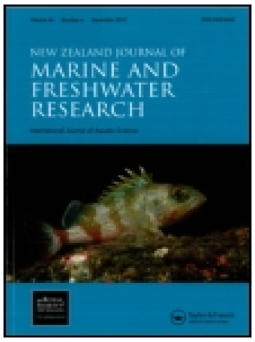

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Growth of two species of freshwater crayfish (*Paranephrops* spp.) in New Zealand

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Populations of *Paranephrops planifrons* and *P. zealandicus* were reared in aquaria and their growth rates monitored. When reared in unheated aquaria (10–21 °C) *P. planifrons* grew to 20 mm orbit–carapace length in 12–18 months and *P. zealandicus* reached the same size in 9–10 months. This is faster, for both species, than in feral populations. When reared in an aquarium at 18–21 °C however, *P. planifrons* could be grown to 35 mm orbit–carapace length in 18 months. Mortality in both species was very high (60–93%).

Keywords: Parastacidae; *Paranephrops* spp.; growth; aquaculture.

INTRODUCTION

New Zealand has two species of freshwater crayfish — *Paranephrops planifrons,* confined to the North Island and the Marlborough, Nelson, and West Coast districts of the South Island, and *P. zealandicus* which is found in the North Canterbury, Canterbury Plains, Otago, and Southland districts of the South Island, and Stewart Island (Hopkins 1970).

The only previous information on the biology of *Paranephrops,* apart from the observations of early naturalists such as Archey (1915), comes from a study by Hopkins (1966, 1967a, b) on stream-dwelling populations of *P. planifrons* in the lower North Island. The studies on aquaculture outlined by Shaddick (1976) were never completed. There have been no published studies on the biology or growth of *P. zealandicus.*

In response to an increasing number of requests for biological data on both species, particularly from people interested in the aquaculture potential of *Paranephrops,* a study of the growth rates of aquarium populations of both species was begun in late 1976. The results of this study have been supplemented by data gathered while studying the parasite fauna of feral *P. zealandicus,* and from *P. planifrons* reared in PVC ponds at the Te Kaha Aquaculture Station.

METHODS

LABORATORY POPULATIONS

The breeding stock from which laboratory populations were established came from four areas: Leith Stream (NZMSI S164/150765) and Manorburn Creek (NZMSI S144/384229) for *P. zealandicus,* and Te Aro Stream (NZMSI N164/202318) and the Patea River (N129/028124) for *P. planifrons.* The crayfish were maintained in aquaria at a maximum density of one per 150 cm^2. Except where otherwise stated, each aquarium was at ambient temperature (10–21 °C) and had a fine gravel bottom or a layer of black mud. This mud had built up over 2–3 months and contained over 70% crayfish faecal pellets by volume; it supported flourishing populations of ostracods, nematodes, and periodic blooms of harpacticoid copepods. Shelter was provided in the form of PVC pipes and stones. The crayfish were fed to excess on an artificial diet (50% soya flour, 50% commercial eel food) having the following composition: 51.6% protein, 27.7% carbohydrate, 9.0% ash, 2.1% fibre, 1.5% calcium, 1.3% fat, 1.1% phosphorus. The dry food was mixed to a stiff dough with water and a vitamin supplement, then shaped into pellets immediately before use.

When juveniles left the female, she was removed to prevent cannibalism and the growth of the juveniles was monitored. Crayfish were measured from the back of the eye socket to the posterior edge of the carapace to give the orbit–carapace length (OCL).

TE KAHA POPULATION

The offspring of female *P. planifrons* caught at Lake Taupo (central North Island) were transferred to the Te Kaha Aquaculture Station in the Bay of Plenty. They were reared in PVC ponds (3 m diameter) and fed weekly with lucerne pellets. Pond temperatures fluctuated between 8 °C in July and 26 °C in December–January.

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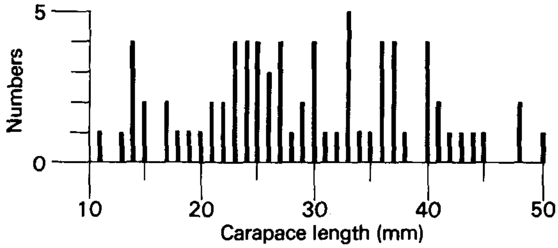

Fig. 1 Length-frequency histogram for 74 female *Paranephrops zealandicus* captured in Leith Stream, Apr 1977.

