

# AGE AND GROWTH OF THE ANTARCTIC FISH *NOTOTHENIA ROSSII* FROM SOUTH GEORGIA

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**ABSTRACT.** An investigation of the nearshore population of *Notothenia rossii* was carried out at South Georgia during 1978 and 1979 to study the age, growth, distribution and seasonal variations. The total length ( $L_t$ /mm) to fresh weight ( $W_f$ /g) relationship of a sample of 664 fingerling fish was:  $W_f = 6.495 \times 10^{-7} \times L_t^{3.608}$ ; and for a sample of 2851 juvenile fish was:  $W_f = 1.630 \times 10^{-5} \times L_t^{3.968}$ . *Notothenia rossii* spawned in April–May, hatched about September and entered the fjords along the northern coastline of South Georgia between late January and late February. Length at hatching was estimated to be 15.1 mm. Juvenile *N. rossii* inhabit the nearshore for the first five years of life, then migrate offshore by the time they reach a length of about 410 mm (equivalent to age class V). Using the Von Bertalanffy growth equations, fitted growth curves were calculated and the growth parameters estimated to be:  $k = 0.0673$ ;  $t_0 = -0.589$  years,  $L_\infty = 1255$  mm. There were no significant differences in growth between male and female juveniles nearshore. The sex ratio of males to females was 1:1.39 in age class V and males migrated offshore earlier than females. There were marked seasonal variations in relative condition, with peak relative condition occurring in early winter (April–May:  $\bar{x} = 1.398 \pm 0.106$ ) and poorest relative condition coinciding with the end of winter (November:  $\bar{x} = 1.323 \pm 0.111$ ).

This paper reports on the distribution, age-length composition, life-cycle, growth, relative condition, relative liver size and seasonal variations of the biology of *Notothenia rossii*. The species was chosen for a detailed study because it is the dominant nearshore fish in terms of numbers and biomass (Burchett, 1982; Burchett and others, 1983). Offshore, the adult stock has been intensively fished over the past 16 years.

Work was carried out from Grytviken, South Georgia (54°17'S, 36°30'W) during the period from January 1978 to January 1981 (Fig. 1). The study concentrated upon young 0-group fingerling and juvenile stages in the life-cycle of *N. rossii*. The life-cycle exhibited an inshore migration of pelagic offshore fingerlings, a nearshore demersal juvenile phase and an offshore migration of juveniles to join the demersal pelagic population of adults. These changes in life-cycle and habitat were accompanied by changes in growth and distribution of the fish. A comparison of past work on *N. rossii* by Olsen (1954) and Freytag (1980) is discussed with relation to future stock assessment.

## MATERIALS AND METHODS

Samples of *Notothenia rossii* were collected from Cumberland East Bay, South Georgia, between January 1978 and January 1980. A variety of sampling techniques was employed to obtain the size ranges and condition of fish required.

Nearshore fingerlings of *N. rossii* were attracted to the surface by mercury vapour lamps and caught by using hand-operated dip nets from King Edward Point jetty. Juvenile fish between the age classes I and V were sampled using 27-m-long trammel nets laid in the evening on the seabed and collected the following morning. Adult specimens of *N. rossii* were obtained from research and fishing vessels operating

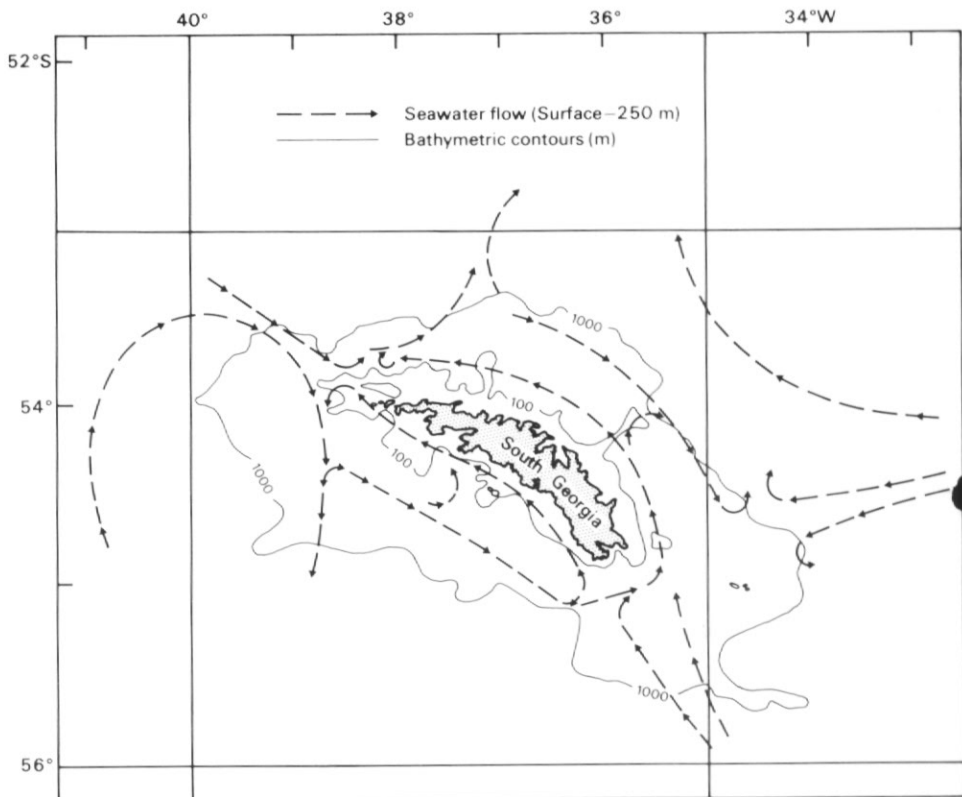


Fig. 1. Diagram of South Georgia showing seawater flow at 0-250 m, and depth contours.

around the island. Offshore fingerlings were caught during the *John Biscoe* cruises as part of the British Antarctic Survey's Offshore Biological Programme (OBP), between 1978 and 1981, each month during the sampling period, eighty to one hundred specimens of *N. rossii* over a wide size range were sampled nearshore. Body measurements were made on the fish by the methods defined by Holden and Raitt (1974). Age was determined using a relatively new method of thin sectioning otoliths embedded in black polyester resin (Bedford, 1983). This enabled a large number of otoliths to be rapidly processed. Two thousand seven hundred and one *N. rossii* specimens were caught and investigated nearshore during the two years.

