

## Phenology and parasitism of the red admiral butterfly *Bassaris gonerilla* (Lepidoptera: Nymphalidae)

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**Abstract:** Population densities of the endemic red admiral butterfly, *Bassaris gonerilla*, were monitored over two summers on Banks Peninsula, New Zealand. Egg-laying usually begins in September and ends in late May. Peaks in egg, larval and adult densities suggest that *B. gonerilla* completes two full generations per season and in favourable years, a third generation is started but not completed. Population density was lower in a low-rainfall season probably because of the lower survival and nutritional quality of the host plant, *Urtica ferox*. "Non-target" parasitism levels by *Pteromalus puparum* (introduced to manage populations of the small white butterfly *Pieris rapae*) were low at 3.5–16.9% of pupae collected from the field. However, parasitism by the self-introduced pupal parasitoid *Echthromorpha intricatoria* was very high at 67.5–82.3%. *Echthromorpha intricatoria* can overwinter in *B. gonerilla* pupae and is thus capable of attacking all generations of *B. gonerilla*. More long-term data are needed to determine the status of, and regulatory mechanisms affecting *B. gonerilla* populations.

**Keywords:** *Bassaris gonerilla*; *Echthromorpha intricatoria*; non-target parasitism; phenology; *Pteromalus puparum*.

## Introduction

Populations of the endemic New Zealand red admiral butterfly, *Bassaris gonerilla* (Lepidoptera: Nymphalidae), are thought to have declined since the early 1900s. Hudson (1928) described it as being "very common", but in the later part of the twentieth century there was anecdotal evidence suggesting that its numbers had declined (Miller, 1971; Gibbs, 1980). The most thorough review of *B. gonerilla* natural history is given by Gibbs (1980), who described it as widespread throughout New Zealand but not very common. It is difficult to assess the current status of *B. gonerilla* populations because there are no historical records of red admiral abundance to determine any changes in population levels. Similarly, data on the other twelve endemic butterfly species are scarce, although two species, the forest ringlet *Dodonidia helmsii* and the southern blue *Zizina labradus oxleyi*, are thought to be threatened (Patrick and Dugdale, 2000).

The establishment of two exotic pupal parasitoids has been linked to the suspected decline of *B. gonerilla*. *Echthromorpha intricatoria* (Hymenoptera: Ichneumonidae) is a solitary pupal endoparasitoid which parasitises a wide range of Lepidoptera. For example, in New Zealand it has been reared from

lepidopteran pupae in the Arctiidae, Hyspidae, Nymphalidae, Psychidae, Pyraustidae, Saturniidae and Tortricidae families (Valentine, 1967). It was first recorded in New Zealand in 1900 and is believed to be self-introduced from Australia (Parrott, 1952). Very high parasitism levels have been recorded. In 1937 over 66% of 50 *B. gonerilla* pupae collected were parasitised by *E. intricatoria* (Hudson, 1950), and in 1977, 94% of 194 pupae collected in the Orongorongo Valley were parasitised (Gibbs, 1980). The other exotic arrival was *Pteromalus puparum* (Hymenoptera: Pteromalidae), a gregarious pupal endoparasitoid that was deliberately introduced in 1933 for the biological control of the cabbage white butterfly (*Pieris rapae*) (Muggeridge, 1933). It proved to be a successful control agent of the target species, but it also attacked three non-target species: *B. gonerilla*, the yellow admiral *Bassaris itea*, and the monarch *Danaus plexippus*. The level of parasitism of *B. gonerilla* by *P. puparum* has never been quantified and is of some concern because parasitism by introduced biocontrol agents has been implicated as the cause of population decline and loss in non-target species such as native North American Saturniid silk moths, which have been heavily parasitised by the introduced tachinid *Compsilura concinnata* (Boettner *et al.*, 2000).

The preferred larval food plant of *B. gonerilla* is

the endemic tree nettle or ongaonga, *Urtica ferox*. The larvae also feed on the native herbaceous nettle *U. incisa* (Gibbs, 1980), the endemic nettle *U. aspera* (Patrick, 1989) and the introduced nettle *U. urens*. Eggs are laid (mostly singly) on nettle leaves throughout spring and summer and hatch after eight to ten days. The larvae develop through five instars over a period of five to six weeks. They construct "tents" by bending over the tip of the nettle leaf and securing it by silken threads. The larvae then feed from within these tents, probably also emerging at night to feed. Pupation occurs on the nettle stem or on a nearby solid structure and typically lasts two to three weeks. The emerging adult butterflies feed on nectar and the fermenting sap of *Nothofagus* spp. trees. They are strong fliers but do not appear to migrate (Gibbs, 1980). The red admiral is multivoltine (i.e. has multiple generations per year), but the timing and number of generations has never been studied. Adults emerging in late autumn are long-lived; they spend the winter in a quiescent state, sheltering in dry foliage, flying only on warm days in winter to bask in the sun and collect nectar.

This paper presents phenological data and pupal parasitism levels for *B. gonerilla* based on two seasons in which *B. gonerilla* densities were recorded on Banks Peninsula.

## Methods

### Estimates of egg, larval and adult density

*Bassaris gonerilla* populations were studied at six field sites on Banks Peninsula, near Christchurch, New Zealand (43°35'19"S, 172°44'18"E to 43°46'08"S, 172°42'38"E). The six sites were: Orton Bradley Park, Buckleys Bay, Jollies Bush Reserve, Prices Valley Reserve, Kaituna-Packhorse track, and Ahuriri Valley. Sites were visited mostly weekly, but on a few occasions at two-week intervals from 9 Oct 2000–5 June 2001 and 12 Oct 2001–31 May 2002.

