MORPHOLOGY AND MORPHOMETRY OF THE ANTARCTIC NOTOTHENIID *Notothenia rossii marmorata*

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ABSTRACT. The changes in morphology and morphometry during the life cycle of *Notothenia rossii marmorata* were investigated at South Georgia from 1978 to 1980. The development of this species can be divided into seven stages, five of which (young fingerling, blue phase fingerling, brown phase fingerling, juvenile and adult) are described in this paper. The use of morphological and morphometric characteristics as criteria in stock separation are discussed with relation to other investigations.

The life cycle of *Notothenia rossii* includes an inshore migration of pelagic fingerlings, a nearshore demersal juvenile phase and an offshore migration of fish to join the demersal–pelagic adult population. These changes in life-style and habitat are accompanied by changes in body shape. Stock separation based upon morphometric variation of *Notothenia rossii* from different island locations is not feasible since significant variations occur among fish at the same location. The existence of separate stocks at the adult stage is probable as fish stay within the vicinity of South Georgia and only migrate locally. However, the possibility of genetic exchange of young pelagic fish distributed by ocean current drifts cannot be overlooked.

The morphology and distribution of *Notothenia rossii* has been outlined by Everson (1969) and Hureau (1970). However, all the stages of development of *Notothenia rossii* have not yet been described. As a result, confusion exists over the identification of the younger stages, especially in distinguishing them from *Notothenia neglecta*. Both morphometric and morphological characteristics are required to describe fully a species or subspecies of fish and in some cases these characteristics will allow the differentiation of genetically distinct stocks.

Early descriptive work on the external anatomy of *Notothenia rossii* was undertaken by Fischer (1885), Lönnberg (1905), and Regan (1913). Their investigations were primarily taxonomic. Nybelin (1947, 1951) divided *Notothenia rossii* into two subspecies: *Notothenia rossii marmorata* from the Scotia arc and *Notothenia rossii rossii* from east Antarctica. Unless otherwise stated *Notothenia rossii marmorata* will be referred to as *Notothenia rossii* in this paper.

The Nototheniiformes are a division of the percomorph fish which includes 75% of all coastal fish in Antarctica and comprises five families. One of these is the Nototheniidae, to which *Notothenia rossii* belongs. Unlike most percoids, the Nototheniiform fish have flexible fin rays, jugular pelvic fins and a single nostril on each side of the head (Marshall, 1964).

This paper describes in detail the morphometric and morphological characteristics of *Notothenia rossii marmorata* during its life cycle. The value of using such criteria for differentiating stocks of *N. rossii* is briefly discussed.

METHODS

Fingerling stages of *N. rossii* were lured to the surface by powerful mercury vapour lamps and caught in hand-operated dip nets. Juvenile fish, between the ages of one and five years, were sampled with 27-m trammel nets laid overnight on the seabed in waters less than 30 m deep. Both sites were in the small bay of King Edward Cove on

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the northern coastline of South Georgia. Adult fish were obtained from research and fishing vessels operating around the island. Measurements and descriptions were taken from fresh specimens.

Thirteen hundred juvenile *N. rossii* were caught and marked with serially numbered Peterson discs, 1 cm in diameter, secured with stainless steel wire. Discs were placed below and between the second and third fin rays on the second dorsal fin. Once marked and measured, the fish were returned to King Edward Cove. Proportional body measurements used in this study are the same as those defined by Everson (1969).

Results

Young fingerlings

Material. Two specimens, one 25 mm and one 26 mm in length, were caught by means of a hand-operated dip net and light source from King Edward Point Jetty, Grytviken, on 12 December 1979 (Fig. 1).

