.5	9
N. rossii												
Males	33.2	–	1	–	–	0	–	–	0	–	–	0
Females	33.4 ± 0.5	33.0–33.7	2	–	–	0	–	–	0	–	–	0
T. bernacchii												
Males	18.3 ± 1.8	16.5–21.2	6	19.5 ± 0.7	18.4–20.0	3	–	–	0	–	–	0
Females	21.1 ± 3.1	18.0–25.7	5	23.3 ± 2.3	18.5–27.0	13	25.8 ± 3.6	21.5–31.3	7	–	–	0
T. hansoni												
Males	–	–	0	26.0	–	1	–	–	0	–	–	0
Females	–	–	0	–	–	0	–	–	0	32.7	–	1
T. newnesi												
Males	19.5 ± 1.7	14.4–22.5	24	20.0 ± 1.7	15.5–23.5	58	21.4 ± 1.6	19.0–24.3	21	–	–	0
Females	–	–	0	21.0 ± 1.0	19.8–22.3	7	20.8 ± 1.1	17.5–24.3	116	21.9 ± 1.1	19.4–23.6	3
C. aceratus												
Males	–	–	0	–	–	0	49.8	–	1	–	–	0
Females	–	–	0	55.4 ± 2.6	53.5–57.2	2	–	–	0	57.1 ± 4.8	53.7–60.5	2
P. charcoti												
Males	39.2 ± 3.1	37.3–42.7	3	47.0	–	1	–	–	0	44.9	–	1
Females	33.0	–	1	46.5 ± 3.7	43.0–52.2	5	–	–	0	–	–	0

Table 9 Stomach fullness stages (%) in the fish caught at the Danco Coast, Antarctic Peninsula. The number of stomachs examined is shown in *parentheses*

	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4
G. gibberifrons (180)	5.6	12.2	25.6	27.2	29.4
L. nudifrons (25)	4.0	8.0	44.0	16.0	28.0
N. coriiceps (372)	14.0	10.0	20.7	22.3	33.0
N. rossii (3)	0.0	33.3	33.3	33.3	0.0
T. bernacchii (35)	40.0	28.6	22.9	5.7	2.8
T. hansoni (2)	100	0.0	0.0	0.0	0.0
T. newnesi (232)	30.6	17.7	11.2	18.5	22.0
C. aceratus (5)	100	0.0	0.0	0.0	0.0
P. charcoti (12)	25.0	25.0	25.0	0.0	25.0

1989; Casaux et al. 1990; Kulesz 1994). However, the analysis of the sizes of *G. gibberifrons* at the sampling sites in the Danco Coast showed a decrease with the increment of depth. We have no conclusive explanation for this finding but one possibility is that the size distribution with depth of *G. gibberifrons* in the sampling area may have been altered by the intensive foraging activity of the Antarctic shag on this fish species (Casaux et al. 2002). Alteration in inshore waters of the structure of fish populations by cormorant predation has been documented in other ecosystems (Birt et al. 1987; Leopold et al. 1998).

Although the information presented in Tables 4, 5 and 6 is not discussed in this work, it could be useful not only for analysis of fish morphological parameters but also for size and mass estimations of fish represented in food samples from top-predators, such as the seabirds and seals from the Antarctic Peninsula area.

The analysis of the *N. coriiceps*, *T. newnesi*, *L. nudifrons*, *T. hansoni*, *C. aceratus* and *P. charcoti* specimens at gonad stages III and IV indicates that the sampling time and the size of these fish (Table 8) agree with the spawning time and the length at first spawning reported for these species at other localities (see Bellisio 1967; Everson 1970; Hureau 1970; Hourigan and Radtke 1989; Kock 1989; Casaux et al. 1990; Kock and Kellermann 1991; Vacchi et al. 1996, among others).

A high proportion of the *L. nudifrons* (91.7%) and *T. bernacchii* (73.5%) specimens were females (Table 7). Except one stage III, all *L. nudifrons* ovaries were at stage IV, which suggests a pre-spawning female aggregation in the sampling area at that time.

