



Inter-individual and seasonal variability of biological indices in notothenioid fishes from Admiralty Bay, Antarctica

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ABSTRACT: *Notothenia coriiceps*, *N. rossii* and *Lepidonotothen nudifrons* were sampled from Admiralty Bay from March to November 1997 and from January to February 1999. The ratio of *N. coriiceps* to *N. rossii* individuals in catches regularly increased during 22 years from 0.4 in 1977 to 9.5 in 1999. Owing to its reproductive strategy and avoidance of shallow waters *N. rossii* may be more vulnerable to overfishing. The condition factor was the most stable (CV 6–10%), variations in the of hepatosomatic index and index of stomach fullness were intermediate (21–38% and 40–43%, respectively), and the gonadosomatic index was the most variable (65–100%). Lack of seasonality in two somatic indices (condition factor and index of stomach fullness) in *N. coriiceps* adults is a direct effect of high food availability and unlimited food detection all year round. In contrast, the seasonality of a reproductive index (gonadosomatic index) of these fish is a response to the highly seasonal trophic conditions for pelagic larvae.

Key words: Antarctica, notothenioid fishes, endangered species, seasonal changes.

Introduction

Notothenia coriiceps Richardson, 1844 (previously known as *N. neglecta*), *Notothenia rossii* Richardson, 1844 (syn. *N. marmorata*) and *Lepidonotothen (Lindbergichthys) nudifrons* (Lönnberg 1905) are common demersal notothenioids in Admiralty Bay, endemic to the Antarctic waters (reviews in Gon and Heemstra 1990, Skóra 1993, Kulesz 1998).

A shift in dominance among the *Notothenia* species from *rossii* to *coriiceps*, observed in Admiralty Bay between 1977 and 1997, was highlighted by Zadróźny (1996), Rakusa-Suszczewski (1998) and Kulesz (1999). *Notothenia rossii* is an

important commercial species (DeWitt *et al.* 1990), so recovery of its populations, or, alternatively, their further retreat, are of interest.

The Southern Ocean system is characterised by a strong seasonality (reviews in Lutjeharms 1990, Knox 1994 and many others). How does that seasonality reflect on benthic fishes? Somatic and reproductive indices of *N. coriiceps* were measured in a nearly complete annual cycle, their variability assessed, and seasonal changes considered.

This paper provides information on the present state of *N. rossii* and discusses the mechanisms behind the decline in its population. It also touches on the individual and seasonal variability of biological indices in *N. coriiceps* and shows that somatic indices (condition factor and index of stomach fullness) do not show any distinct seasonal changes, in contrast to a reproductive index (gonadosomatic index), which is seasonal.

Materials and methods

Fish (late juveniles and adults) were collected from Admiralty Bay (King George Island, South Shetlands, Antarctica, 62°10'S, 58°29'W). The sampling was made with gill nets of 35 and 44 mm size from March to November 1997, (*i.e.* during austral autumn, winter and spring) by Tomasz Zadróźny; size frequency distribution, weight-to-length relationship and gonad developmental stages were described by Kulesz (1999). My own collection was made with baited traps in January and February 1999 (austral summer). Species were identified according to Fischer and Hureau (1985) and DeWitt *et al.* (1990). In total, 145 specimens of *N. coriiceps*, 23 *N. rossii*, and 10 individuals of *L. nudifrons* were caught. In Table 1 the materials collected and methods used are summarised, and equations are shown from which the indices were computed. Scales for age determination were sampled from the region just below the upper right lateral line. In fish collected in 1999 the gut content was inspected for main diet items.

Results

Comparisons between species

Lepidonotothen nudifrons was smaller than the two *Notothenia* species and more slender (lower CF) (Table 2). In contrast, *L. nudifrons* had a higher hepatosomatic index (*t* – test, $P = 0.036$ with *N. coriiceps* '99 and $P = 0.014$ with *N. rossii*). *Notothenia coriiceps* was larger than *N. rossii* (higher W_w , *t* – test, $P = 0.0021$ in 1997) and more robust (higher CF) (Table 2).