Description. Fin ray counts were possible on both specimens and the results are given in Table I. Differentiation had not taken place between the first and second dorsal fins, so dorsal fin ray counts are low. Scales could not be seen with the naked

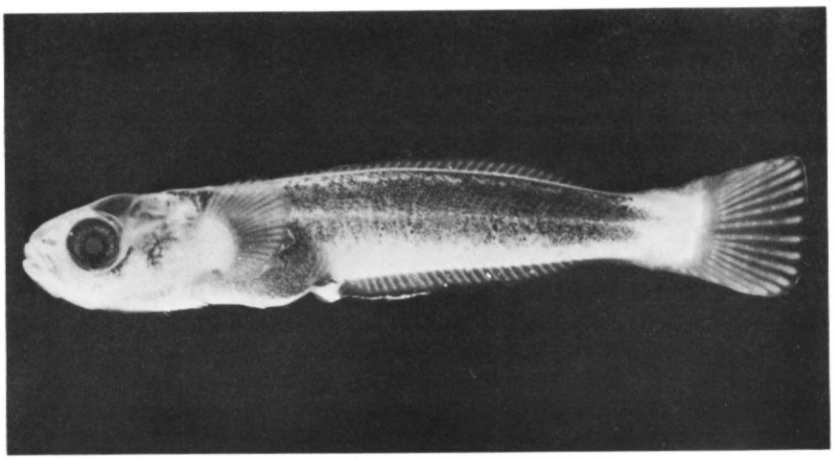

Fig. 1. A young *Notothenia rossii* fingerling, 25 mm in length, caught in King Edward Cove, South Georgia, on 12 December 1979.

Table I. The fin ray counts of two young *Notothenia rossii* fingerlings, one 25 mm in length (specimen 1) and one 26 mm in length (specimen 2), caught in King Edward Cove, South Georgia, on 12 December 1979.

Fin	*Specimen 1*	*Specimen 2*
Dorsal	31	29
Anal	25	25
Pectoral	22	22
Caudal	16	16

eye, but under the microscope the first stages of scale development could clearly be seen.

Pigmentation. In the head region, patches of chromatophores could be observed on the mouth, lower jaw and ventro-anteriorly around the rim of the orbit. The skin overlying the gut and brain cavity was heavily pigmented. A line of chromatophores at the angle of the jaws extended marginally to the dorsal edges of the operculum. Pigmented areas occurred in dorsal regions of the body from behind the head to the caudal junction, but chromatophores became less dense below the lateral line and towards the ventral surface. The ventral surface was a creamy white colour. There were pigment spots around the base of the pectoral fins but no pigmentation was present on any of the fins. Fin rays were clear and separate in outline. The apparent overall colour of the fish at this stage was dark blue.

Blue phase fingerlings

Material. Twenty specimens were caught. Their mean length was 6.1 cm (± 0.6 cm) and the absolute length range from 4.0 to 7.1 cm. Their mean fresh weight was 2.1 g (± 0.6 g) with an absolute range from 0.41 to 3.31 g. Fish were caught by means of a dip net and light source from King Edward Point jetty on 25 February 1979 (Fig. 2).

Description. Fin ray counts were possible on all specimens and the results are given in Table II and Fig. 3. At this stage the first and second dorsal fins have differentiated into two separate parts and the number of dorsal fin rays has increased. Scales can now be seen with the naked eye. The caudal fin is forked and the body thin and tapering; all the characteristics reflect a pelagic existence. Proportional body measurements are given in Table III.

Pigmentation. The head region to the dorsal orbit was heavily pigmented. There were dense patches of chromatophores in the central areas of the upper and lower jaw, upper and lower opercular, the ventral surface and scattered patches around the gills. Continuous pigmentation was present on the dorsal surface from behind the orbit to the caudal junction. Below the lateral line and towards the ventral surface, pigmentation became less pronounced with scattered patches of chromatophores on the lower flanks. Fin rays were white in appearance except at their bases where some pigmentation was present and the skin folds of the fins transparent. The overall

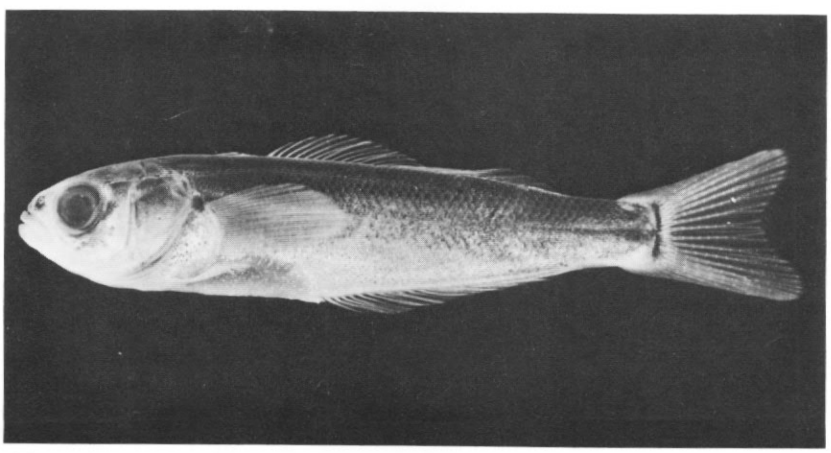

Fig. 2. A blue phase fingerling of *Notothenia rossii*, 55 mm in length, caught in King Edward Cove, South Georgia, in February 1979.