A detailed study of the growth and distribution of young 0-group and 1-group fish was undertaken in order to clarify some of the confusion that has existed in the past. 0-group fingerlings were used also in controlled laboratory growth experiments over a 135-day period from 14 March to 27 July 1979. Twenty specimens were placed in each of six polythene tanks. An open seawater system provided a flow of fresh seawater through the tanks. Water conditions in the tanks closely followed natural sub-littoral seawater conditions and nearshore environmental seawater temperatures. Seawater temperatures during the growth experiment fluctuated from  $+2.1^{\circ}\text{C}$  in March to  $0.7^{\circ}\text{C}$  in July. Food was provided in the form of finely chopped *N. rossii* muscle. It was supplied to the fish in satiation quantities with a surplus provided at all times. An additional natural food source of planktonic organisms was

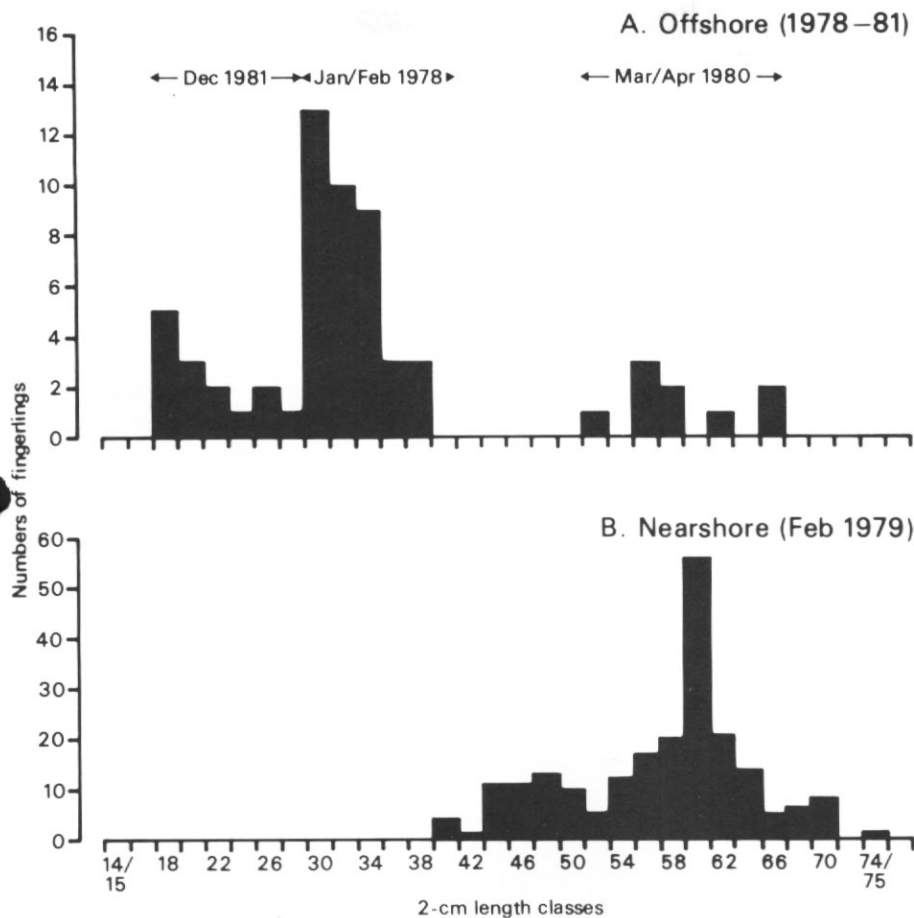


Fig. 2. Length–frequency distribution of *Notothenia rossii* fingerlings sampled offshore and nearshore at South Georgia.

pumped into the tanks with the open flow of seawater. At regular intervals, fish were moved from the tanks and weighed in seawater on an analytical balance to the nearest gram. Total length was measured to the nearest millimetre.

## RESULTS

### *Offshore (pelagic) fingerlings*

Fingerling *N. rossii* can be grouped into either offshore (pelagic or blue phase) or nearshore (fjord or brown phase) specimens. The length frequency of 0-group fingerlings caught offshore is presented in Fig. 2a. This shows that there were several size classes of fingerlings offshore during different years, but this size difference was probably related to different periods of sampling. An analysis of size classes sampled is given in Table I. Most offshore fingerlings were sampled by neuston net at night at depths of  $<0.5$  m (M. G. White, personal communication) which agrees with the findings of Shcherbich (1975).

Table I. Length (mm) and weight (g) measurements of nearshore and offshore fingerlings of *Notothenia rossii* sampled at South Georgia.

Fingerling population	Date	Measurement	$\bar{x}$	sd	n
Laboratory growth experiment	1979	Length	69.3	9.56	220
Laboratory growth experiment	1979	Weight	3.66	2.32	220
Nearshore natural population	Mar 1979	Length	61.9	4.64	107
Nearshore natural population	Mar 1979	Weight	1.95	0.51	107
Offshore population	1978	Length	33.0	2.54	40
Offshore population	1980	Length	59.3	4.69	9
Offshore population	1981	Length	21.0	3.14	13

To investigate the possibility of fingerlings coming from different spawning seasons, scales and otoliths of 14 fjord specimens caught on 2 March 1979 and 110 fjord fingerlings caught on 19 April 1979 were examined. All otoliths observed whole under the microscope had opaque nuclei and no hyaline increments. On the equivalent scale structures, 12.1% had the first fast growing (summer) zone and 87.9% showed initiation of the first annual check.

#### Nearshore (fjord) fingerlings

It is known that larvae of *N. rossii* hatch out between September and November (Shcherbich, 1975) and this has been confirmed by North and others (1979). Each summer there was an influx of pelagic offshore fingerlings into the fjords along the northern coastline of South Georgia. From observations in seven successive years, fingerlings of *N. rossii* arrived in large numbers in King Edward Cove between late January and late February of each year. Fingerlings arrived nearshore at South Georgia have a mean total length of  $61.9 \pm 4.6$  mm and a total weight of  $1.95 \pm 0.51$  g (Table I). Between 1978 and 1981 fingerlings *N. rossii* were caught offshore from December to April and nearshore from December to July and in September and October. Peak nearshore catches of fingerlings occurred in February and March, after which the numbers declined until only occasional specimens were caught.

#### Growth of fingerlings

Fingerling *N. rossii* were sampled soon after they arrived nearshore (Fig. 2b) and used in laboratory growth experiments. Linear regressions of mean lengths and mean weights against time were calculated (Table II) and the annual growth increments estimated. It was calculated that the annual increment in total length for laboratory reared fingerlings was  $118 \pm 14$  mm, while the natural population had an estimated annual increment of  $109 \pm 21$  mm. A regression of length against time was calculated for all fingerlings obtained offshore and nearshore (Fig. 3). Extrapolation of the regression line of length against time back to a hatching length of 15.1 mm, bisected the time axis at September.

Table II. Length (mm), weight (g) and time (days) relationships of fingerling *Notothenia rossii* sampled at South Georgia.