The main food item of all three species were Amphipoda (mean individual wet weight 0.033 g). Significant amounts of benthic macroalgae were found in the guts

Table 1

Summary of materials and methods.

Attributes and indices	Materials		Methods
	1997 ^a	1999 ^b	
Sex	+	+	Determined by gonad examination
Age (A, years)	–	+	Assessed from scales
Total length (L_t , cm)	+	+	Measured to the nearest 0.1 cm
Standard length (L_s , cm)	+	+	Measured to the nearest 0.1 cm
Total body weight (W_w , g)	+	+	Taken to the nearest 1g (<i>Nototh.</i>) or 0.1 g (<i>Lepidonototh.</i>)
Eviscerated body weight (W_e , g)	+	–	Taken to the nearest 1 g
Weight of stomach + food (W_s , g)	+	–	Taken to the nearest 1g
Liver wet weight (W_l , g)	–	+	Taken to the nearest 0.01 g
Gonad weight (W_g , g)	+	–	Taken to the nearest 0.1 g
Condition factor (CF)	+	+	Computed from: $CF = 100 * W_w * L_s^{-3}$
Index of stomach fullness (ISF, % \bullet)	+	–	Computed from: $ISF = 10\ 000 * W_s * W_e^{-1}$
Hepatosomatic index (HSI, %)	–	+	Computed from: $HSI = 100 * W_l * W_w^{-1}$
Gonadosomatic index (GSI, %)	+	–	Computed from: $GSI = 100 * W_g * W_w^{-1}$

^a Materials collected in autumn, winter and spring 1997 by Tomasz Zadróźny: *N. coriiceps* (126 individuals), and *N. rossii* (21); ^b My own materials collected in summer 1999: *N. coriiceps* (19), *N. rossii* (2) and *L. nudifrons* (10 individuals).

Table 2

Attributes and indices ^a in fish collected from Admiralty Bay in 1997 and 1999.

Attributes and indices	1997		1999		
	<i>N. coriiceps</i> (n = 126)	<i>N. rossii</i> (n = 21)	<i>N. coriiceps</i> (n = 19)	<i>N. rossii</i> (n = 2)	<i>L. nudifrons</i> (n = 10)
Sex (F – females, M – males)	69F, 56M ^b	3F, 18M	7F, 7M ^b	1F, 1M	9F, 1M
Age (A, years)	–	–	6.2±1.2	4.0	4.9±2.1
Range of total length (L_t , cm)	15.0–40.5	16.5–36.5	28.5–50.3	31.0, 35.0	13.4–17.7
Standard length (L_s , cm)	24.8±4.6	22.6 ±3.9	33.6±4.9	29.6	14.1±1.3
Total body weight (W_w , g)	383.1±196.1	244.7±121.5	954.4±411.1	587.5	49.1±15.1
Eviscerated body weight (W_e , g)	333.9±164.3	214.1±104.4	–	–	–
Weight of stomach + food (W_s , g)	19.0±13.0	12.1±10.8	–	–	–
Liver wet weight (W_l , g)	–	–	27.5±18.4	12.0	1.9±0.8
Gonad weight (W_g , g)	1.93 ± 2.88	0.44±0.47	–	–	–
Condition factor (CF)	2.3 ± 0.2	1.9±0.2	2.4±0.3	2.3	1.7±0.1
Index of stomach fullness (ISF, % \bullet) ^c	579.0 ± 233.6	557.8±241.7	–	–	–
Hepatosomatic index (HSI, %)	–	–	2.6±1.0	2.0	3.8±0.8
Gonadosomatic index (GSI, %)	0.42±0.42	0.17±0.11	–	–	–

^a mean ± SD; ^b sex was not identified in remaining individuals; ^c no fish with empty stomachs were found.