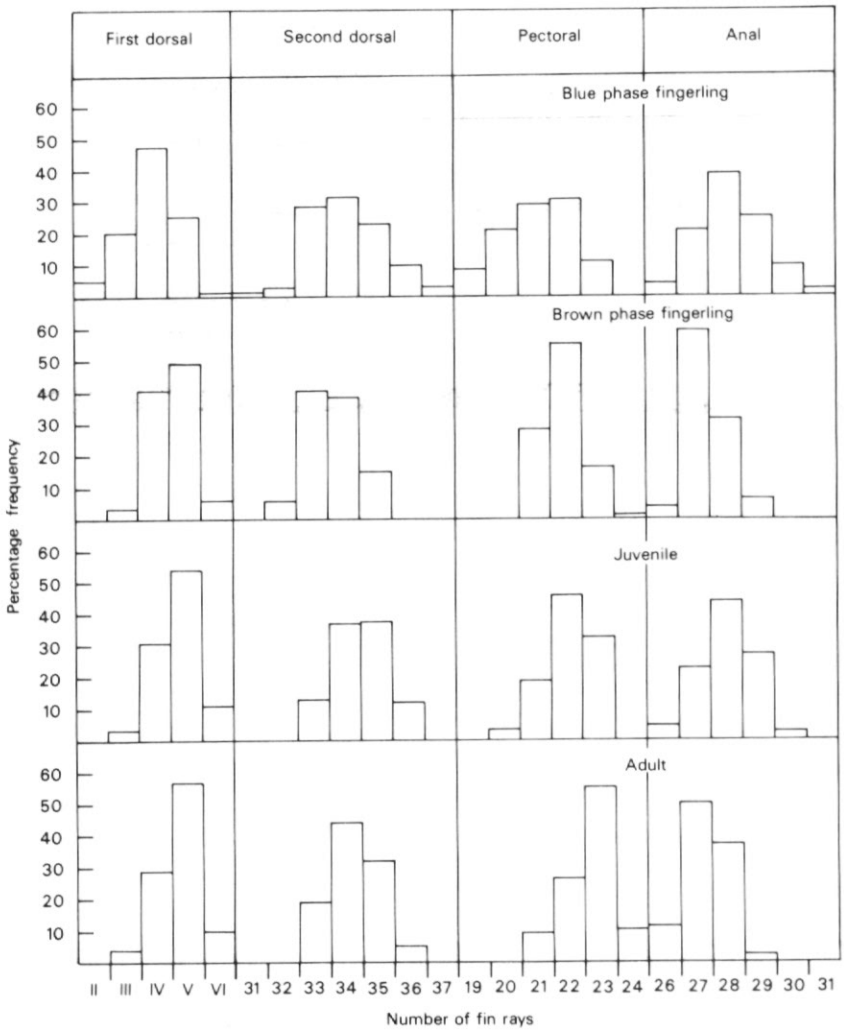

Fig. 3. The fin ray frequency of *Notothenia rossii* during different stages of the life cycle at South Georgia.

colour of the fish was dark blue in natural light, but under artificial illumination appeared green with faint cross-bands on the dorsal surface.

Brown phase fingerlings

Material. Thirty-one specimens were caught by means of a dip net and light source from King Edward Point jetty on 14 March 1979. Their mean length was 6.2 cm (± 0.5 cm) and their mean weight 1.95 g (± 0.51 g) (Fig. 4).

Description. Fin ray counts were possible on all specimens and the results are given in Table II and Fig. 3. As the pelagic blue phase fingerling settles to the bottom to become a demersal brown phase fingerling, the body becomes more flattened dorso-ventrally and there is an increase in girth, especially in the anterior half of the body. The fork shape of the caudal fin had almost disappeared and the posterior margin became straight.