Empty stomachs was the only stage in *C. aceratus* and *T. hansoni* and this stage predominated in *T. bernacchii* and *T. newnesi*; full stomachs predominated in the two most important fish by mass, *N. coriiceps* and *G. gibberi-*

Table 10 Diet composition of the fish sampled at the Danco Coast, Antarctic Peninsula (*F* % frequency of occurrence percent; *Q* dietary coefficient)

	G. gibberifrons		*L. nudifrons*		*N. coriiceps*		*N. rossii*	
	F %	*Q*	*F* %	*Q*	*F* %	*Q*	*F* %	*Q*
Algae	24.1	2.3	12.5	2.3	66.8	299.6	66.7	590.2
Errant polychaetes	26.5	18.4	25.0	74.8	5.8	0.3	–	–
Gastropods								
Nacella concinna	11.8	10.5	–	–	12.2	9.8	–	–
Unidentified	10.0	1.0	20.8	34.8	14.6	12.6	–	–
Bivalves								
Clams	26.5	84.1	–	–	0.8	0.0	–	–
Laternula elliptica	3.5	0.4	–	–	–	–	–	–
Quitons	5.9	1.1	4.2	0.2	0.8	0.0	–	–
Squids	–	–	–	–	0.3	0.0	–	–
Euphausiids								
Euphausia superba	0.6	0.0	8.3	9.2	12.7	94.8	66.7	2557.4
Decapods	–	–	–	–	0.3	0.0	–	–
Amphipods								
Gammarids	52.4	1970.2	70.8	4382.0	45.4	263.8	–	–
Hyperiids	0.6	0.0	–	–	1.3	0.0	–	–
Isopods								
Glyptonotus antarcticus	0.6	0.1	–	–	1.6	0.2	–	–
Serolis sp.	22.9	34.5	–	–	11.1	9.5	–	–
Unidentified	1.2	0.0	–	–	0.3	0.0	–	–
Ophiuroids	8.2	1.2	–	–	–	–	–	–
Echinoids								
Sterechinus neumayeri	–	–	–	–	0.6	0.0	–	–
Nemerteans	0.6	0.0	–	–	0.6	0.0	–	–
Priapulids	6.5	3.9	–	–	0.3	0.0	–	–
Asciids	2.9	0.3	–	–	3.2	1.1	–	–
Salps	15.3	14.6	–	–	17.0	48.4	33.3	16.4
Fish	1.2	0.0	–	–	15.7	56.4	–	–
Unidentified	47.1	–	20.8	–	14.3	–	66.7	–

Table 11 Diet composition of further fish sampled at the Danco Coast, Antarctic Peninsula (*F* % frequency of occurrence percent; *Q* dietary coefficient)

	T. bernacchii		*T. newnesi*		*P. charcoti*	
	F %	*Q*	*F* %	*Q*	*F* %	*Q*
Gastropods	19.1	15.2	–	–	–	–
Euphausiids						
Euphausia superba	4.8	0.5	94.4	9707.0	11.1	4.3
Decapods	–	–	–	–	11.1	16.8
Amphipods						
Gammarids	52.4	3502.9	2.5	0.3	–	–
Hyperiids	–	–	1.9	0.0	–	–
Priapulids	–	–	–	–	11.1	5.2
Asciids	9.5	8.7	0.6	0.0	–	–
Salps	9.5	53.7	0.6	0.0	–	–
Fish	–	–	–	–	77.8	6473.3
Unidentified	47.6	–	1.9	0.0	–	–

frons. Fasting before spawning and a wider prey range in opportunistic feeders are factors that could be related to these results.