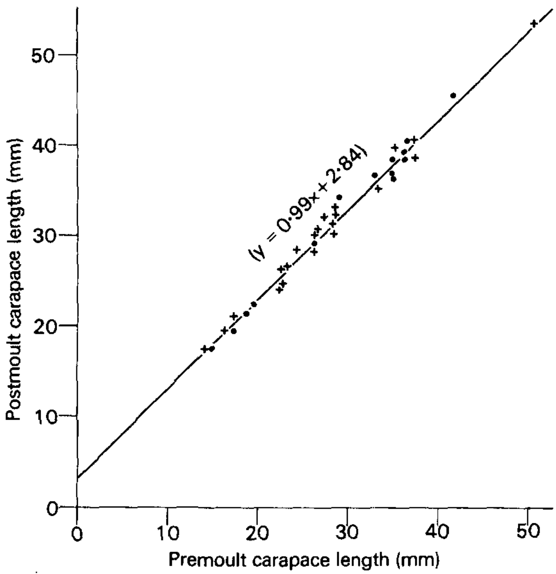

Fig. 2 *Paranephrops zealandicus,* Leith Stream; post-moult carapace length plotted against pre-moult carapace length (+, female; ●, male).

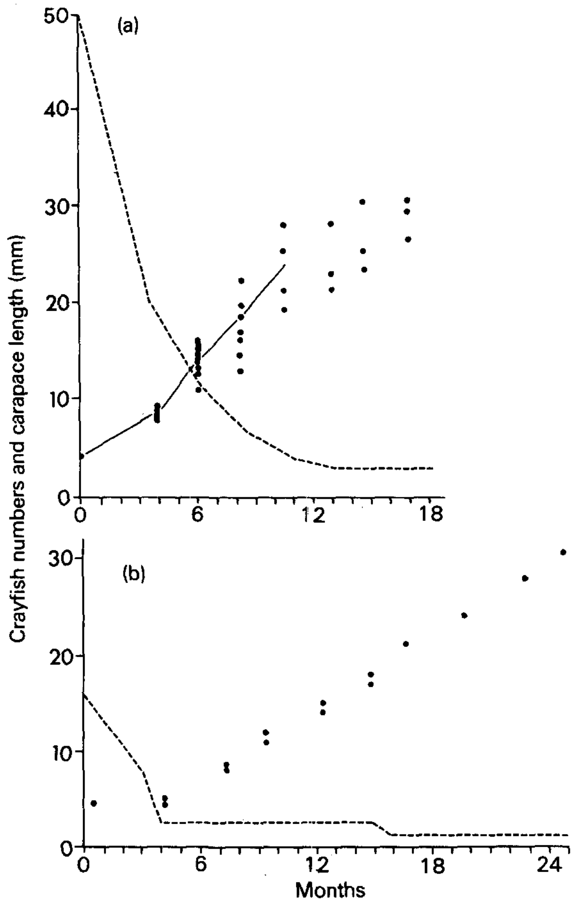

Fig. 3 Growth and survival of *Paranephrops zealandicus* in aquaria. (a) Manorburn Creek stock; (b) Leith stream stock (broken line, number of surviving crayfish; solid line, mean OCL of crayfish; dots represent individuals.)

FERAL POPULATIONS

A population of *P. zealandicus* was studied at the Leith Stream, Dunedin, in the area described by Quilter (1976). Samples were taken every 2 months for 14 months. Crayfish were collected with a small dip net, and then sexed, marked (after the method of Hopkins (1967b)) and measured before return to the water. Water temperatures fluctuated between 3 °C in July and 12 °C in February.

RESULTS

Paranephrops zealandicus

SIZE-FREQUENCY ANALYSIS. Probability paper can be used to solve bimodal or polymodal frequency distributions (Cassie 1954): this method was used by Hopkins (1967b) to analyse the population year classes of *P. planifrons.* When applied to a sample of 74 Leith Stream females collected during April 1977 (the length frequencies of which are shown in Fig. 1), the points on the arithmetic probability paper approached a straight line and showed no evidence of multi-modality, so this method of analysis was abandoned (see Discussion).

CAPTURE-RECAPTURE DATA. From recaptures made in the Leith Stream, pre- and post-moult measurements were obtained for 37 moults completed by 15 males and 14 females; pre-moult size ranged from 15.2 to 41.8 mm in males, and from 14.3 to 50.6 mm in females. An additional 7 moults completed in aquaria gave a total of 44 moults for which the growth increment was known.

Table 1 Orbit-carapace lengths (mm) of selected *Paranephrops zealandicus* with months of release and recapture to show growth increment over summer and over year, Leith Stream 1976–79 (-, no recapture).