Table II. The meristic features of *Notothenia rossii* during the life cycle and from different locations along the Scotia arc.

Ref.	Age (yr)	Development	Size range (cm)	Number of first dorsal fin rays				Number of second dorsal fin rays				Number of pectoral fin rays			
				Range	Mean	S	N	Range	Mean	S	N	Range	Mean	S	N
1	0	Blue phase fingerling	3.5–6.8 (TL)	III–VII	4.97	0.85	78	31–37	34.13	1.19	70	19–23	21.15	1.13	72
2	0	Brown phase fingerling	4.8–10.6 (TL)	IV–VII	5.58	0.67	81	32–35	33.62	0.81	81	21–24	21.90	0.70	82
3	0	All fingerlings	3.5–10.6 (TL)	III–VII	5.28	0.82	159	32–37	33.85	1.03	151	19–23	21.55	1.00	154
4	1–5	Juvenile	15.0–44.0 (TL)	IV–VII	5.74	0.70	1062	33–36	34.50	0.90	1064	20–23	22.08	0.82	884
5	1–5	Juvenile	17.5–33.1 (SL)	IV–VII	5.48	0.70	83	33–36	34.36	0.91	85	20–23	21.47	0.63	87
6	6+	Adult	41.0–73.0 (TL)	IV–VII	5.76	0.68	37	33–36	34.22	0.83	36	21–24	22.32	0.70	38
7	1–5	Juvenile	17.0–37.0 (SL)	IV–VII	5.79	0.74	58	32–36	34.34	0.98	58	21–23	21.98	0.66	58
8	6+	Adult	35.0–71.0 (TL)	IV–VII	5.74	0.67	57	32–36	34.22	0.98	55	20–23	21.55	0.69	54

Table II (continued).

Ref.	Age (yr)	Development	Size range (cm)	Number of anal fin rays				Number of vertebrae			
				Range	Mean	S	N	Range	Mean	S	N
1	0	Blue phase fingerling	3.5–6.8 (TL)	26–31	28.21	1.07	52	–	–	–	–
2	0	Brown phase fingerling	4.8–10.6 (TL)	26–29	27.39	0.66	81	–	–	–	–
3	0	All fingerlings	3.5–10.6 (TL)	26–30	27.71	0.93	133	–	–	–	–
4	1–5	Juvenile	15.0–44.0 (TL)	26–30	28.00	0.89	1060	51–54	51.91	0.80	192
5	1–5	Juvenile	17.5–33.1 (SL)	26–30	27.94	0.88	87	–	–	–	–
6	6+	Adult	41.0–73.0 (TL)	26–29	27.66	0.79	32	51–53	52.31	0.58	36
7	1–5	Juvenile	17.0–37.0 (SL)	26–29	27.67	0.89	57	–	–	–	–
8	6+	Adult	35.0–71.0 (TL)	25–29	27.72	0.82	57	51–55	52.59	0.68	66

References: 1–4, Burchett, South Georgia; 5, Everson (1969), South Georgia; 6, Freytag (1980), South Georgia; 7, Everson (1969), South Orkney Islands; 8, Freytag (1980), South Shetland Islands.

Size range of fish is total length (TL) in centimetres or standard length (SL) in centimetres.

N is the number of fish in the sample and S is the standard deviation.

Table III. The percentage proportional body measurements of blue phase fingerling and juvenile *Notothenia rossii* from South Georgia.

Developmental stage of fish	*Parameter*	*% HD/SL*	*% ED/HL*	*% Sn/HL*	*% IOW/HL*	*% BD/SL*	*% LOP1/HL*
Blue phase fingerling (3.5–5.6 cm)	Mean	29.4	28.4	27.7	31.1	21.8	78.6
	S	1.64	3.08	3.52	2.80	1.00	6.72
	N	124	124	124	124	124	124
Juvenile (15–35 cm)	Mean	28.0	21.5	28.4	28.0	25.8	79.9
	S	1.88	1.91	3.72	2.49	1.55	3.89
	N	245	150	150	150	150	150

N is the number of fish in the sample and S the standard deviation.

