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Introduction and extinction of brown trout (*Salmo trutta* L.) in an impoverished subantarctic stream

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Abstract: Brown trout were introduced to the Van den Boogaard River on subantarctic Marion Island in 1964, and a small population became established. The last individual was seen in 1984, and the species is now considered to be extinct on the island. Their diet was exclusively allochthonous, with snails and spiders predominating. Ages estimated at six to eleven years showed that spawning must have occurred since the original introduction. Since the Van den Boogaard River enters the sea via a waterfall, it is postulated that trout were not able to practice an anadromous life-style, and that this, as well as other factors connected with the impoverished nature of the stream, led to dwarfing of the resident population. No further introductions of alien fish to Marion Island should be contemplated.

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Introduction

Subantarctic islands support relatively pristine ecosystems, which unfortunately have often been affected by the introduction and establishment of alien flora and fauna in the past (e.g. Holdgate & Wace 1961, Holdgate 1967, Lesel & Derenne 1975, Leader-Williams 1985). At several subantarctic islands attempts are now being made to eradicate terrestrial alien species but less attention has been paid to the desirability of control or eradication of aquatic aliens, such as fish. Attempts to introduce salmonid fish, not all successful, have been made at a number of islands in the Southern Ocean, including the Falkland Islands (two species), Iles Kerguelen (six species), Ile de la Possession, Iles Crozet (two species), South Georgia (one species) and Marion Island, Prince Edward Islands (two species) (Arrowsmith & Pentelow 1965, Davaine & Beall 1982, Headland 1984, Watkins & Cooper 1986, Davaine 1989).

Subantarctic rivers, streams and lakes are small and relatively impoverished (e.g. Grobbelaar 1975,1978) and only at Iles Kerguelen, where relatively large rivers occur, have salmonid fish flourished (Davaine & Beall 1982). However, brown trout (*Salmo trutta* L.) survived for at least 20 years (Watkins & Cooper 1986) in a single, near-perennial stream, the Van den Boogaard River, at Marion Island.

This paper describes the introduction, survival and extinction of brown trout at Marion Island, and details what is known of the species' diet, sex ratio, size and age structure and growth. These findings are discussed in relation to survival in an impoverished environment and the life-history styles of brown trout.

Methods

Information was gained from published and unpublished sources on the introduction to and subsequent survival of brown trout at subantarctic Marion Island (46°54'S,37°45'E). Brown trout were caught at night, with the aid of a hand net and spotlight, in April 1981 and May 1983 (Watkins & Cooper 1986). Further observations were made during the period 1984 to 1990 by JC and JEC.

The 1981 collection of fish was deep-frozen and returned to South Africa for analysis. After defrosting, the fish were blotted dry and weighed to the nearest g (wet mass) and total, standard (to fork of tail) and head length measured to the nearest mm. The fish were then sexed by dissection, and their stomach contents and otoliths removed. The two fish from 1983 were not included in the analyses.

Stomach contents were stored in alcohol and identified from published accounts of the invertebrates of Marion Island (Solem 1968, Lawrence 1971, Sims 1971, Crafford *et al.* 1986). The lateral and medial sides of the otoliths were ground by hand, using 600-grade water paper and two rubbing compounds (200 and 50 micron), to an average thickness of 0.5 mm. The opaque and hyaline zones were clearly visible and distinct (see Fig. 1) allowing 19 of the 27 otoliths to be read successfully for age. The radius of each otolith was measured as was the distance from the opaque nucleus to the outer edge of each consecutive hyaline zone. The back-calculated lengths-at-age were then fitted by the minimization technique to the von Bertalanffy special growth equation by way of the relative error model, and the variance was calculated using the bootstrap technique (Punt & Hughes 1989).