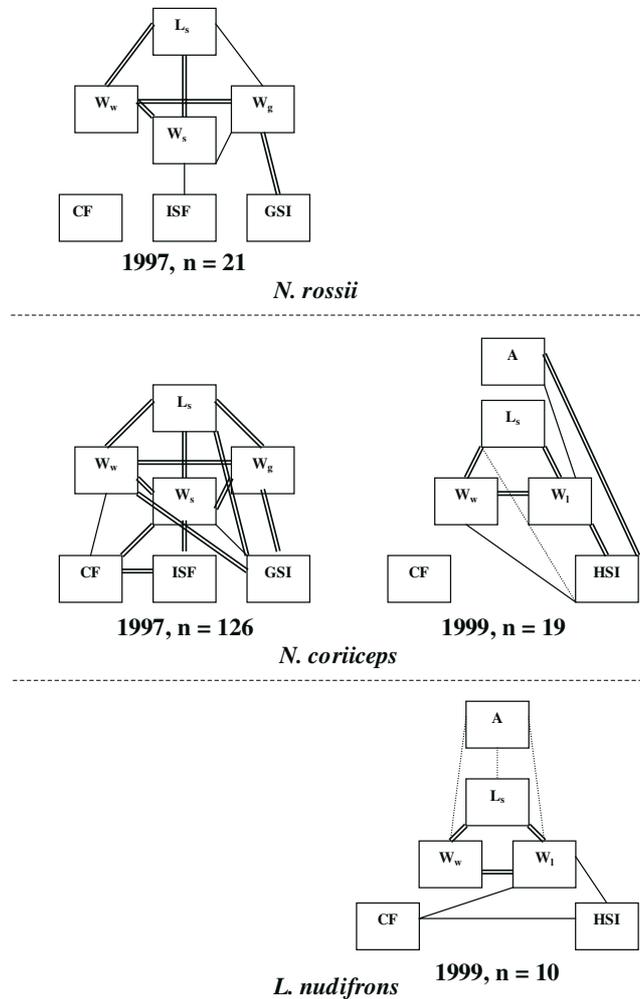


Fig. 1. Interrelations between attributes and indices of fishes collected in 1997 and 1999. Abbreviations as in Table 1. Lines – significant positive correlations (dotted line – $P < 0.05$, continuous line – $P < 0.01$, double line – $P < 0.001$).

of both *Notothenia* species. Single specimens of *L. nudifrons* were also found in the largest *N. coriiceps* individuals.

In 1997, and especially in 1999, more *N. coriiceps* than *N. rossii* were found (Table 2). Sex ratio was close 1:1 in *N. coriiceps* '97 and '99, but in *N. rossii* more males were collected in 1997 (sex ratio M:F 6:1).

Interrelationships among fish attributes and indices

Condition factor (CF) was the least variable (coefficient of variation, $CV = SD \cdot 100 / \text{mean}$, ranged from 6 to 10%) (Table 2). The remaining indices – hepato-

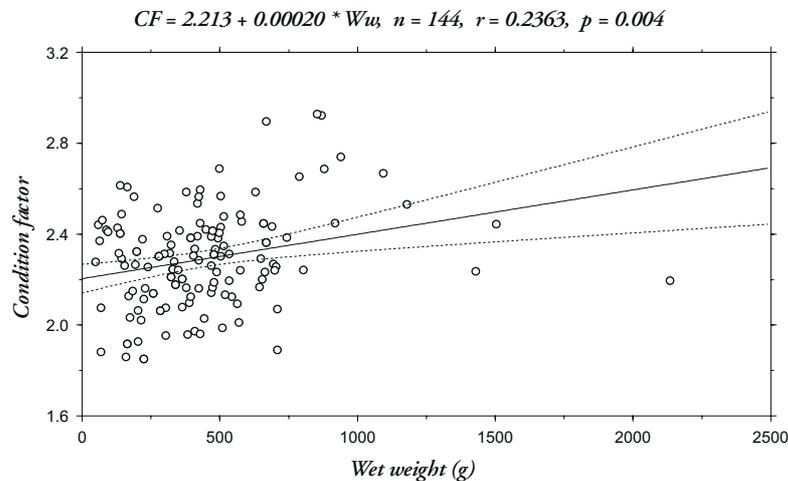


Fig. 2. Relationship between the condition factor and total wet weight in *N. coriiceps* collected in autumn–winter–spring 1997 and in summer 1999. Regression line and 95% confidence intervals are shown.

somatic index (HSI) and index of stomach fullness (ISF) – were more variable (21–38% and 40–43%, respectively) while the gonadosomatic index (GSI) was very variable (65–100%).