HD, Head diameter; SL, Standard length; ED, Eye diameter; HL, Head length; Sn, Snout length; IOW, Interorbital width; BD, Body depth; LOP1, Length of front pectoral fin.

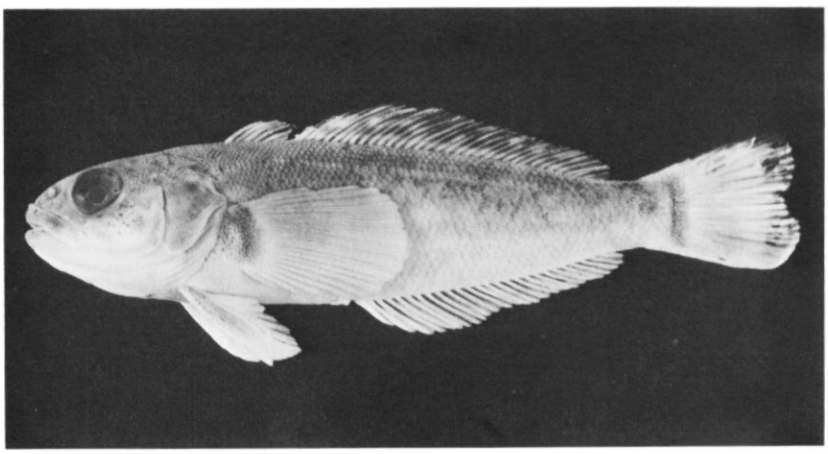

Fig. 4. A brown phase fingerling of *Notothenia rossii*, 87 mm in length, caught and raised in an aquarium at Grytviken, South Georgia, in 1979.

Pigmentation. The distribution of pigment on the head and body was similar to that of the blue phase fingerling, however the overall colour of the body had changed to brown. The junction of the caudal fin with the body had more pigment and the first and second dorsal fins had a faint series of brown cross-hatchings. There were also scattered chromatophores on the caudal fin, but anal, opercular and pectoral fins were devoid of chromatophores.

Juveniles

Material. Three thousand specimens, ranging in length from 15 to 44 cm, and with a mean total length of 30.1 cm (± 9.64 cm) were caught inshore by trammel net in waters less than 30 m deep. Most of the specimens were sampled in and around King Edward Cove in Cumberland East Bay between 1978 and 1980 (Fig. 5).

Description. Fin ray counts were possible on all specimens and the results are given in Table II and Fig. 3. Body measurements are presented in Table III. During the juvenile stage, demersal body characteristics became increasingly pronounced

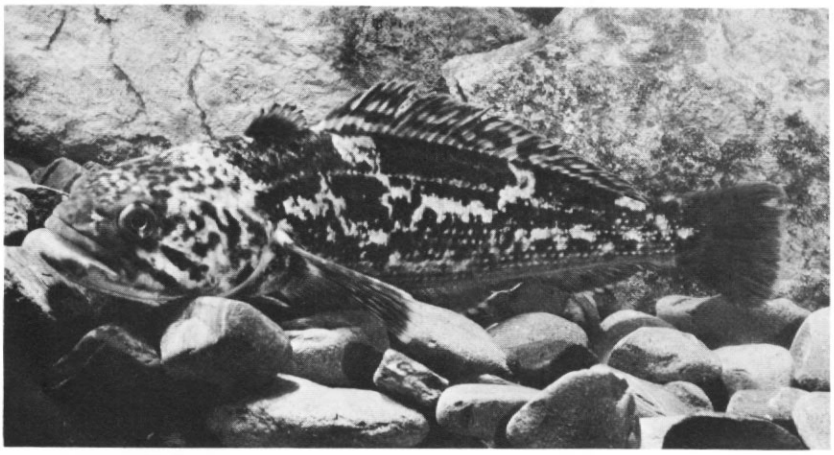

Fig. 5. A juvenile *Notothenia rossii*, 300 mm in length, caught in King Edward Cove, South Geogia, in March 1979.

with a further expansion in girth and a lobed caudal fin to facilitate manoeverability while swimming.