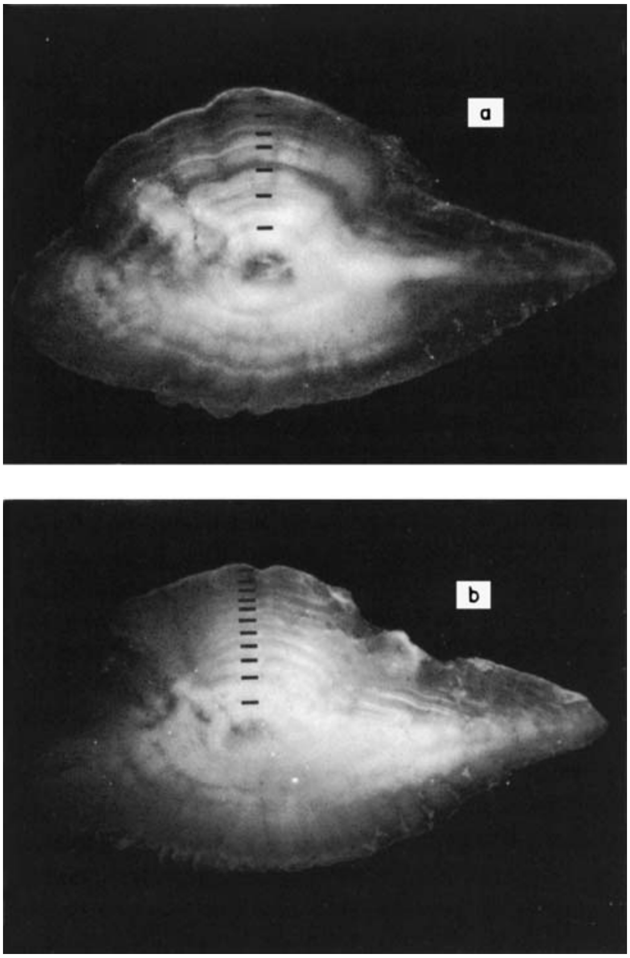

Fig. 1. Prepared sections through otoliths of Marion Island brown trout, showing annuli. **a.** 4.5 mm-long otolith from a seven year-old female; **b.** 5.5 mm-long otolith from an eleven year-old male.

The rings could not be independently validated because all the material was collected at one time. Beall & Devaine (1982,1988) demonstrated that ring formation on scales from brown trout at Iles Kerguelen was annual. It has therefore been assumed that one opaque and one hyaline zone were deposited per year. The unvalidated ages of Marion Island trout must, however, be regarded with some caution.

A simple "Water's" aquatic interception trap (Southwood 1981), consisting of a 1 m long aluminium-framed muslin funnel with a 0.25 m^2 rectangular entrance, was placed in a natural narrowing of the stream above the section where the trout occurred, approximately 600 m from the coast. The trap was moved after 14 days to a second site about 300 m downstream, within the river section inhabited by trout, for a further 14 days. Sampling at the two sites was repeated monthly from April to October 1983. In addition, a hand net was used to sample several pools and a small dam (see below), irregularly and opportunistically, throughout 1983/84. Samples of the stream substratum were taken at several sites along the river throughout the same period, and examined for invertebrates.

In August 1989 a qualitative description was made of the morphology of the section of the Van den Boogaard River known to have supported brown trout.

Results

Introduction and extinction

Approximately 130 brown trout fingerlings were introduced in March 1964 into the lower part of the river at at place unofficially known as "Waterfalls" (Watkins & Cooper 1986) to provide "much needed recreation facilities for the base staff to say nothing of the welcome addition to their diet" (C. Bredenkamp, letter of 9 January 1964). Little is known of the subsequent fate of this introduction between 1964 and 1981. In December 1970 trout were reported to be "numerous" (Anon 1970). In 1973 a few brown trout were caught and examined (Watkins & Cooper 1986), but "only a few snails" were noted in their stomachs (A.F. de Villiers personal communication 1989).

Between October 1979 and April 1980, base personnel removed approximately 20 fish from the Van den Boogaard River, some with the aid of a makeshift electro-fishing apparatus. The stomach contents of one of these fish was examined and consisted mainly of aquatic moss—*Schistidium falcatum*—and earthworms. No measurements were made of these individuals (S. Russell personal communication 1991).

Twenty-seven fish were caught on 27 April 1981 and two were caught on 19 May 1983, when a third individual was seen but not captured (Watkins & Cooper 1986). A single individual (*c.* 275 mm long) was often observed during the summer of 1983/1984 and was last seen during January 1984. Searches of the river were made during the day and at night with the aid of a powerful spotlight during November 1984 (Watkins & Cooper 1986), April–May 1987, August 1989 and April 1990, but no trout was seen on any occasion. Based on these unsuccessful searches, we consider that the brown trout is now extinct at Marion Island.

Diet

Of 122 identifiable prey items, representing 10 taxa (Table I) the most abundant prey species were an agelenid spider *Myro kerguelenensis* Cambridge and the endodontid subantarctic land snail *Notodiscus hookeri* (Reeve). These together formed 73.8% by numbers of the prey items identified. *Notodiscus hookeri* occurred in just over half of all stomachs examined. The total number of identified prey items per stomach ranged from 0 to 13 (mean 4.5 ± 4.0). The total number of identified taxa per stomach ranged from 0 to 4 (mean 1.7 ± 1.1). There were no discernible trends in the numbers of prey individuals or numbers of prey taxa in relation to either fish size or sex.