Apart from the obvious strong correlations between the parameters A , L_s , W_w , W_s , W_g and W_l (Fig. 1), few other interrelationships will be considered. Correlations between the condition factor (CF) and total wet weight (W_w) were not detected in small samples (*N. rossii* '97, *N. coriiceps* '99 and *L. nudifrons* '99), but it was found in a large sample of *N. coriiceps* '97 (Fig. 1). From pooled data of *N. coriiceps* collected in both 1997 and 1999, ($n = 145$) a positive, highly significant correlation ($P = 0.004$) was found between CF and W_w (Fig. 2), but only 5.6% of the variation in condition factor could be attributed to weight (W_w). Similarly, no significant L_s – induced and W_w – induced changes in GSI were found in a small sample of *N. rossii* '97 (Fig. 1). These relationships came to light in a large sample of *N. coriiceps* '97 ($P = 0.0001$ and $P = 0.0000$, respectively), but only 12.8% of the variation in GSI could be explained by standard length and only 14.4% by total body weight. Older and larger fish had higher hepatosomatic indices (HSI). In *N. coriiceps* HSI was influenced by age and size both directly and indirectly through liver weight (W_l), while in *L. nudifrons* only the indirect influence was detected. A strong positive relation between index of stomach fullness (ISF) and condition factor (CF) was found in a large sample of *N. coriiceps* '97, but not in a smaller sample of *N. rossii* '97 (Fig. 1).

Effect of sex was evaluated only for those months in which the numbers of females and males were high enough. No differences in condition factor (CF) between females and males were found in both *N. coriiceps* (Fig. 3, t – test, $P > 0.05$

Table 3
Evaluation of differences between monthly values of biological indices using analysis of variance.

Index	Species, sex	F	d.f.	P*	Figure No
Condition factor, CF	<i>N. coriiceps</i> ♀	2.17	6.69	0.056 N	3
	<i>N. coriiceps</i> ♂	2.23	7.56	0.045 S	3
	<i>N. rossii</i> ♂	0.82	3.15	0.504 N	
Index of stomach fullness, ISF	<i>N. coriiceps</i> ♀	1.40	5.61	0.238 N	4
	<i>N. coriiceps</i> ♂	2.85	6.48	0.020 S	4
	<i>N. rossii</i> ♂	1.23	2.15	0.320 N	
Gonadosomatic index, GSI	<i>N. coriiceps</i> ♀	7.44	5.63	0.000015 HS	5
	<i>N. coriiceps</i> ♂	6.07	6.49	0.000083 HS	5
	<i>N. rossii</i> ♂	4.58	2.15	0.028 S	

*N – non-significant, S – significant, HS – highly significant.

Table 4
Changes in the ratio of *N. coriiceps* to *N. rossii* numbers caught from Admiralty Bay during the last 22 years.

Year	Number of <i>N. coriiceps</i>	Number of <i>N. rossii</i>	Ratio <i>N. coriiceps</i> / <i>N. rossii</i>	Source
1977	232	578	0.4	Linkowski and Żukowski (1980)
1979	246	247	1.0	Skóra and Neyelov (1992)
1988	436	107	4.1	Kulesz (1994)
1994/95	468	136	3.4	Zadróźny (1996)
1997	126	21	6.0	Kulesz (1999) and present work (materials collected by Zadróźny)
1999	19	2	9.5	Present work

in March, April, May, June and August 1997 and January 1999) and *N. rossii* ($P > 0.05$ in April 1997). Similarly, no effects of sex on the index of stomach fullness (ISF) were detected (Fig. 4). In contrast, the hepatosomatic index (HSI) was greater in females than in males (*N. coriiceps*, January 1999, $P = 0.043$). Also, a greater gonadosomatic index (GSI) was found in females of *N. coriiceps* (Fig. 5, $P < 0.01$ in March, April and October 1997) as well as in females of *N. rossii* ($P < 0.05$ in April 1997) as compared with the respective males.