Fingerling population	Date	Equation
Nearshore/offshore populations	1978-1981	$L_t = 0.220t + 28.8$
Laboratory growth experiment	1979	$L_t = 0.153t + 61.7$
Laboratory growth experiment	1979	$W_f = 0.039t + 1.74$

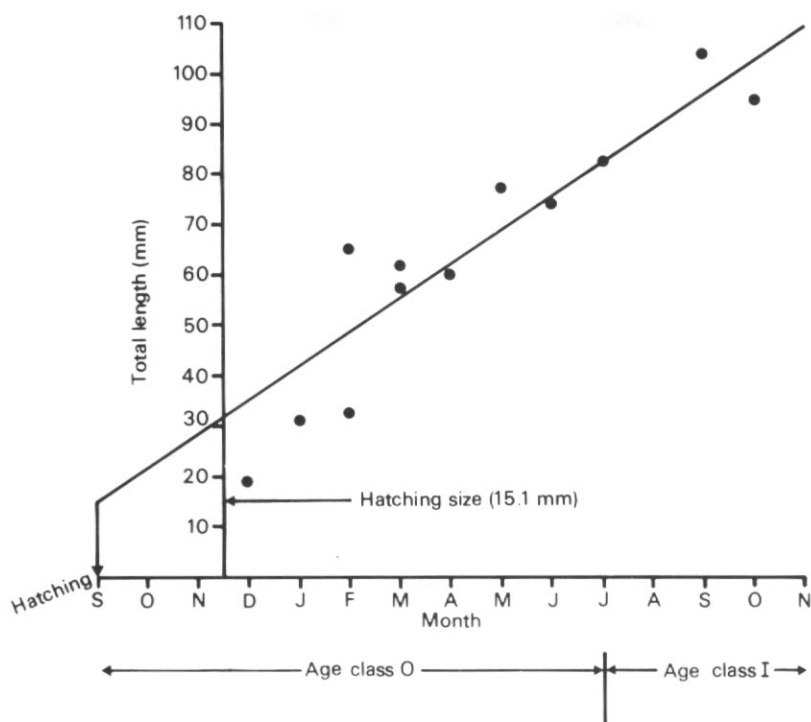


Fig. 3. Linear regression of mean total lengths (mm) against time (months) for all *Notothenia rossii* fingerlings sampled at South Georgia between 1978 and 1979.

#### *Age composition and length-frequency of juvenile N. rossii*

The nearshore population of *N. rossii* was sampled for its age composition and results for the years 1978 and 1979 are presented in Table III. Age class III dominated the age composition in 1979 (55.5%) in terms of numbers of fish, while in 1978 age class IV was the most abundant (46.8%). With data from both years combined, age class III was the most abundant year class (49.6%) in the nearshore population of juvenile *N. rossii*. The combined length-frequency distribution with age of juvenile *N. rossii* at South Georgia caught by trammel net is presented in Table IV and the length frequency polygon at specific ages is given in Fig. 4. There are distinctive peaks according to the age class. They included a peak at 26 cm for age class III; 30 cm for age class IV and 38 cm for age class V. Fish below age class III were not adequately represented in trammel net hauls. However data of age classes III to V allowed a length range to be assigned to each age class. Based upon one centimetre length intervals, age class III had a length range of 23–29 cm, age class IV a range of 29–38 cm and age class V a range of 37–45 cm. In an age length distribution, fish of a certain size will sometimes occur in more than one age class as indicated by shaded areas in Fig. 4. Using one-centimetre length intervals, the overlap between age classes in the nearshore *N. rossii* population sample occurred at 23 cm (between age classes II and III); 28–29 cm (between age classes III and IV) and 37–38 cm (between age classes IV and V).

The length-frequency distribution of the nearshore population sampled by trammel net at three-monthly intervals from January 1978 to October 1979 is presented in Fig. 5 and for each year class is presented in Fig. 6. It is clear that age

Table III. Age composition of juvenile *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979.

Year	Age classes												Total
	I		II		III		IV		V		VI		
	n	%	n	%	n	%	n	%	n	%	n	%	
1978	1	0.1	24	1.6	673	45.2	697	46.8	94	6.3	0	0	1489
1979	0	0	23	2.1	605	55.5	382	35.0	78	7.2	2	0.2	1090
1978/1979	1	0.03	47	1.8	1278	49.6	1079	44.8	172	6.7	2	0.07	2579

Table IV. Age-length composition of *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979.

2-cm length interval	Age classes																				
	1978						1979						1978/1979								
	I	II	III	IV	V	n	I	II	III	IV	V	VI	n	I	II	III	IV	V	VI	n	
14-15	1					1							0	1							1
16-17		4				4		3					3		7						7
18-19		7				7		4					4		11						11
20-21		8				8		12					12		20						20
22-23		5	11			16		4	17				21		9	28					37
24-25			104			104			126				126			230					230
26-27			303			303			276				276			579					579
28-29			255	48		303		186	28				214			441	76				517
30-31				231		231			128				128				359				359
32-33				180		180			91				91				271				271
34-35				145		145			79				79				224				224
36-37				91	3	94			54	1			55				145	4			149
38-39				2	48	50			2	40			42				4	88			92
40-41					22	22				20			20					42			42
42-43					12	12				11			11					23			23
44-45					8	8				6			6					14			14
46-47					1	1						2	2					1	2		3
Total	1	24	673	697	94	1489		23	605	382	78	2	1090	1	47	1278	1079	172	2		2579