Digested remains or hair of the house mouse *Mus musculus*

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Table I. Stomach contents of 27 brown trout caught at Marion Island, 27 April 1981.

Prey items	Relative abundance No.	Relative abundance %	Frequency of occurrence No.	Frequency of occurrence %
Gastropoda				
Notodiscus hookeri	41	33.6	14	51.9
Arachnida				
Myro kerguelenensis	49	40.2	11	40.7
Erigone vagans	2	1.6	3	11.1
Coleoptera				
Ectemnorhinus similis	15	12.3	6	22.2
Mesembriorhinus parvulus	1	0.8	1	3.7
Lepidoptera				
Pringleophaga marioni				
adults	1	0.8	1	3.7
larvae	3	2.5	3	11.1
(combined)	(4)	(3.3)	(4)	(14.8)
Embryonopsis halticella				
larvae	2	1.6	2	7.4
Oligochaeta				
earthworms	4	3.3	4	14.8
Mallophaga				
bird louse	1	0.8	1	3.7
Mammalia				
Mus musculus	3	2.5	3	11.1
Total	122			

L. constituted the entire contents of three stomachs. They occurred in the three largest fish, all males (total lengths 33.8, 31.9 and 30.0 cm and masses 403, 339 and 309 g, respectively).

Small pebbles were found in 17 (63%) individuals; 10 pebbles in one stomach weighed a total of 0.91 g. The mean number of pebbles in the 17 fish with pebbles was 12 ± 10 (range 2–32). There were no trends in relation to fish size or sex with presence or number of pebbles. Vegetable matter was found in eight stomachs (29.6%) and unidentified matter in two stomachs (7.4%). This material has not been included in the above analyses.

Sex ratio and morphometrics

Twelve of the 27 trout collected in April 1981 were females and 15 were males. This ratio of 0.80 is not significantly different from one ($\chi^2 = 0.33$; $P > 0.5$). The fish ranged in

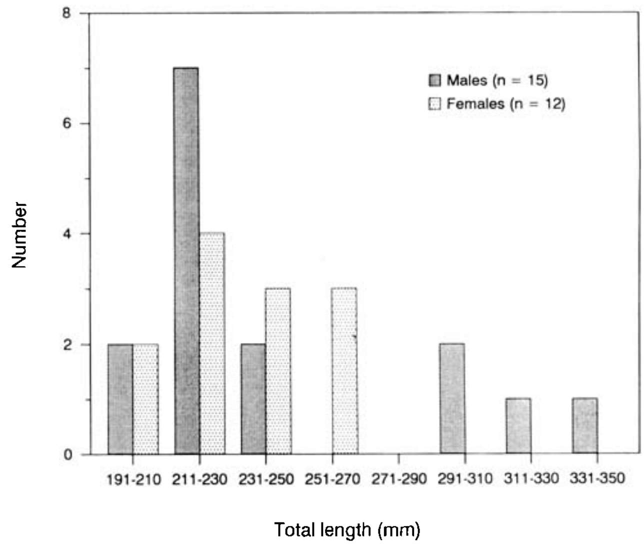

Fig. 2. Size distribution of male and female brown trout collected at Marion Island in 1981.

size from a total length of 192-333 mm and a mass of 55–403 g (Table II). Males attained larger dimensions and, on average, were larger than females, although only head length was significantly different (Fig. 2, Table II).

The total length (TL) in mm to mass (M) in g relationship for females and males combined is described by the equation $M = 3.08 \times 10^{-6} TL^{3.22}$ ($r^2 = 0.95$; $n = 27$). The relationship for females is $M = 3.38 \times 10^{-5} TL^{2.78}$ (r^2 0.88; $n = 12$) and for males is $M = 1.18 \times 10^{-6} TL^{3.39}$ ($r^2 = 0.98$; $n = 15$). There is no significant difference between the total length/mass relationships for females and males ($P > 0.5$). The total length/standard length (SL) relationship is linear and is described by the equation $SL = 0.865 TL - 0.320$ ($r^2 = 0.99$; $n = 27$).