Seasonal changes

No seasonality was found in the yearly course of the condition factor of *N. coriiceps* (Fig. 3) and *N. rossii*, or the differences were observed on the edge of significance (Table 3). Similarly, no distinct seasonal changes were observed in the index of stomach fullness (Fig. 4, Table 3). Post hoc comparisons (Tukey's t – test for a unequal sample size) between the values for any specific pair of months within any of the six species/sex combinations yielded no significant results.

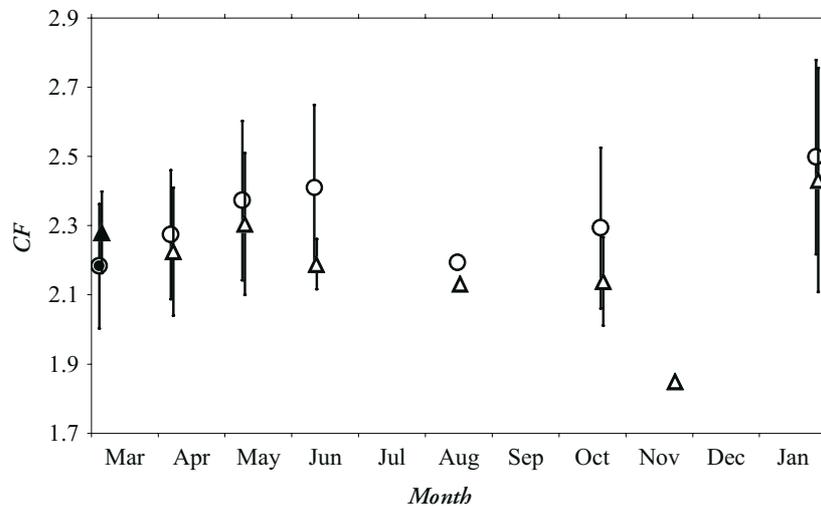


Fig. 3. Seasonal changes in the condition factor in *N. coriiceps*. Circles – females, triangles – males. Mean values \pm SD are shown.

Compared with the somatic indices (CF and IFS), the gonadosomatic index (GSI) varied between months (Fig. 5, Table 3). Significant decreases of GSI were confirmed using the Tukey *t*-test in *N. coriiceps* females between March and May ($P = 0.039$), in males between March and April ($P = 0.014$) and in males between March and May ($P = 0.001$). In females GSI increased between May and June ($P = 0.002$). Between June and November no significant changes were found.

Discussion

Comparisons between species

Between 1977 and 1999 a steady shift in dominance from *N. rossii* to *N. coriiceps* was observed (Table 4). A similar trend in *Notothenia* dominance was reported by Barrera-Oro and Marschoff (1990) from Potter Cove, which is in close vicinity to Admiralty Bay: until 1984 *N. rossii* dominated, but *N. coriiceps* thereafter. The high ratio of 9.5 in the Admiralty Bay in 1999 (Table 4) is not very reliable because of low number of fish sampled. However, from the region of South Shetlands and the Bransfield Strait at 0–500 m in March 1998 Kock *et al.* (2000) reported catches of *N. coriiceps* and *N. rossii* 1249.9 kg and 18.3 kg, respectively, thus producing an even higher ratio of 68.3. Taken together, the accelerated shift of dominance from *N. rossii* to *N. coriiceps* is confirmed. It is a general phenomenon, rather than a local one limited to Admiralty Bay.