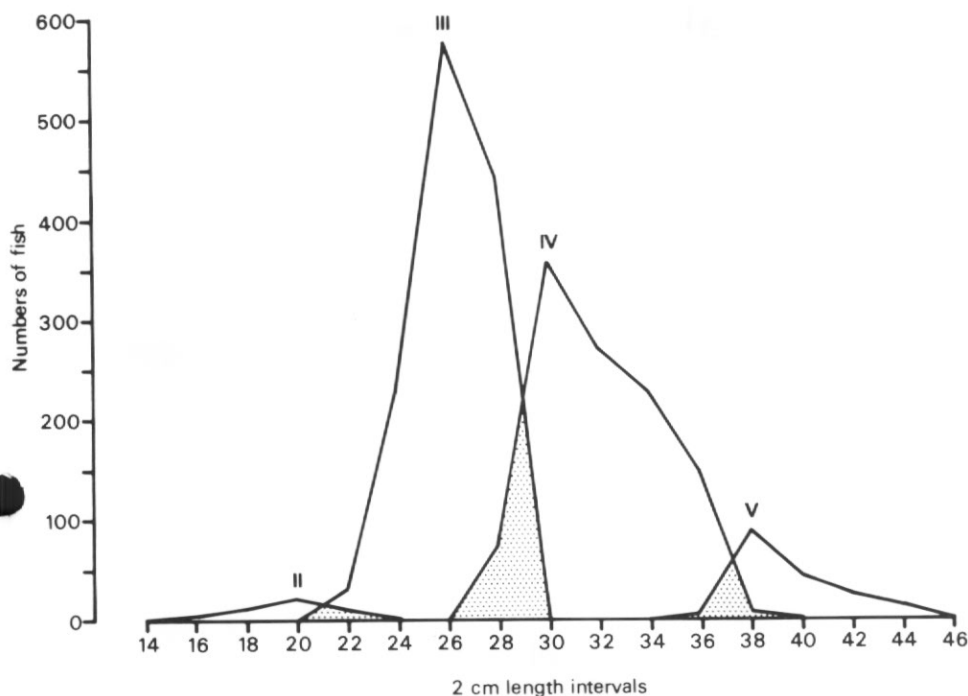


Fig. 4. Age-frequency polygon of *Notothenia rossii* caught nearshore by trammel net at South Georgia during 1978 and 1979.

class IV was stronger in 1978 when compared with 1979 and in 1979 there were fewer larger sizes of fish more than 36 cm long, especially among specimens belonging to age class V.

#### Length-weight relationships

The total length to fresh weight relationship ( $W_f = bL^k$ ) was calculated for nearshore *N. rossii* during different years and seasons and also for both sexes and various stages of development. Results of log length against log weight are presented in Table V. It was found that the constant  $k$  of the length-weight relationship ( $W_f = bL^k$ ) varied according to the stage in the life-cycle of *N. rossii*. The constant  $k$  varied from .4 in brown phase fingerlings to 2.7 in juvenile fish of age class III. However, as the juveniles became older and grew in size, the constant approached the value of  $k = 3$  (age class V,  $k = 2.98$ ) where growth is isometric. There were significant differences of the length to weight relationship between different years, winters and summers, blue and brown phase fingerlings and between different age classes when  $p = 0.05$ . Therefore there is no single length to weight equation which will represent all juvenile *N. rossii*. However, there was no significant difference between juvenile males and females.

#### Morphometric transformations

Since many papers express the growth of *N. rossii* using total length, while others use standard length, a knowledge of the relationship between the two measurements is useful for comparative purposes. Conversions of different body measurements for *N. rossii* of age classes I to IV from South Georgia are given in Table VI.

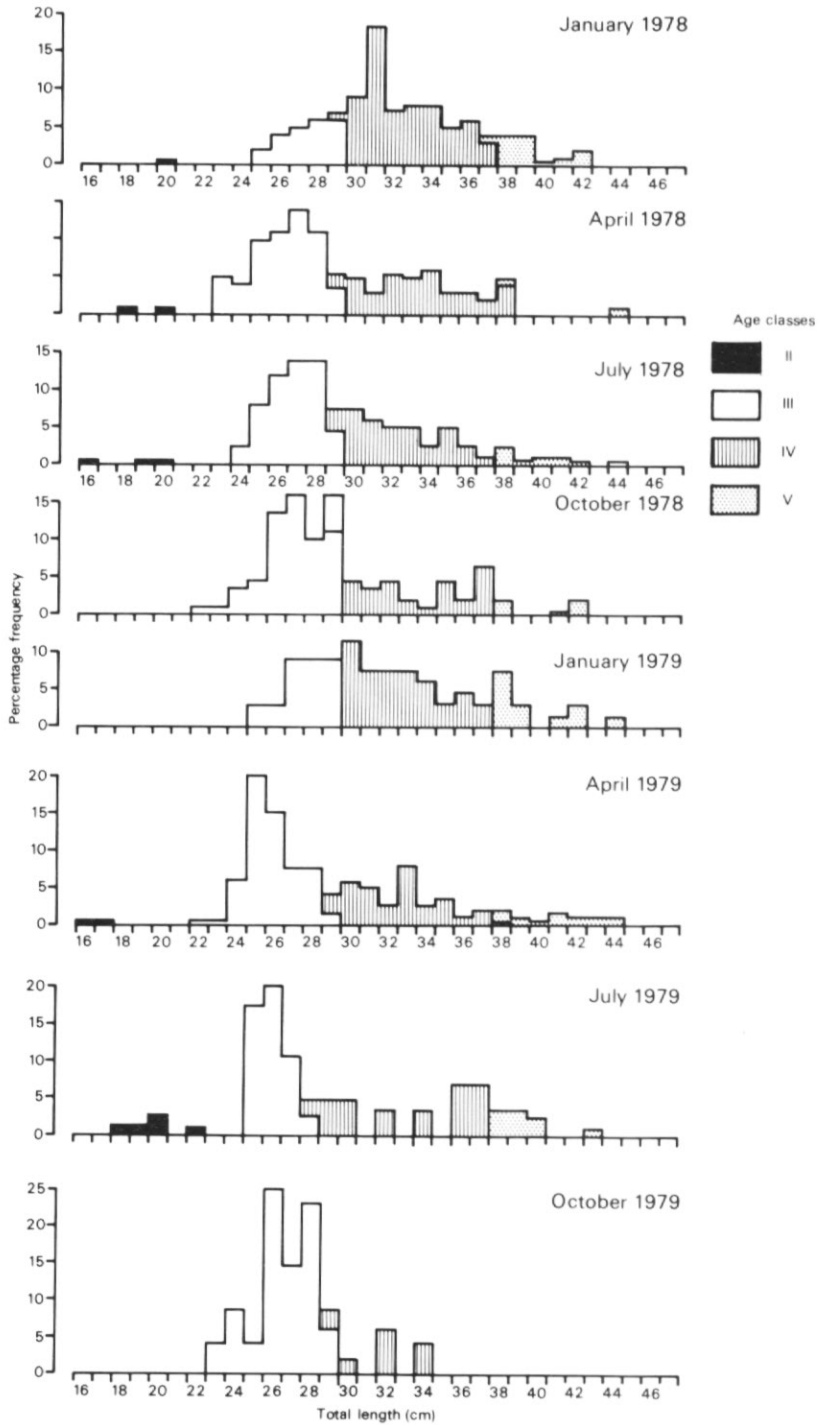


Fig. 5. Length-frequencies at age of *Notothenia rossii* sampled at three-monthly intervals, nearshore at South Georgia.