	1976			1977		1979	Growth increment		Estimated no. of
Sep	Nov	Feb	Apr	Jun	Dec	Mar	(mm)	Months	moults
				Female					
20.5	-	-	26.5				6.0	7	2
22.6	-	-	-	24.0			1.4	9	1
	23.0	-	-	31.6			8.6	8	3
	26.7	-	-	30.3			3.6	8	1
27.6	-	-	32.0				4.4	7	1 or 2
28.9	-	-	-	33.1			4.2	9	1 or 2
28.9	-	-	32.4				3.5	7	1
		32.6	-	-	-	38.1	5.5	25	2
	37.5	-	-	-	38.4		1.0	13	1
		37.7	-	-	-	45.6	7.9	25	2 or 3
				Male					
23.7	-	-	-	-	26.7		3.0	15	1
24.0	-	-	29.0				5.0	7	2
27.7	-	-	-	-	30.7		3.0	15	1
27.9	-	-	31.1				3.2	7	1
	29.1	-	-	34.1			5.0	8	1 or 2
	35.1	-	-	-	36.5		1.4	13	1
35.5	-	-	39.8				4.3	7	1 or 2
36.8	-	-	40.4				3.6	7	1

A plot of the pre-moult OCL against post-moult OCL gave a regression line $y = 0.99x + 2.84$ (Fig. 2) where x is the pre-moult OCL and y is the post-moult OCL. Student's t-tests for differences between the slope coefficient b for x on y and between males and females showed no significant difference ($P > 0.01$).

The temporal distribution of recaptures was such that accurate information on the frequency of moulting over the summer was limited to 12 crayfish, and data for both the summer and winter were confined to 6 crayfish, of which 2 were recaptured in March 1979 after 2 years' freedom. From the moult increment, and using Fig. 2, it was calculated that these two crayfish had moulted only two to three times over this period. The combined data (Table 1) give a good indication that the growth of feral *P. zealandicus* is very slow.

LABORATORY GROWTH DATA. The laboratory growth data are summarised in Fig. 3. A difference is apparent between the Manorburn stock, grown in an aquarium with a mud bottom (mean OCL 24 mm after 12 months growth), and the Leith stock which was reared on a fine gravel bottom (OCL 14 mm after 12 months' growth). Whether the difference is due to environmental or genetic factors is unknown.

Paranephrops planifrons

LABORATORY GROWTH DATA. Fig. 4a shows data from Te Aro (Wellington) broodstock (the eggs of which hatched in the laboratory in November 1977) which were reared in a mud-bottomed aquarium. Their diet was supplemented with white worms (Oligochaetae: Enchytraeidae).

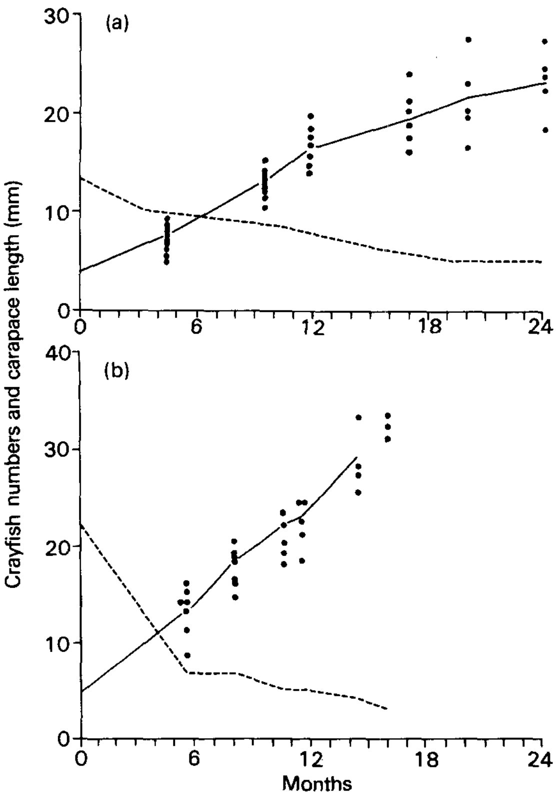

Fig. 4 Growth and survival of *Paranephrops planifrons* in aquaria. (a) Te Aro stock; (b) Patea River stock (broken line, number of surviving crayfish; solid line, mean orbit - carapace length of crayfish).