The analysis of the diet of the fish species sampled at the Danco Coast showed general agreement on the feeding types and feeding behaviour of these species in other areas. In general, the main preys reported here have been previously indicated in the diet of the same fish species considered in this study (see Moreno and Bahamonde 1975; Richardson 1975; Daniels 1982; Burchett 1983; Linkowski et al. 1983; Casaux et al. 1990; Vacchi et al. 1994; Barrera-Oro 1996; La Mesa et al. 2000). Although they seem to be primarily benthos (*N. coriiceps*, *G. gibberifrons*, *L. nudifrons* and *T. bernacchii*) or plankton/water-column feeders (*T. newnesi*, *N. rossii* and *P. charcoti*), all of them preyed on both benthic-demersal and pelagic organisms. Most of these fish species are specialised feeders (see *Q* index in Tables 10, 11). Gammarid amphipods were largely the main food of *G. gibberifrons*, *L. nudifrons* and *T. bernacchii*; krill was the main prey of *N. rossii* and *T. newnesi* whereas *P. charcoti* foraged mainly on fish. The diet composition of *N. coriiceps* was the most diverse and changed in the different sampling sites. This fish is an opportunistic feeder, and therefore its diet reflects the food availability of benthos at different sites and depths. Grazing is an important feeding strategy

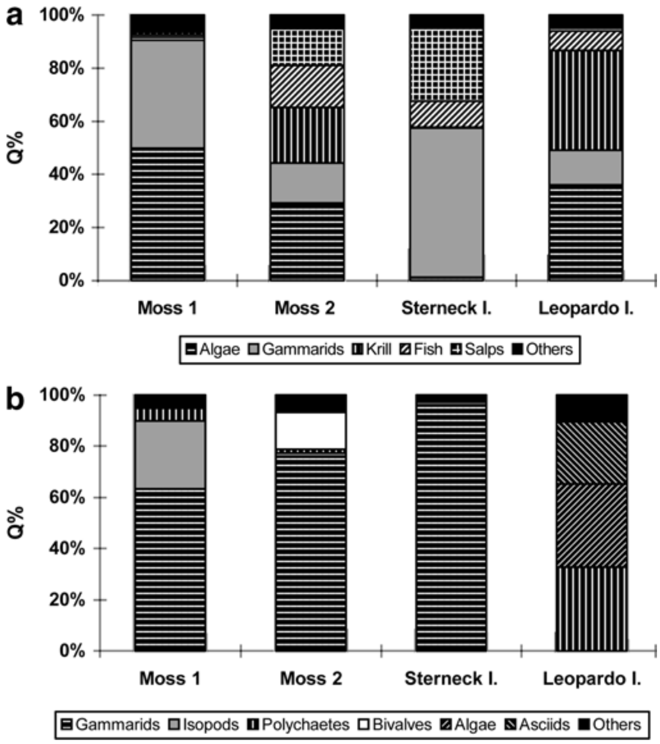

Fig. 4 Diet composition (dietary coefficient *Q* percent) of *Notothenia coriiceps* (**a**) and *Gobionotothen gibberifrons* (**b**) at different sampling sites in the Danco Coast, Antarctic Peninsula

in some Antarctic demersal, shallow-water fish species. In this study, algae constituted a main food item for *N. coriiceps* and *N. rossii*. It has been demonstrated that algae are actively selected and consumed deliberately by fish (Barrera-Oro and Casaux 1990; Casaux et al. 1990; Iken et al. 1997).

Comparison of relative abundance of *G. gibberifrons* in inshore trammel-net catches between the present results from the Danco Coast and those from the South Shetland Islands area indicates high and very low values, respectively (this study; Barrera-Oro et al. 2000). In fact, this difference has been also reflected in the analysis of the diet of the Antarctic shag from both areas, in which the low predation by this bird on *G. gibberifrons* in inshore waters (< 120 m depth) of the South Shetland Islands is evident (Casaux and Barrera-Oro 1993; Barrera-Oro and Casaux 1996; Casaux et al. 1997; Casaux et al. 2002). Barrera-Oro and Marschoff (1991) and later on Barrera-Oro et al. (2000) indicated that the effect of the commercial fishery around the South Shetland Islands at the end of the 1970s is the most likely reason for the decrease in the inshore population of G. gibberifrons in that area during the last 19 years. This explanation is supported by the data from this study, due to the fact that they were obtained in an area that has remained outside the influence of the commercial fishery. Likewise, present results validate the utility of the standard method implemented by the Ecosystem Monitoring and Management Working Group of CCAMLR, on the use of the Antarctic shag to monitor changes in the abundance of inshore demersal fish populations (SC-CAMLR-XVII/3, 1998).