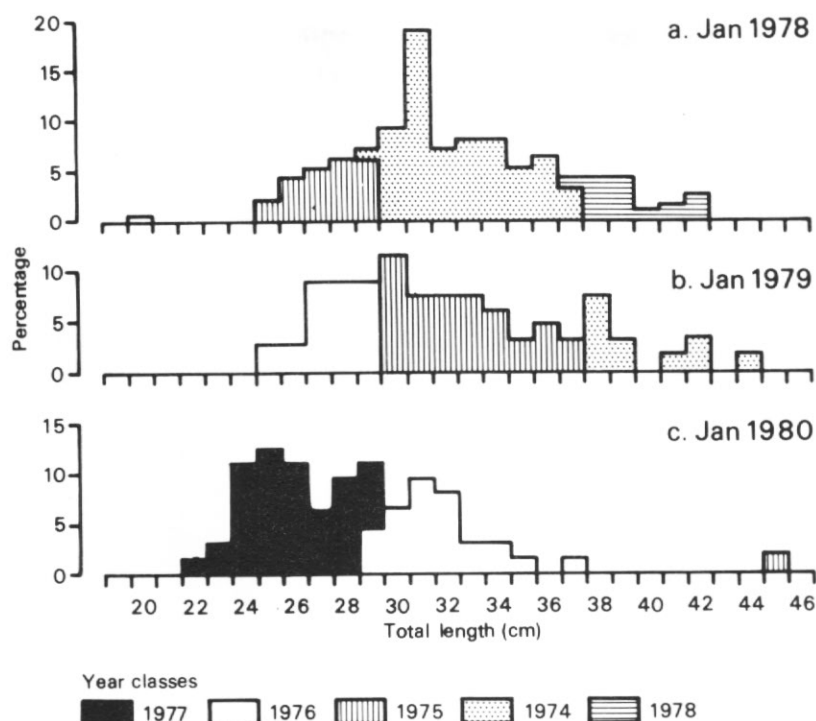


Fig. 6. Year-class composition in January for three consecutive years between 1978 and 1981 of the nearshore population of *Notothenia rossii* sampled at South Georgia.

Table V. Length to weight relationships (length/mm; weight/g) of *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979.

	Length/weight relationship $\pm$ SE	n	$r^2$
1978	$2.39 \times 10^{-5} \times L^{2.900 \pm 0.017}$	1483	0.95
1979	$1.12 \times 10^{-5} \times L^{3.037 \pm 0.020}$	1092	0.95
Blue fingerlings	$2.81 \times 10^{-6} \times L^{3.114 \pm 0.096}$	110	0.96
Brown fingerlings	$1.88 \times 10^{-6} \times L^{3.403 \pm 0.112}$	80	0.95
Age class II	$1.32 \times 10^{-6} \times L^{3.435 \pm 0.208}$	85	0.77
Age class III	$7.51 \times 10^{-5} \times L^{2.696 \pm 0.043}$	1397	0.74
Age class IV	$1.90 \times 10^{-5} \times L^{2.939 \pm 0.047}$	1176	0.77
Age class V	$1.52 \times 10^{-5} \times L^{2.983 \pm 0.136}$	192	0.72
Juvenile males	$1.76 \times 10^{-5} \times L^{2.953 \pm 0.021}$	1274	0.94
Juvenile females	$1.69 \times 10^{-5} \times L^{2.964 \pm 0.016}$	1320	0.96

### Growth curves

A Von Bertalanffy growth curve of length against age for *N. rossii* using a non-linear, weighted, least squares regression with the residuals weighted by  $\sqrt{n}/\bar{L}$  where  $n$  is the sample size and  $\bar{L}$  is the mean length in each age class. Only age classes II to X were used for the calculations as age class 0 did not conform to the sampling and age class I was not truly represented. A comparison of fitted growth curves is shown in Fig. 7. The growth parameters,  $L_{\infty}$ ,  $k$  and  $t_0$  were estimated to be:  $L_{\infty} = 1255$  mm,  $k = 0.0673$  and  $t_0 = -0.589$  years. The growth parameters were substituted into the expression:

$$L_t = L_{\infty} [1 - \exp\{-k(t - t_0)\}].$$

Table VI. Growth transformations for the conversions of different body measurements of *Notothenia rossii* sampled at South Georgia;  $L_t$  = total length,  $L_s$  = standard length,  $W_t$  = total weight,  $W_v$  = viscera free weight.

Conversion factors		$n$	$r^2$
$L_t = (L_s \times 1.117) + 5.4$	$L_s = (L_t - 5.4)/1.117$	2852	0.98
$W_t = (W_v \times 0.729) + 147.8$	$W_v = (W_t - 147.8)/0.729$	2551	0.61