Typically, Antarctic fishes mature late, *N. coriiceps* for example matures after 7–8 years of growth (Everson 1970). Antarctic fish species produce a few large

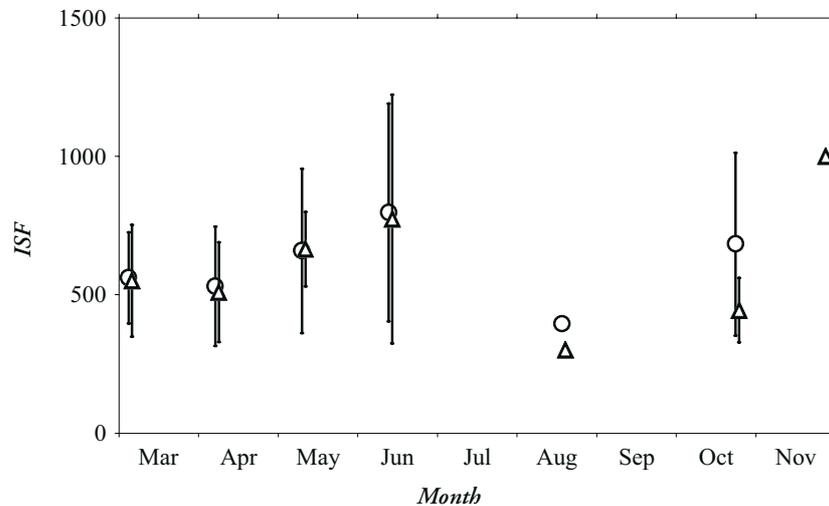


Fig. 4. Seasonal changes in the index of stomach fullness in *N. coriiceps*. Denotations as in Fig. 3.

eggs (Christiansen *et al.* 1998) which have a protracted incubation time (Burchett *et al.* 1983). All these factors contribute to vulnerability of the Antarctic fish species to over-fishing. *Notothenia coriiceps* and *N. rossii* are placed as close taxa in phylogenetic reconstructions for notothenioid species (Bargelloni *et al.* 2000, Stankovic *et al.* 2002). Both are benthic fishes noted at a depth range of 0–500 m, but *N. coriiceps* exhibits a preference for shallow waters, and *N. rossii* performs annual spawning migrations (DeWitt *et al.* 1990). These behaviors may keep some *N. coriiceps* out of reach of fishing vessels and make *N. rossii* more vulnerable to fishing mortality. Selective elimination of *N. rossii* possibly contributes to changes in the structure of fish communities observed in the Southern Ocean as a result of intensive fishing, which peaked in 1965–1975 (Neyelov, *personal commun.*). In the early 70's *N. rossii* responded to the commercial fishing by a dramatic decline in the catch in the Southern Ocean (Hureau and Slosarczyk 1990). In addition, the depressed number of females in *N. rossii* may be indicative of an endangered population. Stocks of another fish endangered with extinction, a Central European riverine cyprinid, *Chondrostoma nasus*, have declined dramatically during last few decades; new male recruits entered the population in intervals of one to four years, while females recruited only once over a period of six years (Kamler and Keckeis 2000). Thus, the state of the *N. rossii* population in Admiralty Bay well illustrates the endangered state of that species, in spite of the conservation measures (Hureau and Slosarczyk 1990) that have been adopted in the 80's.

Interrelationships among fish attributes and indices

A high variability in the gonadosomatic index (GSI) in *N. coriiceps* '97 (CV 60–100%) was found. Kulesz (1999) analysed gonad maturity stages in the same