Acknowledgements We thank M. Favero and P. Silva for their help in the field and the staff of Primavera Station in summer 2000 for logistic support.

References

Barrera-Oro E (1989) Age determination of *Notothenia gibberifrons* from the South Shetland Islands, Antarctic Peninsula subarea (subarea 48.1). CCAMLR Sci Sel Pap 2:143–160

Barrera-Oro E (1996) Ecology of inshore demersal fish (Notothenioidei) from the South Shetland Islands. PhD Thesis, University of Bremen

Barrera-Oro E, Casaux R (1990) Feeding selectivity in *Notothenia neglecta*, Nybelin, from Potter Cove, South Shetland Islands, Antarctica. Antarct Sci 2:207–213

Barrera-Oro E, Casaux R (1996) Fish as diet of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* at Half-moon Island, South Shetland Islands. Cybium 20:37–45

Barrera-Oro E, Casaux R (1998) Ecology of demersal fish species from Potter Cove. In: Wiencke C, Ferreyra G, Arntz W, Rinaldi C (eds) The Potter Cove coastal ecosystem, Antarctica. Berichte 299, Bremerhaven, pp 156–167

Barrera-Oro E, Marschoff E (1991) A declining trend in the abundance of *Notothenia rossii marmorata* and *Notothenia gibberifrons* observed in fjords in two sites in the South Shetland Islands. Selected Scientific Papers 1990 (SC-CAMLR-SSP/7). CCAMLR, Hobart, Australia 263–274

Barrera-Oro E, Marschoff E, Casaux R (2000) Trends in relative abundance of fjord *Notothenia rossii*, *Gobionotothen gibberifrons* and *Notothenia coriiceps* at Potter Cove, South Shetland Islands, after the commercial fishing in the area. CCAMLR Sci 7:43–52

Bellisio N (1967) Peces antárticos del Sector Argentino (parte IV): *Parachaenichthys charcoti*, *P. georgianus* y *Harpagifer bispinis antarcticus* de Bahía Luna. Serv Hidrogr Nav 904:1–57

Birt V, Birt T, Goulet D, Lairus D, Montevecchi W (1987) Ashmole's halo: direct evidence for prey depletion by a seabird. Mar Ecol Prog Ser 40:205–208

Burchett M (1983) Food, feeding and behaviour of *Notothenia rossii* nearshore at South Georgia. Br Antarct Surv Bull 61:45–51

Casaux R, Barrera-Oro E (1993) The diet of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* feeding in the Bransfield Strait. Antarct Sci 5:335–338

Casaux R, Mazzotta A, Barrera-Oro E (1990) Seasonal aspects of the biology and diet of nearshore nototheniid fish at Potter Cove, South Shetland Islands, Antarctica. Polar Biol 11:63–72

Casaux R, Favero M, Coria N, Silva P (1997) Diet of the imperial cormorant *Phalacrocorax atriceps*: comparison of pellets and stomach contents. Mar Ornithol 25:1–4

Casaux R, Baroni A, Barrera-Oro E (2002) Fish in the diet of breeding Antarctic shags *Phalacrocorax bransfieldensis* at four colonies in the Danco Coast, Antarctic Peninsula. Antarct Sci (in press)

Daniels R (1982) Feeding ecology of some fishes of the Antarctic Peninsula. Fish Bull 80:575–588