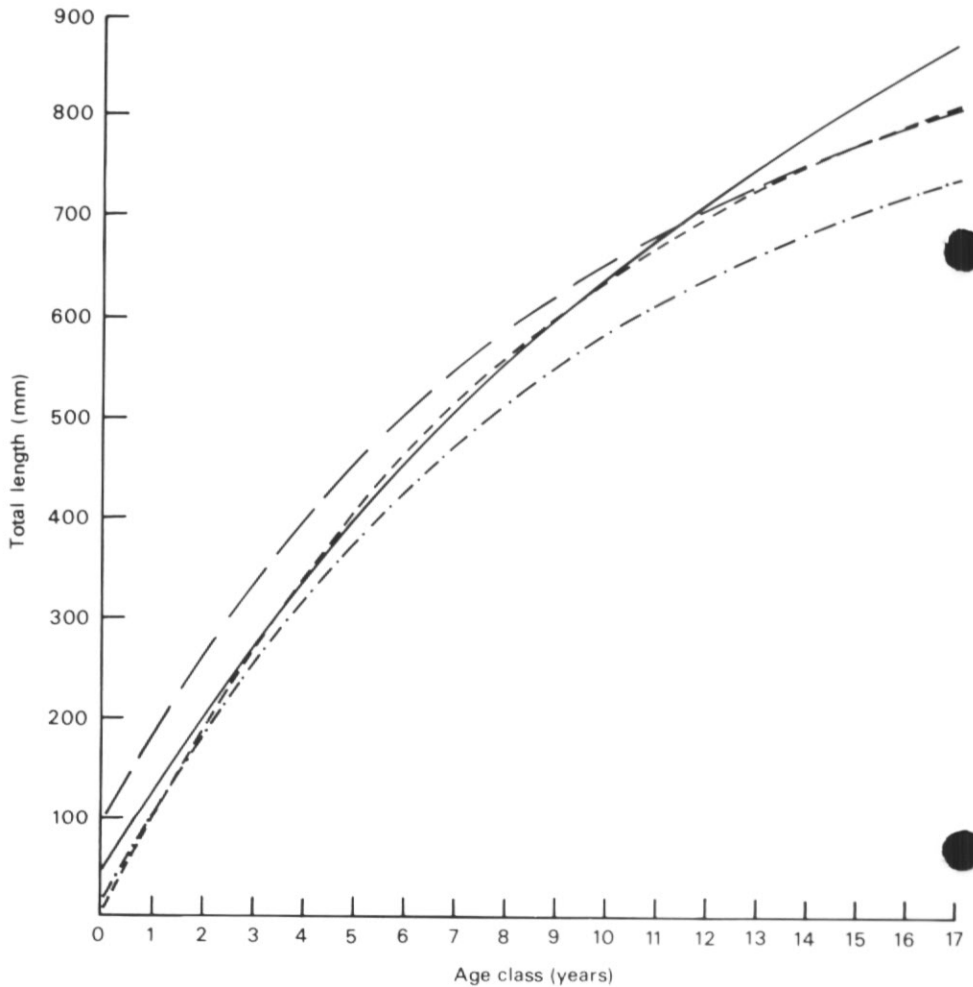


Fig. 7. Length (mm) plotted against age for *Notothenia rossii* using fitted Von Bertalanffy curves: ——— Olsen (1954), South Georgia; - - - - Freytag (1980), South Georgia; ——— Burchett (this paper), South Georgia; ····· Freytag (1980), South Shetland Islands.

Therefore, the growth equation for *N. rossii* at South Georgia was:

$$L_t = 1255 [1 - \exp(-0.0673) \{t - (-0.589)\}]$$

The growth parameters calculated for the growth curves and a comparison with other published work are given in Tables VII and VIII.

Table VII. Comparison of mean lengths (mm) at each age class for *Notothenia rossii* sampled nearshore at South Georgia.

Age class	South Georgia	South Georgia	South Georgia	South Shetland Islands	South Georgia
	Olsen (1954) ♂	Olsen (1954) ♀	Freitag (1980) ♂ + ♀	Freitag (1980) ♂ + ♀	Burchett (this paper) ♂ + ♀
0	70	70	—	—	54
I	120	120	—	—	133
II	240	240	192	—	197
III	290	290	269	—	271
IV	340	340	334	—	330
V	450	450	428	401	404
VI	510	530	458	438	471
VII	570	600	513	469	513
VIII	600	630	547	518	546
IX	630	660	596	553	589
X	660	690	643	561	630
XI	680	720	—	611	—
XII	700	740	670	645	—
XIII	700	740	—	677	—
XIV	—	—	—	—	—
XV	—	—	790	—	—

Table VIII. Comparison of growth parameters used in the Von Bertalanffy growth equations for *Notothenia rossii* ( $L_{\infty}$  in mm).

Location	Sex	K	$t_0$	$L_{\infty}$	Reference
South Georgia	♂ + ♀	0.067	-0.589	1255	Burchett (this paper)
South Georgia	♂ + ♀	0.107	-0.007	972	Freitag (1980)
South Shetlands	♂ + ♀	0.112	-0.099	862	Freitag (1980)
South Georgia	♂	0.119	-0.960	882	Olsen (1954)
South Georgia	♀	0.108	-0.970	971	Olsen (1954)

### Sex ratio

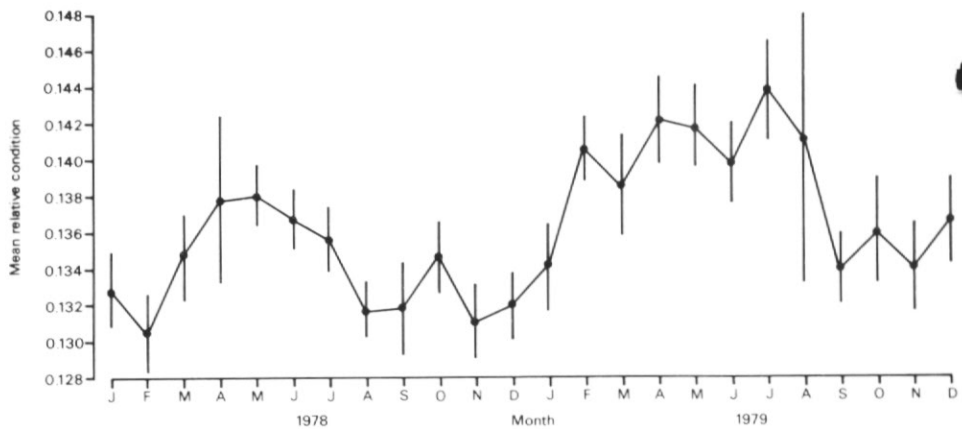
Data for sex ratio determination were available for 2244 specimens from age classes II to V. The distribution of the sexes according to age class is presented in Table IX. In the nearshore population, the ratio of males to females became larger as age increased. By age class V there was a significant difference between numbers of males and females ( $\chi^2 = 4.22$ ) with 8.1% more females than males. This evidence suggested that males probably migrated to join the offshore adult population slightly earlier than the females.

### Relative condition

The mean relative condition ( $100W/L^3$ ) for juvenile *N. rossii* was calculated using about 100 specimens each month. Size of gonads made no significant difference to the relative condition as they contributed less than 1% of body weight. Therefore condition could not be used as an indicator to determine time and duration of gonad maturation. Mean monthly relative condition of *N. rossii* juveniles over a 24-month period using 2573 specimens is shown in Fig. 8. During 1978 relative condition was

Table IX. Sex ratio for each age class of *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979.

Age class	$n \delta$	$n \varphi$	Ratio $\delta : \varphi$	Significant difference (5% levels)
II	23	21	1:0.91	No
III	543	562	1:1.03	No
IV	452	483	1:1.07	No
V	67	93	1:1.39	Yes
Total	1085	1159	1:1.07	No

Fig. 8. Annual variation of mean relative condition of juvenile *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979. Vertical bars represent 95% confidence limits.

high from April ( $\bar{x} = 1.378 \pm 0.264$ ;  $n = 129$ ) to July ( $\bar{x} = 1.375 \pm 0.125$ ;  $n = 159$ ). This was a period of four months compared with seven months in 1979 when relative condition was high from February ( $\bar{x} = 1.407 \pm 0.111$ ;  $n = 133$ ) to August ( $\bar{x} = 1.411 \pm 0.418$ ;  $n = 104$ ). During 1978 the overall relative condition amongst the juvenile population sampled was lower ( $\bar{x} = 1.339 \pm 0.138$ ;  $n = 1481$ ) than in 1979 ( $\bar{x} = 1.389 \pm 0.175$ ;  $n = 1091$ ). Therefore there were clear differences in relative condition of the nearshore *N. rossii* population within the two year study period, and in 1979 the population had relatively better condition than the population of the previous year.