Age and growth

The ages estimated from otoliths of 19 brown trout from Marion Island ranged from six to 11 years. The age/total length key for the sample is given in Table III. The parameters of the von Bertalanffy special growth model, based on back-calculated total lengths-at-age are (with se)

Table II. Morphometrics (mean, standard deviation and range) of brown trout caught at Marion Island, 27 April 1981.

Parameter (mm; g)	Males (n = 15)		Females (n = 12)		Sexes combined (n = 27)		Sexes compared t	P
Total length	244.9 ± 44.8	(194–338)	230.3 ± 24.0	(192–270)	239.1 ± 37.2	(192–338)	0.995	ns
Standard length	212.5 ± 39.3	(162-291)	197.5 ± 19.5	(164–222)	205.8 ± 32.4	(162–291)	1.206	ns
Head length	63.8 ± 11.4	(50–86)	56.3 ± 4.5	(51–66)	60.4 ± 9.6	(50–86)	2.143	<0.05
Mass	164.5 ± 108.6	(55–403)	128.6 ± 39.1	(93–189)	148.6 ± 85.6	(55-403)	1.087	ns

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Table III. Age/total length key for 19 brown trout caught at Marion Island, 27 April 1981. The sex of fish in each category is shown as F = female and M = male.

	Age in years					
Total length (mm)	6	7	8	9	10	11
200–209			1F			
210–219	1F	1F		1F		
220–229		1M	1F2M	1M		
230–239					1F	
240–249			1M			
250–259		2F				
260–269						
270–279				1F		
280–289						
290–299				1M		
300–309				2M		
310–319						1M
320–329						
330–339					1M	
Totals	1	4	5	6	2	1

TL = 283.6 ±25.6, k = 0.1783 ±0.033, t° = -0.6174 ±0.1909. The growth rate for sexes combined (n = 19), back-calculated to one year of age, is illustrated in Fig. 3.

Description and biota of the Van den Boogaard River

The Van den Boogaard River is a near-perennial stream with a length of *c.* 4 km. A long profile of the lower 400 m of the stream is given by Hall (1977). The stream enters the sea via a waterfall over a 7 m high cliff and by underground drainage. Brown trout were present in a 400 m section of the stream between "Waterfalls" and the waterfall entering the sea. In this section the stream, when flowing between full banks, is approximately 1–2 m wide and varies from 0.5–1 m deep. There are pools 0.5–1.5 m deep below two 2–5 m high waterfalls. The stream floor is mainly small pebbles and gravel with larger boulders in the pools. The natural flow pattern of the river may have been altered by the reconstruction of a small dam for hydroelectric generation approximately 1 km upstream from "Waterfalls" in 1982. Spates, of usually limited (<24 h) duration, are common allowing the river to spread over the adjacent mires to a width of up to 10 m.

All freshwater bodies on Marion Island are acidic and, away from biotic influences, are low in nutrients and have very low levels of primary production (Grobbelaar 1975,1978).

It is possible during a particularly cold spell for lakes, streams, and the Van den Boogaard River, to freeze over as happened in September 1984 (Anon 1984). In January 1987 the stream dried up totally, apparently including its pools (S. Hunter, personal communication 1987).

Qualitative sampling of the water column at two sites regularly yielded earthworms, rarely yielded the other invertebrates found in the trout stomachs (Table I) and never yielded any aquatic invertebrates. The larvae of an alien chironomid midge *Limnophyes pusillus* Eaton constitute "the entire benthic fauna" of streams at Marion Island (Crafford 1986). Neither *L. pusillus* larvae nor pupae were collected in the water column, but larvae occurred in samples of substratum from pools, and are numerous in the substrata of lentic waterbodies on the island. Pupae were often collected with a hand net, both in pools and in the dam on the Van den Boogaard River.

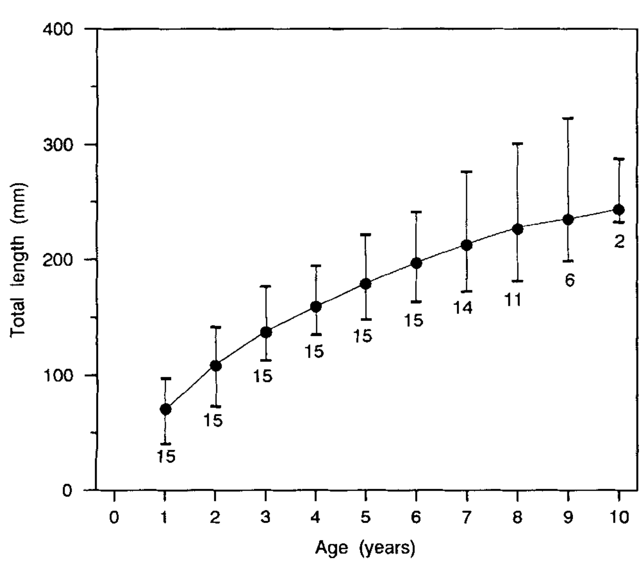

Fig. 3. Growth rate of brown trout at Marion Island, calculated using the von Bertalanffy special growth model. Figures below vertical bars are sample sizes.

