Observations on the ecology and behaviour of *Ctenognathus novaezelandiae* (Fairmaire) (Coleoptera: Carabidae)

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Abstract

Adults of the carabid *Ctenognathus novaezelandiae* (Fairmaire) were collected from Woodhill pine forest north of Auckland between 2000 and 2003. Although the beetles were collected specifically for experimental purposes, we present incidental data and observations on *C. novaezelandiae* ecology and behaviour. Adults, at least in spring and summer, are gregarious. The sex ratio of those caught by searching forest floor litter heavily favoured males, while females dominated pitfall trap collections. *Ctenognathus novaezelandiae* appears to be univoltine in Auckland. Adults emerged in spring, were essentially inactive over summer, and bred in autumn and winter. Larvae were present during autumn and winter, and adult numbers decreased from about mid-winter onwards. While this pattern fits the classic Northern Hemisphere model of autumn-breeding carabids, it is different from that of other New Zealand carabids studied, adults of which have a prolonged period of activity between spring and autumn with one or two peaks of activity, and are mostly inactive over winter.

Keywords: carabid beetle, New Zealand, endemic, pine forest, seasonality

Introduction

Ctenognathus novaezelandiae (Fairmaire, 1843) is a predatory carabid beetle endemic to New Zealand and found in coastal lowland forests throughout the North Island (Larochelle & Larivière 2001). As with most New Zealand carabids, little is known of its ecology and behaviour. In the Northern Hemisphere, most carabid species either emerge as adults in spring, breed in late summer and hibernate as larvae, or emerge in late summer, hibernate as adults and breed in spring (Forsythe 1987). Most *C. novaezelandiae* tenerals appear in spring, which suggests that, if New Zealand carabid life cycles are similar to those in the Northern Hemisphere, they could be late summer breeders (A. Larochelle, pers. comm.).

Carabid beetles are considered useful ecological indicator species and a key taxonomic group for assessing biodiversity and environmental impacts (Lopez *et al.* 2005; Boscaini *et al.* 2000), and larvae and adults of *C. novaezelandiae* were used in our laboratory trials to investigate the tri-trophic impacts of transgenic insect-resistant plants (Burgess *et al.* 2008). For these experiments, adult beetles and prey invertebrates were collected from the field. In this paper, we present incidental ecological and behavioural information about *C. novaezelandiae* from these field collections and compare it with what little such information is known about other New Zealand carabids.

Materials and Methods

Recently emerged *C. novaezelandiae* adults were collected from the coastal Woodhill *Pinus radiata* plantation north of Auckland (Lat. 36° 44'S, Long. 174° 23'E), during September-December 2000 (spring/early summer), September and October (spring) 2001, November (late spring) 2002 and December (early summer) 2003 and from an isolated single collection in March (early autumn) 2001. Most field collection was carried out by searching under and around logs and fallen branches and in the litter at the bases of mature trees, but from 18 September to 16 October 2001, 32 small pitfall traps (110 mm diameter, 100 mm deep) were used to supplement manual collection. Prey invertebrates were collected from 64 small pitfall traps, and litter sieving, from 5 December 2002 to 22 October 2003, and from 12 large pitfall traps (310 x 245 x 130 mm) between 24 December 2003 and 13 July 2004.

The sex of each beetle was determined by examination of the protarsi and ambulatory setae on the last abdominal segment. Segments 1-4 of male

protarsi are widened and possess 2 rows of scale-like setae on the underside, while female protarsi are narrower (unmodified) and without the scale-like setae. Males typically have 2-4, though occasionally up to 6, ambulatory setae on the posterior margin of the last abdominal sternite, while females have 8 or more (A. Larochelle, pers. comm.).

Results and Discussion

Sex ratio

Over 4 consecutive years (2000 to 2003) a total of 1,830 *C. novaezelandiae* adults were taken from Woodhill Forest, all but 68 of them (which were collected in early autumn) in spring and early summer (Table 1). Overall, considerably more males were caught than females, although this trend was reversed for the relatively few caught by pitfall trapping, contrary to the belief that pitfall trapping favours males because of their presumed higher activity (Müller 1984). How these figures relate to the actual sex ratio of the population is difficult to say. Cartellieri and Lövei (2003) note that the sex ratio of pitfall trapped carabids depends on the relative activity of the sexes and doesn't necessarily reflect the true ratio. Similarly, the sex ratio of beetles caught by searching may be influenced by different male and female resting behaviours. Cartellieri and Lövei (2003) and Butcher and Emberson (1981) caught a predominance of males in pitfall traps for eight of the 12 New Zealand carabid species that were caught in significant numbers. In only one species (*zolus* c.f. *femoralis* Broun) were females markedly more abundant.