#### Relative liver size (HSI)

Relative liver size (hepatosomatic index,  $100W_l/W_t$ ) was calculated for each fish sample from the nearshore population. Each month the mean relative liver size was calculated and the annual fluctuations are shown in Fig. 9. Maximum relative HSI was in April of 1978 and March of 1979. Therefore mean relative HSI remained high from March to August and low from September to February.

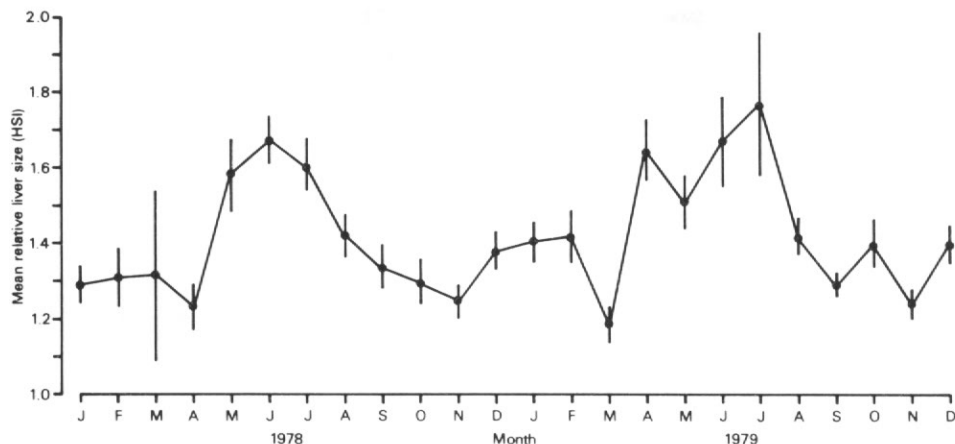


Fig. 9. Annual variation of mean relative liver size (HSI) of juvenile *Notothenia rossii* sampled nearshore at South Georgia during 1978 and 1979. Vertical bars represent 95% confidence limits of the mean.

#### DISCUSSION

The life-cycle of *Notothenia rossii* at South Georgia involves three major phases; an offshore pelagic fingerling, a nearshore demersal juvenile and an offshore demerso-pelagic adult. Adult *N. rossii* have been described as spawning demersally on the continental shelf surrounding South Georgia, at depths of 120m to 350m (Permitin and Silyanova, 1971). Offshore, the adult population consists mainly of age classes VI to XVI, attaining an observed maximum length in the region of 900 mm (Shust and Silyanova, 1971). Spawning takes place around April and May (Shcherbich, 1975) and the fertilized eggs have a mean diameter of 4.8 mm (Permitin and Silyanova, 1971). Hatching occurs about September and the pelagic offshore fingerlings inhabit the surface waters (Shcherbich, 1975).

It has been suggested by Shcherbich (1975) that offshore fingerlings contain groups from two different spawning seasons. Therefore there would be overwintering fingerlings at sea, comprising two age classes (0-group and 1-group fish). However, on examination of the scales from fingerlings arriving at the coast, it was found that the scales were at the stage of first annulus formation. Equivalent otolith structures had only opaque nuclei and no evidence of winter growth. From the examination of these structures *N. rossii* showed no evidence of winter growth zones, therefore the concept of fingerlings overwintering at sea is not supported by these observations. However, slight differences in size of offshore fingerlings could be the result of different growth rates and temporal differences in spawning time and spawning locations on the continental shelf surrounding South Georgia. Offshore fingerlings caught during the cruises of *John Biscoe* were found to be in the top 15 m of the water column at night. This type of behaviour may be linked to pelagic surface feeding on plankton, and surface currents may assist dispersal of the young fish along the northern coastline of South Georgia (Fig. 1).

Pelagic 0-group fingerlings migrate inshore and enter Cumberland East Bay from late January to late February. This was observed in seven successive years from 1975 to 1982. Maximum influx of fingerlings occurred in the first two or three week period after first arrivals were observed, after which the numbers declined until only occasional specimens were caught. Observation of time scale and periodicity of

fingerling capture during the year, supported the idea that there were some differences in spawning time and possible spawning locations around South Georgia.

Growth studies in the laboratory and from the field using young 0-group and I-group fingerling *N. rossii*, demonstrated that the young stages had the fastest growth rates. Subsequently, growth rate declined as the age of the fish increased. A comparison between the regression coefficients of the length-weight relationships at the beginning and end of the laboratory growth experiment showed that length to weight remained constant during the experimental period. A further comparison of regression coefficients between laboratory maintained fingerlings and nearshore fingerlings caught on arrival at the coast gave a highly significant difference between the growth rates of laboratory reared fingerlings and fingerlings sampled from the natural population. Caution should therefore be exercised when extrapolating growth data from the laboratory to the natural situation. Using the linear regressions of length and weight against time, an annual incremental increase in length of *N. rossii* during the first year of life was estimated to be  $118 \text{ mm} \pm 13.7$  for laboratory fingerlings and  $109 \text{ mm} \pm 21.1$  for fingerlings sampled from the natural population.

The length of *N. rossii* larvae at hatching was estimated from the approximation that hatching length equals circumference of the egg at spawning. For *N. rossii* at South Georgia, with a mean egg diameter of 4.8 mm (Permitin and Silyanova, 1971), the equivalent hatching length would be 15.1 mm. Extrapolation of the regression line of length against time (Fig. 3) back to the hatching length of 15.1 mm, bisected the time axis at September. This compared favourably with the hatching period cited in previously published literature for South Georgia (Permitin and Silyanova, 1971; Burchett and others, in press).

The length frequency with age of juvenile *N. rossii* sampled by trammel net (Fig. 5), clearly shows that fish below age class III were under-represented in the net hauls. This scarcity could be attributed to the selective action of the trammel nets used with mesh sizes too large to retain the smaller fish or to migration and possible dispersal of fish according to size. The reduction in numbers of fish belonging to age class IV and subsequent reduction in age class V nearshore (Fig. 4) was primarily caused by fish migrating to join the adult offshore population on the continental shelf surrounding South Georgia. Evidence from length frequency distributions with age at three monthly intervals (Fig. 5) suggests that an offshore migration of the larger individuals from the nearshore was taking place in late winter and early spring. However it must be remembered that mortality may be greatest amongst the fish population towards the end of winter and beginning of spring when fish were at their poorest condition (Fig. 8). Examination of selected length frequencies from different year classes (Fig. 6) demonstrated that *N. rossii* were taking about five years to pass through the nearshore population. Year classes of 1974 and 1977 were particularly strong with higher proportions of fish in some length groups compared to length groups of other year classes (Figs. 5 and 6).