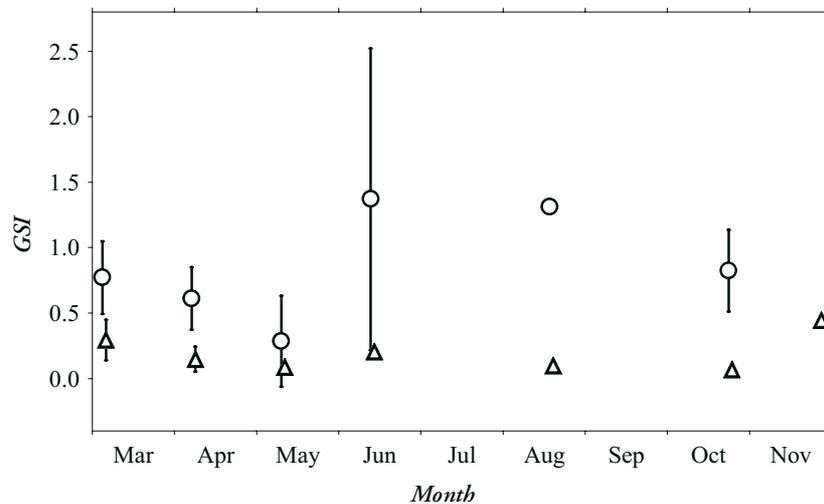


Fig. 5. Seasonal changes in the gonadosomatic index in *N. coriiceps*. Denotations as in Fig. 3.

material collected by T. Zadróźny in 1997 and found both mature and immature individuals, with the smallest mature individuals of 25 cm L_t (cf. L_t range in Table 2). Low mean GSI values (Fig. 5) can also be explained by the proportion of immature individuals. In the largest (L_t 40.5 cm) *N. coriiceps* female sampled 23 March 1997 at 4th stage of gonad maturation, a GSI of 12 was found, which is typical of mature, ready to spawn *N. coriiceps* females (Everson 1970, Sapota 1999, Kock *et al.* 2000).

Condition factor in *N. coriiceps* had a weak tendency to increase with increasing body size (Fig. 2). Kulesz (1999) computed the weight-to-length relationship in *N. coriiceps* '97, $W_w = 0.01 * L_t^{3.19}$; the length exponent slightly exceeded 3.0. Thus a slight change of body shape in growing late juveniles and adults occurred: larger individuals were somewhat more robust. *Notothenia coriiceps* is a relatively large fish (Table 2) with a broad food spectrum: Amphipoda, macroalgae and, in a few of the largest predators single specimens of *L. nudifrons* were found. *Lepidotothen nudifrons* are large food items, and very nutritious, much higher in total lipids than amphipods and algae, and very rich in polyunsaturated fatty acids (Kamler *et al.* 2001). Thus, the large *N. coriiceps* individuals of $W_w > 800$ g (Fig. 2), with large mouth gapes and swimming abilities developed enough to successfully attack large prey, could increase their condition factor.

In older and larger fish a higher hepatosomatic index was reported for *Gadus morhua* (Jangaard *et al.* 1967), *Notothenia rossii* (Bykov 1972), and for *N. coriiceps* and *L. nudifrons* (present paper: HSI in Fig. 1). The hepatosomatic index is considered an indicator of energy storage in fish (review in Ferron and Leggett 1994). Similarly, longer and heavier *N. coriiceps* had higher gonadosomatic indices (GSI, Fig. 1). In females, as compared with males elevated gonadosomatic and

hepatosomatic indices were both found in the present paper. Except for very old individuals, allocation of resources to gonads typically increases with fish age/size, reserves stored in the liver are used to build the gonads, and energy cost for testicular growth is usually smaller than that of ovarian growth (reviews in Wootton 1990 and Kamler 1992).

A relation between the index of stomach fullness (ISF) and condition factor (CF) was detected for the large sample of *N. coriiceps* '97, but not for the smaller sample of *N. rossii* '97 (Fig. 1). Although a positive relation between ISF and CF does exist, it may not be displayed, because these indices respond to feeding conditions on different time scales (Ferron and Leggett 1994).