Daniels R, Lipps J (1982) Distribution and ecology of fishes of the Antarctic Peninsula. J Biogeogr 9:1–9

Everson I (1970) Reproduction in *Notothenia neglecta* Nybelin. Br Antarct Surv Bull 23:81–92

Fischer W, Hureau J (1985) FAO species identification sheets for fishery purposes. Southern Ocean (CCAMLR Convention Area), vol 2. FAO, Rome

Gon O, Heemstra P (eds) (1990) Fishes of the Southern Ocean. J.L.B. Smith Institute of Ichthyology, Grahamstown

Gröhsler T (1994) Feeding habits as indicators of ecological niches: investigations of Antarctic fish conducted near Elephant Island in late autumn/winter 1986. Arch Fish Mar Res 42:17–34

Hourigan T, Radtke R (1989) Reproduction of the Antarctic fish *Nototheniops nudifrons*. Mar Biol 100:277–283

Hureau J (1970) Biologie comparee de quelques poissons antarctiques (Nototheniidae). Bull Inst Océanogr Monaco 68:1–244

Iken K, Barrera-Oro E, Quartino M, Casaux R, Brey T (1997) Grazing by the Antarctic fish *Notothenia coriiceps*: evidence for selective feeding on macroalgae. Antarct Sci 9:386–391

Kock K (1989) Reproduction in fish around Elephant Island. Arch Fischereiwiss 39:171–210

Kock K (1998) Changes in fish biomass around Elephant Island (Subarea 48.1) from 1976 to 1996. CCAMLR Sci 5:165–189

Kock K, Kellermann A (1991) Reproduction in Antarctic notothenioid fish. Antarct Sci 3:125–150

Kulesz J (1994) Seasonal biology of *Notothenia gibberifrons*, *N. rossii* and *Trematomus newnesi*, as well as respiration of young fish from Admiralty Bay (King George, South Shetland Islands). Pol Arch Hydrobiol 41:79–102

La Mesa M, Vacchi M, Zunini Sertorio T (2000) Feeding plasticity of *Trematomus newnesi* (Pisces, Nototheniidae) in Terra Nova Bay, Ross Sea, in relation to environmental conditions. Polar Biol 23:38–45

Leopold M, Damme C van, Veer H van der (1998) Diet of cormorants and the impact of cormorant predation on juvenile flatfish in the Dutch Wadden Sea. J Sea Res 40:93–107

Linkowski T, Presler P, Zukowski C (1983) Food habits of nototheniid fishes (Nototheniidae) in Admiralty Bay (King George Island, South Shetland Islands). Pol Polar Res 4:79–95

Moreno C, Bahamonde N (1975) Nichos alimentarios y competencia por alimento entre *Notothenia coriiceps neglecta* Nybelin y *Notothenia rossii marmorata* Fischer en Shetland del Sur, Antarctica. Ser Cient Inst Antárt Chil 3:45–62

Moreno C, Zamorano J, Duarte W (1977) Distribución y segregación espacial de las poblaciones de peces en Bahía South (Isla Doumer, Antartica). Inst Antárt Chil Ser Cient 5:45–58

Richardson M (1975) The dietary composition of some Antarctic fish. Br Antarct Surv Bull 41, 42:113–120

SC-CAMLR (1998) Report of the Working Group on Ecosystem Monitoring and Management. Report of the Seventeenth Meeting of the Scientific Committee, Annex 4. CCAMLR, Hobart

Tarverdiyeva M, Pinskaya I (1980) The feeding of fishes of the families Nototheniidae and Channichthyidae on the shelves of the Antarctic Peninsula and the South Shetlands. J Ichthyol 20:50–60

Vacchi M, La Mesa M, Castelli A (1994) Diet of two coastal nototheniid fish from Terra Nova Bay, Ross Sea. Antarct Sci 6:61–65

Vacchi M, Williams R, La Mesa M (1996) Reproduction in three species of fish from the Ross Sea and Mawson Sea. Antarct Sci 8:185–192