The length to weight relationship ( $W = bL^k$ ) was calculated for 3530 juvenile *N. rossii*, 664 fingerlings and for a limited number of specimens of age class VI and older (Table V). When considering the constant  $k$  in the length to weight relationship,  $k$  is equal to the regression coefficient. This equation has the special case where  $k = 3$  when growth is isometric and specific shape remains constant. However these conditions are rarely completely satisfied, especially during early stages of development when the body shape of the fish may be undergoing morphological changes. During the early development of *N. rossii*, changes in body proportions take place as the fish adapt to a new habitat and diet (Burchett, 1983). The constant  $k$  varied from 3.4 in brown phase fingerlings to 2.7 in juvenile fish of age class III. However, as

juveniles became older the constant  $k$  approached the isometric value of  $k = 3$ . These changes in the life-cycle and morphology were most rapid in the young fish (Burchett, 1983). Development after hatching from larva to recognizable demersal juveniles took 15 months.

A comparison of regression coefficients (Table V) showed significant differences between the length to weight relationship of fish in 1978 and 1979, between sizes of fish in successive summers and winters and between the different developmental stages in the life-cycle of *N. rossii*. This suggests annual and seasonal variation in year class growth and survival. However, there was no significant difference between the length to weight relationship between juvenile males and females nearshore at South Georgia.

The growth curve of Burchett (this paper) fitted by the Von Bertalanffy growth equation using a weighted regression (Fig. 7) for *N. rossii* at South Georgia was similar to that of Freytag (1980) between age classes 0–11 years. However, the curves of Freytag (1980) and others were fitted using the traditional Ford Walford plot. An asymptotic length of 1255 mm was calculated for *N. rossii* at South Georgia (Burchett, this paper) compared to Freytag's (1980) estimate of 972 mm. Shust and Silyanova (1971) found the maximum length of *N. rossii* adults attained offshore in the catches was in the region of 900 mm, which had an equivalent age of 16 years. This compares well with the length at age read from the fitted curve of Burchett (this paper) with a 16-year-old fish having a length of 850–875 mm.

Olsen (1954) suggested that at South Georgia, mature females grew faster than mature males and females reached a higher asymptotic length of 900 mm compared to 800 mm for males. Freytag (1980) demonstrated that fish from the South Shetland Islands grew at a slower rate than the South Georgia population and reached a lower asymptotic length of 862 mm (for South Shetland Islands) compared to 972 mm at South Georgia. It was interesting to note that a combined fitted curve of males and females taken from Olsen's (1954) data for South Georgia, showed a higher length at age relationship for fish below age class X, compared to the fitted curves of Freytag (1980) and Burchett (this paper). These deviations at the lower part of the fitted curve by Olsen (1954) were probably due to his method of age assessment. It was interesting that the two different ageing techniques, those of Freytag (1980) who used scales and Burchett (this paper) who used otoliths, gave similar results. This should be beneficial for interpreting and comparing future stock assessments of *N. rossii*.

The mean size of the juvenile fish population sampled nearshore showed seasonal and annual variations of length and weight. Using combined data of 1978 and 1979, the sampled fish population was at its minimum size in May ( $\bar{x} = 288 \text{ mm} \pm 37.1$ ;  $n = 219$ ;  $\bar{x} = 351 \text{ g} \pm 152$ ;  $n = 219$ ) and its maximum size was in January ( $\bar{x} = 325 \text{ mm} \pm 41.8$ ;  $n = 232$ ;  $\bar{x} = 481 \text{ g} \pm 212$ ;  $n = 226$ ). The nearshore juvenile population of *N. rossii* sampled was of relatively larger size in 1978 ( $\bar{x} = 306 \text{ mm} \pm 43.6$ ;  $n = 1489$ ;  $\bar{x} = 407 \text{ g} \pm 183$ ;  $n = 1481$ ) compared with that sampled in 1979 ( $\bar{x} = 229 \text{ mm} \pm 46.7$ ;  $n = 1091$ ;  $\bar{x} = 402 \text{ g} \pm 216$ ;  $n = 1091$ ). Therefore there were more larger fish present in the nearshore population during the summer months and smaller fish present during the winter months.

Relative condition ( $100 W/L^3$ ) of a fish is often useful to indicate time and duration of gonad maturation and to follow the fluctuation in feeding activity over an extended period. However, gonads of all nearshore *N. rossii* were immature, therefore the reproductive cycle could not be followed by this method. Relative condition of the nearshore *N. rossii* population sampled demonstrated strong seasonal and annual variation (Fig. 8). Peak relative condition occurred in May 1978 and July

1979, with a combined two year peak in April–May. Poorest condition of *N. rossii* nearshore was recorded in November 1978 and September 1979, with a combined two-year low in November. From a comparison of mean relative condition, there were significant differences in relative condition between summer and winter of the same year, summers and winters of successive years and between each year. During 1978 the overall relative condition amongst the juvenile population sampled was lower than in 1979. Therefore, there were clear differences in relative condition of the nearshore *N. rossii* population within the two-year study period, and in 1979 the population had relatively better condition than the population of the previous year.

Annual and seasonal variations of mean relative liver size (HSI) closely followed fluctuations of mean relative condition although the peak HSI normally occurred two months later than peak relative condition (Fig. 9). Maximum relative HSI was in June of 1978 and July of 1979, while minimum relative HSI was in April of 1978 and March of 1979. From combined data of 1978 and 1979, peak relative HSI occurred in July and minimum relative HSI was in November. Therefore, mean relative HSI remained high from March to August and low from September to February.

It is possible that the liver was being used as an energy store, building up reserves in late summer after the fish had been feeding intensively. During the winter months these reserves would be utilized gradually through the winter. Seasonal fluctuations in lipid content have been demonstrated in *Chorismus antarcticus* at South Georgia (Clarke, 1977). It is known that juvenile *N. rossii* sampled nearshore, feed mostly on amphipods, isopods, gastropods and algae (Burchett, 1982) and these groups of invertebrates are available to the fish all year round. However, it is probably that like *Chorismus*, the calorific contents of the bodies of these invertebrates fluctuate throughout the year. This is the most likely cause of seasonal variations in growth rate, condition and liver size of nearshore juvenile *N. rossii*.

The sex ratio of the nearshore population of *N. rossii* sampled at South Georgia showed a larger proportion of females with increasing age of fish (Table IX). Overall there were 3.4% more females than males. Assuming a 1:1 ratio at all ages in the population, it seems likely that males moved offshore earlier than the females to join the adult population, where it is known males mature one year earlier than females (Olsen, 1954). This offshore migration at age class V was thought to occur in late winter and early spring when there were fewer larger sizes of fish present in the nearshore population.

#### CONCLUSIONS

Growth, behaviour and morphology of young *N. rossii* were more complex than expected. They were profoundly affected by migration and sudden changes in the life-cycle of the species. This study has clarified much of the early growth and behaviour of *N. rossii*.

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