Pigmentation. By this stage the fish have the characteristic marbled pattern over the body. Colour morphs among juveniles varied from pink, orange, brown and dark green through to black. Colour morphs among older juveniles became less distinct and the majority of fish attain a dark olive-black colour by the time they are ready to migrate offshore at about five years of age. The flanks of the fish often had blue iridescent spots interspersed amongst the darker pigment. All fins had some degree of colouration and cross bands were most noticeable on the dorsal, anal and caudal fins.

Adults

Material. Adult specimens with lengths greater than 41 cm were obtained from research fishing vessels and trawlers operating around South Georgia from 1978 to 1980 (Fig. 6).

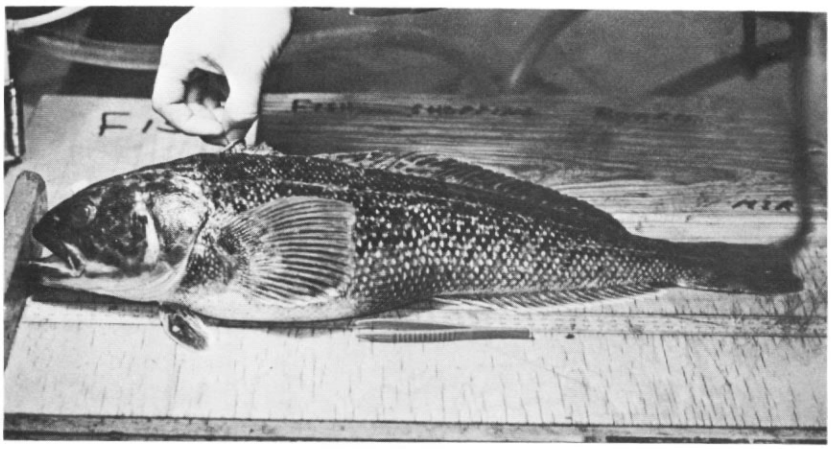

Fig. 6. An adult *Notothenia rossii*, 540 mm in length, caught offshore on the northern shelf area of South Georgia in February 1979.

Description. Fin ray and vertebrae counts of adult *N. rossii* have been investigated by Freytag (1980) and a synopsis of the results is included in Table II. Juvenile *N. rossii* migrate offshore to join the adult population and during this time their growth rate alters considerably due to changes in diet and onset of maturation. The effect of this is to produce a much enhanced growth rate so that the asymptotic length is approached more rapidly. This length is 97.2 cm (Freytag, 1980).

Pigmentation. Distribution of pigment over the body of the adults is similar to the distribution in juvenile fish. However, many of the colour morphs have disappeared by the adult stage. The overall colour of the fish was dark olive-black with the characteristic marbled body pattern (Fig. 6).

Discussion

Morphological changes occur during the development of *Notothenia rossii*. The early fingerling stages are pelagic, but from the brown phase fingerling and during the juvenile stage the fish remain predominantly demersal. This switch from a pelagic to a demersal life form is accompanied by distinct changes in body proportions (Table III). In particular, there is a change in head shape in both length and diameter and a deepening of the body. The relative snout length and pectoral fin length remain mostly unchanged.

Morphometric changes were also taking place among the South Georgia population and this was pronounced during the early stages of development. In particular there was a lack of differentiation between the first and second dorsal fins of young fingerlings (Fig. 1). This accounted for the low dorsal fin ray numbers. As fingerlings progressed to the juvenile phase of their life cycle the fin ray numbers of all fins increased significantly (Table II and Fig. 3). However, by the juvenile stage all fins had fully developed and there was no significant increase in the numbers of fin rays between this and the adult stage.

Table IV. Comparison by the 'student' *t* test of mean fin ray and vertebral counts of *Notothenia rossii* from different locations along the Scotia arc.

Reference	*DI*	*DII*	*PI*	*A*	*V*
4–5	**	0	**	0	–
4–6	0	*	*	*	**
5–6	*	0	**	0	–
4–7	0	0	0	**	–
5–7	**	0	**	0	–
6–7	0	0	**	0	–
4–8	0	*	**	**	**
5–8	*	0	0	0	–
6–8	0	0	**	0	*
7–8	0	0	**	0	–
1–2	**	**	**	**	–
3–4	**	**	**	**	–

References: 1–4, Burchett, South Georgia; 5, Everson (1969), South Georgia; 6, Freytag (1980), South Georgia; 7, Everson (1969), South Orkney Islands; 8, Freytag (1980), South Shetland Islands.