Table 1. Number and sex ratio of *Ctenognathus novaezelandiae* adults caught in Woodhill State Forest 2000-2003, by either searching or in pitfall traps.

	Males caught	Females caught	Total caught	Sex ratio Male:Female
Searching	1,067	594	1,661	1:0.56
Pitfall trapping	71	98	169	1:1.38
Total	1,138	692	1,830	1:0.61

Aggregation

Ctenognathus novaezelandiae adults are gregarious and were frequently found during our spring and early summer collections at Woodhill in groups of up to a dozen or so, occasionally more. This behaviour was mirrored in our laboratory populations (Philip and Burgess 2008a), where adults typically rested in groups, tightly pressed against each other and even one on top of another. While this aggregation behaviour has been noted in only a few British carabids (Forsythe 1987), Larochelle and Larivière (2001) record it for 80 New Zealand species. Forsythe suggests it may help reduce water loss, and indeed the litter at Woodhill, on a base of sand, can become very dry at the height of summer. In several Northern Hemisphere species in which aggregation has been closely studied, it was most marked during the non-reproductive period and declined with the commencement of sexual activity (Thiele 1977; Forsythe 1987). As they were only collected during their non-reproductive phase, we cannot say whether this pattern holds true for *C. novaezelandiae*.

Seasonality

Relatively high numbers of adult beetles were caught in pitfall traps during the four-week period from 18 September to 16 October 2001 (mean 41.5 per week, range 38-47), indicating high surface activity at this time. While collecting forest floor invertebrates from 5 December 2002 to 22 October 2003 at Woodhill, a number of *C. novaezelandiae* adults were caught in small pitfall traps and larvae were collected from the sieved litter (Figure 1). Larvae were seldom found in the pitfall traps, and adults were never caught by sieving. While a similar quantity of litter was sieved at each collection date, this was not standardised, so comparisons of numbers of larvae caught on different dates may not truly reflect numbers present in the field. However, the sequential data do provide a useful indication of when larvae can be found in litter. The number of adults coincidentally caught in large pitfall traps from 24 December 2003 to 13 July 2004 is shown in Figure 2. Litter sieving was not carried out during this period, so there are no corresponding larval data.

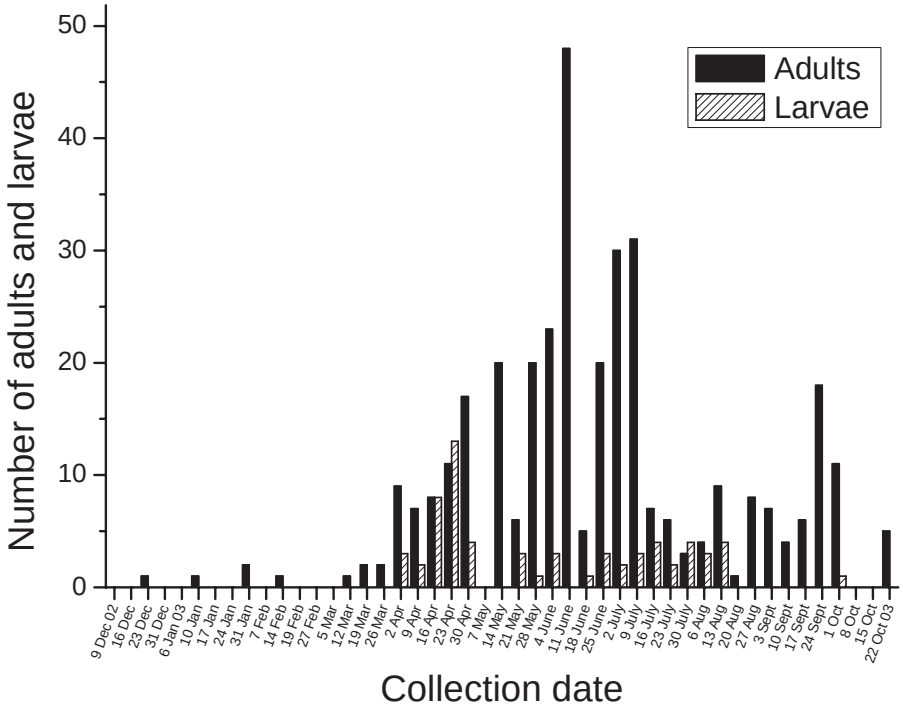

Figure 1. Number of *Ctenognathus novaezelandiae* adults caught in 64 small pitfall traps and larvae caught by litter sieving December 2002 to October 2003 in Woodhill State Forest.