Discussion

Phytosociologists have recognized no distinctive riparian plant communities at Marion Island (e.g. Huntley 1971, Gremmen 1981). Most plant communities on the island support a low diversity but high densities of invertebrate phytophages (Burger 1978, Crafford *et al.* 1986). However, the alien grass *Agrostis stolonifera* L. has, over the past three decades, increasingly invaded sheltered low-lying areas such as the banks of the lower reaches of the Van den Boogaard River (Smith *et al.* 1986). This grass now forms luxuriant monotypic stands along major sections of the stream. The diversity and abundance of native phytophagous invertebrates (and thus of the source of exogenous stream fauna) have probably decreased correspondingly, here as elsewhere in *A. stolonifera* stands on the island (JEC, unpublished data). The snail *N. hookeri* is ubiquitous, occurring in all vegetated habitats at Marion Island, and, with spiders, constitutes the majority of the fauna in *A. stolonifera* stands (JEC). This may explain the predominance of these two prey items in the stomach contents of trout collected at the island (Table I). However, soft-bodied invertebrates

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(such as earthworms and slugs), which are easily digested, may have been under-represented or unrecorded in the stomach contents. A limacid slug *Deroceras caruanae* occurs in some vegetated habitats at Marion Island, including along the banks of the Van den Boogaard River (Burger 1978, JC & JEC).

Brown trout at Marion Island lived in an impoverished stream, surviving on allochthonous prey in a manner similar to salmonid fish introduced to Iles Kerguelen, whose main riverine prey are earthworms and lepidopteran and chironomid larvae and pupae (e.g. Lesel *et al.* 1971,1972, Wojtenka & van Steenberghe 1981). However, in contrast to the situation at Marion Island, brown trout introduced to several rivers at Iles Kerguelen have access to and from the sea and are thus migratory with an anadromous life-history style (Thomas *et al.* 1981, Davaine & Beall 1982, Davaine 1989). Whereas it is feasible that trout at Marion Island could have entered the sea from the Van den Boogaard River, the 7 m high waterfall into the sea is likely to have made it impossible for them to have returned. Migratory brown trout at Iles Kerguelen grow at a faster rate and achieve a greater size than resident fish (Davaine & Beall 1982, Davaine 1989). Slow growth and small size of brown trout at Marion Island may therefore be explained by an enforced resident life-history style in an impoverished environment. McDowall (1988) has pointed out that dwarfing is a common consequence for an anadromous species, such as the brown trout, when land-locked.

The estimated age range of the fish suggests successful spawning in the river prior to 1981. In support of this fish caught in 1973, nine years after the introduction, contained small trout in their stomachs (Watkins & Cooper 1986). The youngest estimated age of six years in the 1981 population implies that successful spawning did not take place subsequent to 1975.

Brown trout can survive to over 15 years of age (Carlander 1969) but no fish older than 11 years was found. It is therefore possible that some of the fish from the original population migrated to the sea prior to 1981 (and were not able to return) or were selectively fished out in the 1960s and 1970s. These explanations may account for the apparent lack of successful spawning after 1975.

In any case the stream's small size, highly variable nature and lack of endogenous fauna, a reduced source of allochthonous fauna due to the spread of *A. stolonifera*, the trout's enforced non-migratory life-history style, and the apparent lack of successful spawning each year, all suggest that natural extinction would have been possible.

In the Northern Hemisphere, the anadromous life-history style of brown trout appears to be highly facultative (McDowall 1988). In contrast, in the subantarctic region anadromy in the brown trout appears to be more obligatory. The success of the migratory brown trout population at Iles Kerguelen, in contrast to the resident fish at Marion Island, supports this conclusion.

Finally, since Marion Island is managed as a *de facto* nature reserve (Cooper & Condy 1988) where the wilful introduction of alien biota is now prohibited by the South African Department of Environment Affairs further deliberate introductions of alien fish should not be possible.

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