* Difference significant (≥ 1.96, ≤ 2.30);

** Difference highly significant (> 2.30);

0 No significant difference (< 1.96);

– No data.

Table V. Position of recapture and size of *Notothenia rossii* that were marked and released in King Edward Cove, South Georgia.

Date of recapture	*Position*		*Depth (m)*	*Length of fish (cm)*	*Weight of fish (g)*	*Days since release*
	Lat.	*Long.*				
13 October 1979	53° 55′ S	37° 00′ W	–	43	–	338
24 April 1980	55° 59′ S	36° 18′ W	235	42	900	416
26 October 1979	54° 19′ S	35° 47′ W	–	41	–	420
8 August 1980	54° 19′ S	35° 11′ W	–	51	2000	617
7 October 1980	54° 05′ S	36° 15′ W	–	43	1010	762
22 December 1980	54° 45′ S	35° 12′ W	320	45	480	838
12 December 1981	54° 00′ S	36° 17′ W	162	51	1930	1108
17 December 1981	54° 00′ S	35° 50′ W	282	–	–	1127
22 December 1981	54° 01′ S	36° 11′ W	261	45	–	1167

It has been proposed by Freytag (1980) that *N. rossii* from South Georgia, South Orkney Islands and South Shetland Islands represent separate stocks of the same species. Her evidence is based upon the following:

1. A phenotypic difference in the number of vertebrae between the populations of South Georgia and the South Shetland Islands.
2. A difference in growth between the two populations and a lower asymptotic length for fish around the South Shetland Islands.
3. A difference in scale development.
4. A marked difference in the fish carrying encysted nematode larvae in their livers.

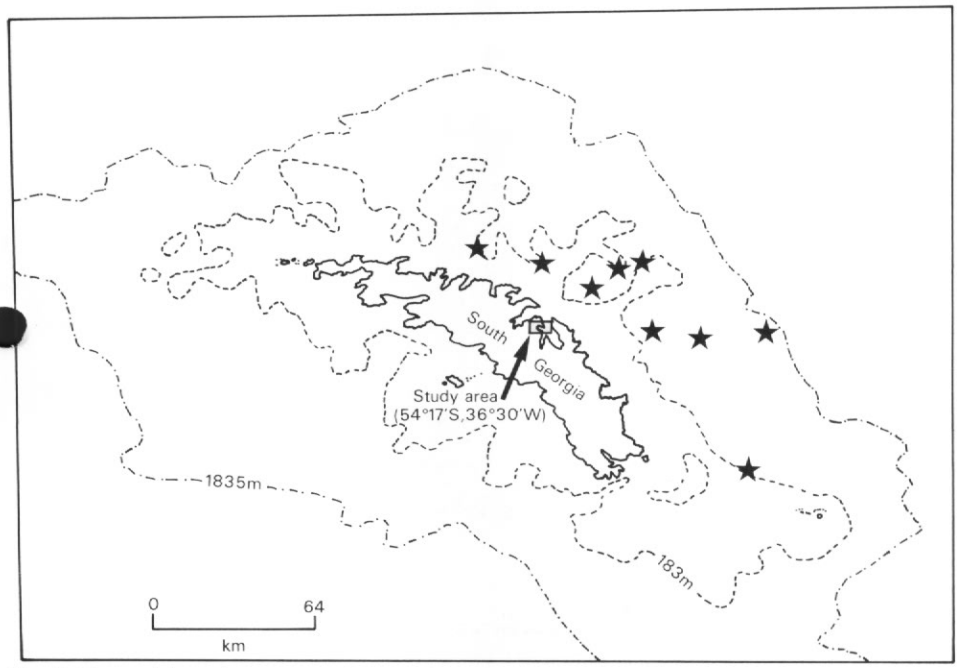

Fig. 7. The positions of recapture of marked *Notothenia rossii* that were released to King Edward Cove, South Georgia, in 1978.

To test this hypothesis that the various stocks were distinguishable morphometrically, statistical comparisons were carried out on the data in Table II. In many cases it was found that there were large morphometric variations among the population at South Georgia. Variations were often greater in the South Georgia population than between populations of different locations (Table IV). According to these observations it would be unreliable to attempt to separate stocks using phenotypic differences in morphometry.