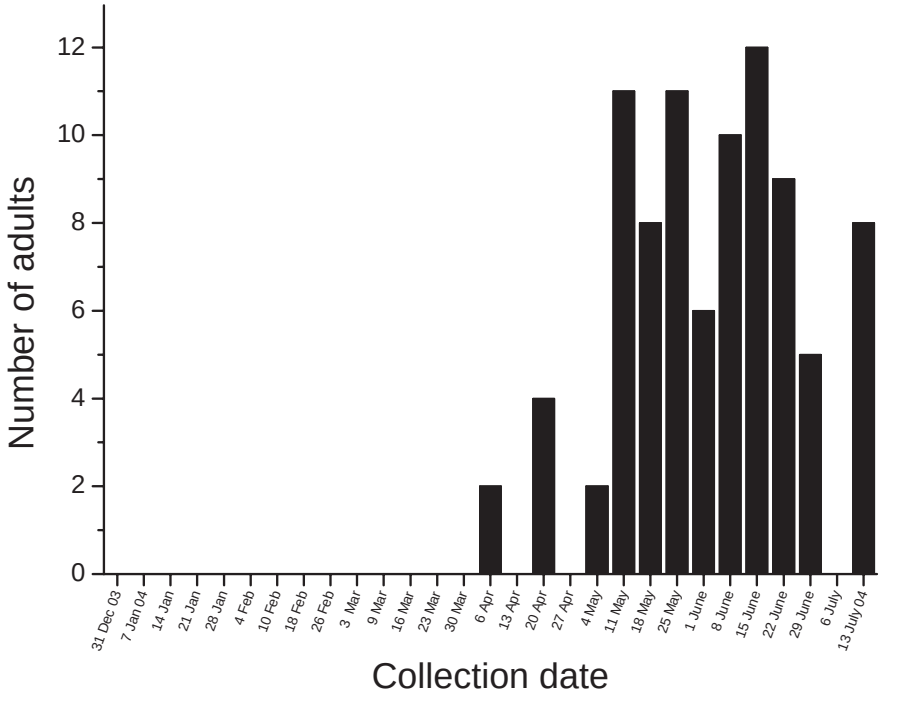

Figure 2. Number of *Ctenognathus novaezelandiae* adults caught in 12 large pitfall traps December 2003 to July 2004 in Woodhill State Forest.

Our collecting and trapping data show that adults were present at Woodhill throughout the year, but the pitfall trap data indicate when they were most active. Adults were only rarely caught in traps between December 2002 and March 2003, and not at all between December 2003 and March 2004, although we could still collect them commonly by actively searching for them. From the beginning of April in both years, numbers increased sharply and remained relatively high until mid July, after which the data from 2003 show that numbers tailed off before beginning to rise again in September (there were no data collected at this time of year in 2004). Presumably most of the adults caught over winter were old reproductive or post-reproductive individuals that had emerged the previous spring, and most of those caught once numbers started to rise again in spring were newly emerged.

Larvae caught in pitfall traps were assumed to be *C. novaezealandiae* as only adults of this species were encountered at the collection site, and we were familiar with *C. novaezelandiae* larvae having reared them in the laboratory. In addition, Larochelle (pers. comm.) found no other species of *Ctenognathus*, and indeed no other carabids of the tribe Platynini, during a year of pitfall trapping at this site. Larvae were first recorded at the beginning of April, at about the same time adults were becoming active again (and coinciding with egg-laying in the laboratory by field-collected adults), and were present for the rest of autumn and throughout winter, with one fully-grown larva being found as late as the beginning of October. The first larvae found were recently emerged first instars; as time went on older, larger larvae were caught as well, although newly emerged larvae continued to be found well into winter, indicating adults were still reproductively active at this time.