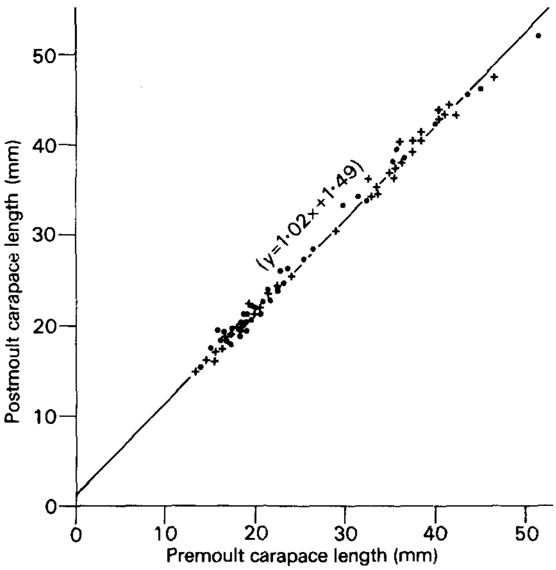

Fig. 5 Post moult carapace length of *Paranephrops planifrons* plotted against pre-moult carapace length (+, female; ●, male).

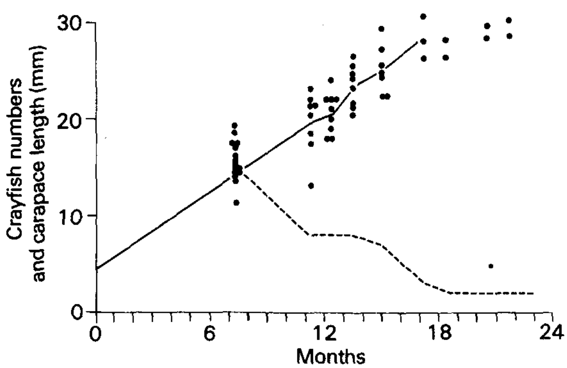

Fig. 6 Growth and survival of *Paranephrops planifrons* in aquaria, Te Kaha stock (broken line, number of surviving crayfish; solid line, mean orbit - carapace length of crayfish).

Fig. 4b shows data from the Patea River stock (which hatched in the laboratory in March 1979) which were reared in a mud-bottomed aquarium heated to a minimum of 18 °C, but which rose to a maximum of 21 °C in January.

From the laboratory populations, data on the pre- and post-moult OCLs were obtained from the moulting of 42 males and 49 females (Fig. 5). As with *P. zealandicus* there was no difference between the males and the females, and when the sexes were grouped the slope coefficient of the regression line ($y = 1.02x + 1.49$) was not significantly different from the *P. zealandicus* data ($P > 0.01$).

TE KAHA POPULATION. Fig. 6 shows the growth data from the Te Kaha population, the eggs of which hatched in November 1977. No measurements were taken during the first summer, but by June 1978 the juveniles had reached a mean OCL of 14.64 mm, and at 12 months old the mean OCL was 20.6 mm.

DISCUSSION

Size-frequency analysis by graphical means is a good first method for analysing a multi-modal distribution (Cassie 1954), but it is extremely difficult to apply satisfactorily when the data are few and/or when many curves form the composite (Taylor 1965). Even if modes were revealed by this analysis, their significance would be doubtful since the size-frequencies are complicated by a period of egg hatching from September to January, and by those crayfish which moult more or less frequently than others in their cohort. For example, six 12-month-old crayfish from the same brood of eggs measured 24.2, 21.8, 20.4, 19.0, 17.4, and 16.2 mm OCL respectively, the largest being 49% larger than the smallest. With increasing age the difference became even more pronounced. A further complication is created by old crayfish which moult less than once per year.

Hopkins (1966) used Cassie's method to successfully predict growth rates, which he confirmed with capture-recapture studies. This method did not work on the Leith crayfish, probably because of the age structure of the two populations. Hopkins (1967b) was studying a young population in that wherever the size distribution showed four or more components, the largest occupied less than 10% of the population. For the Leith stream population, however, over 75% of the crayfish caught were over 20 mm OCL, at which size they were moulting infrequently.

The growth increment curve calculated for *P. planifrons* by Hopkins (1967b) is inaccurate above 25 mm OCL, and the equation derived from the present data does not fit Hopkins's data for moult increments below 15-20 mm OCL. Hopkins's data are probably better fitted by a straight line representing growth increments before maturity with a point of inflection somewhere between 20 and 25 mm OCL (the length at sexual maturity). The line derived from the present data represents growth increments after maturity. A linear relationship has been found for all other crustaceans for which growth increments have been plotted, and many have a point of inflection associated with maturity (Kurata 1962).