Seasonal changes

During Antarctic winter low temperatures and light deficit result in strong limitations of phytoplankton (review in Knox 1994). For example, in Admiralty Bay the peak primary production in austral summer (February) amounted to 82 mg C m⁻³ per day, while in winter (June and July) the values were often below the detection limit (Domanov and Lipski 1990). This strong seasonality in primary production imposes a seasonality in production of zooplankton. As a consequence of the pelagic habits of larvae in the majority of Antarctic fish species (White 1998) the timing of reproduction synchronizes the occurrence of fish larvae with the annual peak of plankton production. Antarctic fish larvae feed mainly on zooplankton during daylight (North and Ward 1990); strong seasonality in their growth rate was explained by seasonal zooplankton limitation (North 1998). Like the majority of Antarctic species larvae of *Notothenia coriiceps* are pelagic and they hatch in austral spring in (October) November (December) from eggs spawned the previous autumn in (April) May (June) (Everson 1970, White *et al.* 1982 and reviews in DeWitt *et al.* 1990, Kock and Kellermann 1991). In the present paper a decrease of *N. coriiceps* GSI from March to May was found (Fig. 5), which reflects egg release by a mature part of the population during protracted spawning. The differences were clouded by the presence of a proportion of immature individuals, but some differences were significant (Fig. 5, Table 3). Summing up, seasonality of the reproductive index, GSI, in adult *N. coriiceps* is a response to highly seasonal trophic conditions for larvae.

In contrast, present studies on late juveniles and adults of *N. coriiceps* did not detect any distinct seasonality in somatic indices: condition factor (Fig. 3) and index of stomach fullness (Fig. 4), which are directly related to trophic conditions. Thus, no winter starvation of subadult/adult *N. coriiceps* is suggested. However, a winter decline in condition factor of juvenile *N. rossii* around South Georgia was found by Burchett (1983). In some nototheniids a reduction in feeding intensity during winter was observed, while for other nototheniids no annual seasonality in feeding intensity was reported (review in Kock and Everson 1998).

The main prey for subadult/adult *N. coriiceps* and *N. rossii* are benthic invertebrates, with amphipods being the predominant food type, although macroalgae are also consumed deliberately and regularly and smaller fish may be a part of the diet of large *N. coriiceps* individuals (Richardson 1975, Linkowski *et al.* 1983 and present paper; review in DeWitt *et al.* 1990). A high summer biomass of total macro-zoobenthos in the Admiralty Bay, 750, 800, 350 and 200 g wet weight m⁻², respectively, at the depth zones of 0–100 m, 100–200 m, 200–300 m and > 300 m, were reported by Jażdżewski *et al.* (1986). Life cycles of benthic animals are long; certain of them may graze on sessile organisms that develop under sea-ice (Clarke 1985) and no depletion of benthic fauna occurs in winter. Annual mean biomass of amphipods in the sublittoral of Admiralty Bay was 180 g m⁻², with peak values over 600 g m⁻² in the early winter (May and July) (Jażdżewski *et al.* 2001). In general, the biomass levels of Antarctic benthos are exceptionally high (review in Knox 1994). Aggregations of benthic macroalgae cover about 30% of the bottom surface of Admiralty Bay at depths 0–90 m (Zieliński 1990). *Lepidototothen nudifrons*, a prey for large *N. coriiceps*, is one of the three most abundant fish species in the Admiralty Bay (review in Kulesz, 1998). Thus rich food resources for benthic fish are available all the year round in the Admiralty Bay.

Winter light deficit does not impede the feeding patterns of these fish. Higher activity of *N. coriiceps* and *N. rossii* during the dark than during the light hours probably results from the synchronization with the activity rhythm of burrowing amphipods (Richardson 1975, Casaux *et al.* 1990). These fish are possibly tactile and/or chemoreceptive feeders rather than visual predators. In another Antarctic benthic fish, *Trematomus bernacchi*, chemosensory and rheosensory information was essential in food search (Montgomery *et al.* 1999). Kidawa and Rakusa-Suszczewski (1996) highlighted the special role of chemoreception for Antarctic marine animals.

Taken together, the abundant food supply and its unlimited detection all year round result in a lack of seasonality in subadult/adult *N. coriiceps* stomach fullness and condition factor. In contrast to *N. coriiceps*, in many temperate zone fish species a yearly cycle of somatic storage and depletion occurs, which makes possible energy investment in gonads during the periods of limited food intake (for example freshwater *Tinca tinca*: Horoszewicz 1981; marine *Clupea harengus pallasii*: Ware 1985; reviews in Shulman 1972 and Wootton 1990).

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