Stock separation on the evidence of differences in scale development and growth can also be misleading. It is possible that these differences are not attributable to genotypic variation but are caused by changes in physical environment. Given the same environmental conditions, fish from different geographical locations may well develop and grow at the same rate.

From the returns of marked fish caught offshore on the shelf area around South Georgia (Table V), it can be seen that juvenile *N. rossii* migrated from the fjords to join the offshore adult population when they reached a length of about 41 cm (five years of age). All marked fish recaptured offshore stayed within the vicinity of the continental shelf along the northern coastline of the island (Fig. 7). However the possibility of exchange between populations in the form of larvae and fingerlings from different areas along the Scotia arc cannot be excluded.

It is known that larvae of *N. rossii* hatch about September (Shcherbich, 1975) and from observations in successive years inshore at South Georgia (1978–81) it was

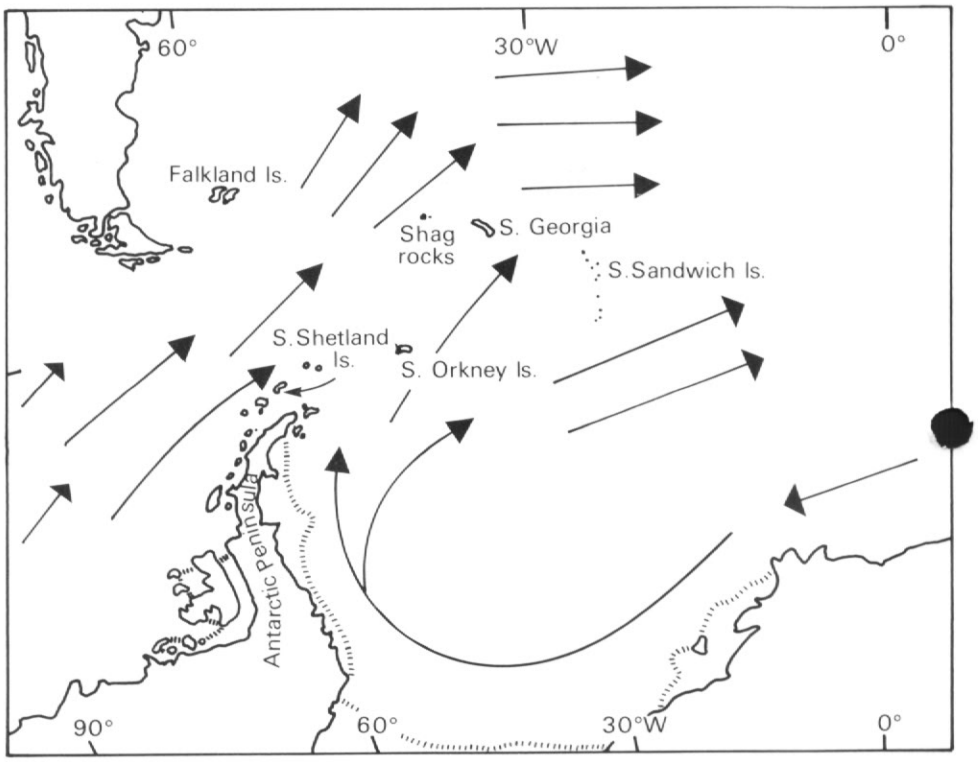

Fig. 8. The Atlantic sector of the Southern Ocean showing major islands along the Scotia arc and surface currents.

discovered that the blue phase fingerlings first entered the fjords along the northern coastline from late January to late February of each year. A period of some 150 days elapsed between hatching and arriving in the fjords. Given the direction and strength of the currents along the Scotia arc (Fig. 8; Hall, 1974) and evidence that fingerlings stay near the surface after hatching (Shcherbich, 1975), it would be possible for fingerlings from the South Shetland Islands and South Orkney Islands to reach South Georgia within the 150-day period. It therefore seems likely that separate populations of *N. rossii* do exist. The adults are local and do not migrate far away from the shelf areas of the islands. Although the level of genetic exchange between the different locations caused by larvae and post-larvae is not known, it seems likely to occur, because these stages are found widely dispersed throughout the Scotia Sea.

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