The growth increment in *Paranephrops* is constant irrespective of the age, as was suggested by Hopkins (1967b) for *P. planifrons*. Moulting frequency, however, may decrease with age due to a lengthening of the intermoult period. This can be seen most clearly in Fig. 4a as a decrease in the growth rate. Such a decrease is not apparent in Fig. 4b where crayfish have the same moult increment but moult at a faster rate than shown in Fig. 4a. Whether this was entirely due to the increase in temperature, or whether genetic factors contributed, is unknown.

The intermoult period is divided into two time components (Kurata 1962), a minimum period which is constant for any given size of crayfish irrespective of the environment, plus an additional period which is highly modified by changes in environmental factors such as light, temperature, and food. It is not possible to accurately measure the intermoult period by capture-recapture techniques, and unless individuals are reared in the laboratory under constant conditions, the two components of the intermoult period cannot be separated. The minimum time period is of importance in aquaculture because it represents a maximum growth rate which cannot be exceeded.

Young of feral *P. zealandicus* first appeared in samples in November at 3.4-6.5 mm OCL, and reached 11-15 mm OCL by the end of the first summer. Moulting almost certainly does not occur in the Leith Stream area during the winter months, when stream temperatures decrease from the summer average of 12 °C to a low of about 3 °C. Crayfish may reach 20-25 mm OCL by the second summer. The most moults observed over one summer was three for two females with initial OCLs of 23.0 and 37.7 mm respectively. Most adult animals moulted only once or twice per year (Table 1), as has been found for other cold water crayfish such as *Austropotamobius pallipes* (Brown & Bowler 1977).

Laboratory populations of *P. zealandicus* can be grown to 20 mm OCL in 9-10 months and 30 mm OCL in 18 months to 2 years, which is much faster than is achieved in the wild. This is probably due to the relative abundance of food in the laboratory and the effect of the higher temperatures, since the range of temperatures to which *P. zealandicus* was exposed (12-23 °C) was very much higher than at Leith or Manorburn. This increase in temperature may have caused the eggs brought to Wellington to hatch in June rather than November (Fig. 3) since temperature controls the rate of development of crayfish eggs (Mason 1974).

In the Wellington aquaria, growth of *P. planifrons* from Te Aro was slightly slower than for laboratory bred *P. zealandicus*, and 12-18 months were required to reach 20 mm OCL. This population was maintained at temperatures within the range encountered by the feral populations studied by Hopkins (1967b) which grew to 18.2-19.3 mm carapace length after 2 years. The growth of *P. planifrons* at Te Kaha was not quite as good as that of the *P. planifrons* from Patea which were raised at 18 °C. Growth of the latter was comparable with that of *P. zealandicus* raised at Wellington (Figs 3-6).

These growth rates for *Paranephrops* compare favourably with those of other species of freshwater crayfish. Abrahamsson (1971) reported that in Swedish lakes growth of *Astacus astacus* was 23 mm total body length in one summer, and 47 mm (female) and 49 mm (male) body length in two summers. *Pacifastacus leniusculus* in the same lake system grew to 40 mm body length in one summer, and 79 mm (female) and 82 mm (male) in the following summer (20 mm OCL is about 45 mm total body length).

Survival was very low in laboratory populations, and ranged from zero to 7% survival over 2 years for *P. zealandicus* and from 4% to 40% survival over 2 years for *P. planifrons* (Fig. 4). There are no figures available for the natural mortality of *Paranephrops*, but Hopkins (1967b) commented that females in his study population seldom survived to breed twice and that most crayfish did not survive beyond the third year.

Other freshwater crayfish species have also been found to have low survival rates. In Michigan, *Orconectes virilis* were found to have survival rates of between 6% and 40.2% of the ovarian egg count, the ovarian egg count often being as high as 48% above the attached egg count (Momot & Gowing 1977). Mason (1974) studied the growth of Canadian *Pacifastacus* species in aquaria and found a survival rate of 2-6% after 245 days of culture. Morrissy (1976) did somewhat better with *Cherax tenuimanus* in Western Australia; he recorded a 25.4-51.7% survival in breeding ponds. Tcherkashina (1977) attributed poor growth and high mortality (90%) of *Astacus leptodactylus cubanicus* in the River Don to shortage of food. He found that pond-reared crayfish fed an abundant diet achieved a survival rate of 85-90% and grew to 30 g in 2 years.

It is quite possible that with a better diet the survival and growth of *Paranephrops* in culture could be improved. To achieve a maximum growth rate, however, the use of heated water is essential.

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