The picture that emerges of *C. novaezelandiae* seasonality in Auckland is of a univoltine species, with tenerals in spring, adults active throughout spring, essentially inactive over summer, breeding from autumn into winter, with larvae present in autumn and winter, and adult numbers decreasing from around mid winter as they begin to die. This pattern of a peak of activity with newly emerged adults in spring, summer inactivity, and another peak of activity as reproduction commences in autumn and continues through winter is similar to the Northern Hemisphere carabid *Nebria brevicollis*. Adults of this species are only active for 2-3 weeks after emergence in early summer, during which time they feed rapidly and build up substantial food reserves before entering diapause, which lasts until the breeding season (Penney 1966). During diapause, *N. brevicollis* beetles aggregate and do not feed. It has been suggested that diapause in carabid beetles may be initiated by low humidity, high temperature or daylength (Forsythe 1987). While it appears likely, given their low activity, that *C. novaezelandiae* do not feed much, or at all, in the field over summer, it is worth noting that individuals brought into the laboratory in spring and kept under constant conditions (18°C, with high humidity and a 16:8h light:dark regime) remained active and continued to feed, although they did not lay eggs any earlier than their field counterparts.

Although little is known of New Zealand carabid seasonality, several studies of adults in native forest provide comparisons with *C. novaezelandiae*. At Banks Peninsula, Canterbury, South Island, Anderson *et al.* (2004) seasonally trapped two species, and Butcher and Emberson (1981) trapped 11 native species, six of them common, and dissected the four most common to assess their reproductive status. In the North Island, Cartellieri and Lövei (2003) trapped and dissected six species near Palmerston North, Manawatu, and Moeed and Meads (1985), in a 14 month survey of invertebrates near Wellington, found 20 species of carabid, although only six of them were relatively common. In all the studies, all species for which there were sufficient data showed a clear and similar seasonality: the main surface activity occurred in spring and summer, with most having some autumn activity as well. All had one or two peaks of activity within this period. Only one, *Holcaspis mucronata* (Broun), at Manawatu, was regularly active throughout winter, though its greatest activity was in autumn, with a less pronounced peak in spring. In contrast, *C. novaezelandiae* was essentially inactive over summer, with peaks of adult activity in late autumn/winter and spring.

While we did not find *C. novaezelandiae* tenerals in our collections, we can presume, based on information from A. Larochelle (pers. comm.) and supported by adult and larval activity patterns, that they appear in spring, and possibly as early as late winter. The reproductive period in this species clearly begins in autumn and probably continues well into winter. By comparison, tenerals of five of the six species studied at Manawatu appeared in

summer, while those of *Ctenognathus adamsi* Broun first appeared in spring, but were found throughout their activity period, spring to autumn (Cartellieri & Lövei 2003). Cartellieri and Lövei (2003) suggest this indicates a long egg-laying period with continuous development of eggs, larvae and pupae. In fact, for all species at Manawatu, reproductively active females were found over a prolonged period, in most cases from spring to autumn. Anderson *et al.* (2004) considered both species they studied at Banks Peninsula likely to be spring/summer breeders with a similarly prolonged breeding period, and Butcher and Emberson (1981), at Banks Peninsula, found three species reproductively active during summer, and one in autumn.

Thus the seasonal patterns of most of the New Zealand carabids for which there is information do not fit the standard Northern Hemisphere division into autumn or spring breeders, perhaps because the milder New Zealand climate allows larvae to remain active over winter (Cartellieri & Lövei 2003). *Ctenognathus novaezelandiae,* however, exhibits a different seasonality from most other New Zealand carabids studied, including the two *Ctenognathus* species described in the studies quoted above (both of which were active from spring to autumn, with a peak of activity in summer), and in fact fits more closely the classic model, with spring tenerals and autumn breeding. Without information on the seasonality of *C. novaezelandiae* in native forest habitats at other North Island sites, we don't know whether this is an inherent seasonal pattern, or a behavioural response to the dryness of the pine litter at Woodhill in summer and the higher winter temperatures than experienced by the more southern sites. However, the observation that adults taken into the laboratory in spring or early summer, kept in moist constant conditions and fed regularly, still did not begin egg-laying until autumn, when females in the field were beginning to lay, suggests autumn/winter breeding may be inherent in this species.

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