To estimate the density of the pre-imaginal stages, at least five *U. ferox* plants were selected randomly and sampled at each site. Egg densities were estimated (in summer 2001/02 only) by randomly sampling 30 shoots from each sample plant and searching all the leaves on that shoot for eggs. Larval density estimates were done by counting all the larvae on the sample plants, except on the very large plants where only those individuals within reach of the observer were counted. The area of the sample plants was determined by measuring and plotting the plant canopy cover onto graph paper; these plots were then digitally scanned and their area calculated using image analysis software (UTHSCSA Image Tool v3.0). The egg and larval counts were divided by the area of the plant searched to give an estimate of larvae per m<sup>2</sup>.

Relative adult density was estimated by a transect walk at each field site. Before the walk, cloud cover, wind direction, ambient temperature and start time were recorded. The observer then walked slowly along a fixed route, counting all *B. gonerilla* adults within their field of vision. The number of adults counted was divided by the transect length to give an estimate of adults per km. The transects ranged from 0.44 to 1.15 km in length.

### Estimates of percent parasitism

*Bassaris gonerilla* pupae were collected from *U. ferox* plants on Banks Peninsula in late summer 2001 and 2002. In 2001, 77 pupae were collected from three sites on 28 February–2 March. In 2002, 113 pupae were collected from five sites on 1 March–6 March. The pupae were kept in a controlled-environment room under a 16h:8h light:dark photoperiod, at 18°C with a 10°C range and 55% RH with a 20% range until emergence. The number of *P. puparum* and *E. intricatoria* emerging from the pupae was used to calculate percent parasitism of *B. gonerilla* pupae.

### Winter records of all life stages

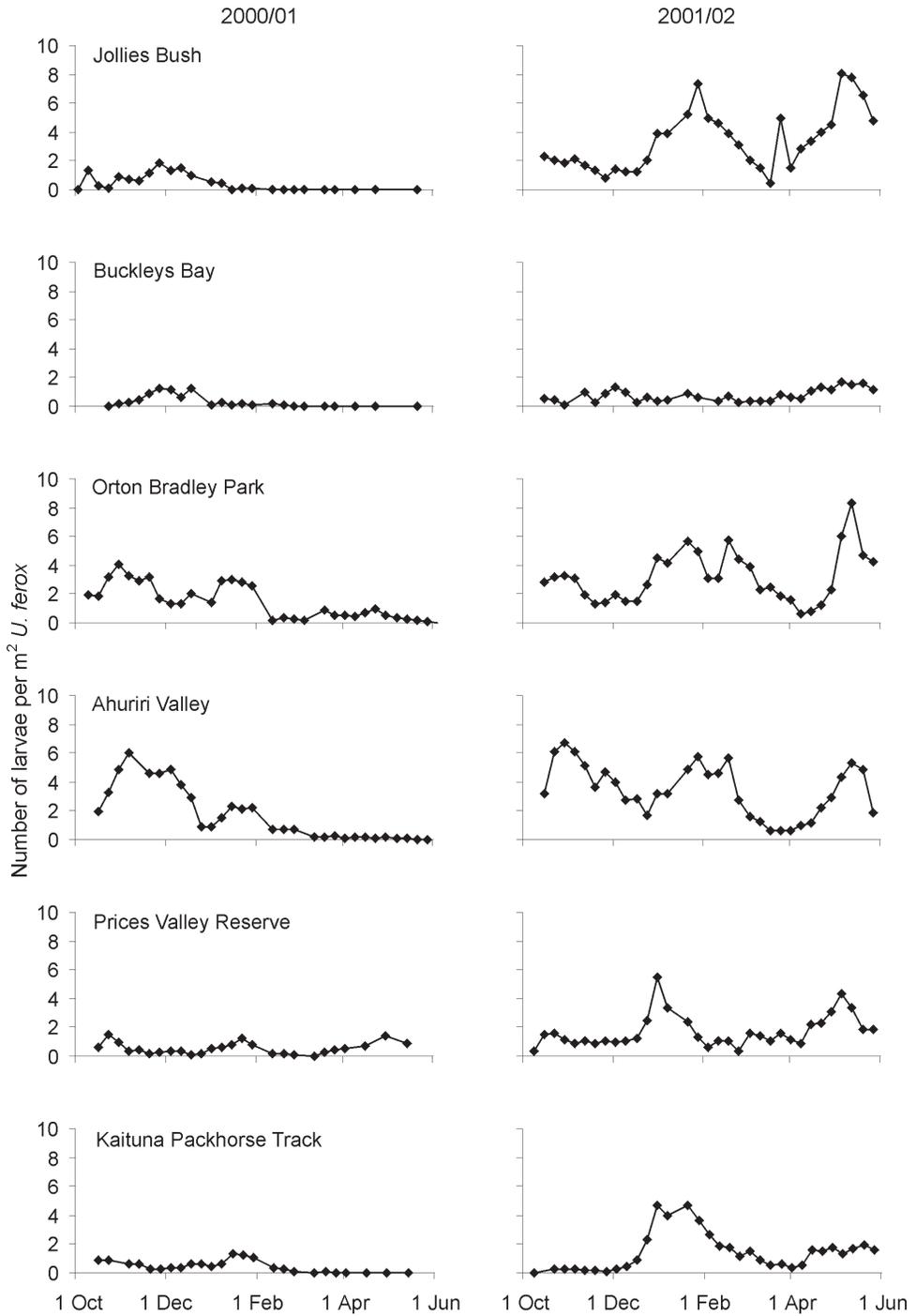
Occasional visits were made to the field sites over winter 2001 and 2002 (June–September) to check for the presence of eggs or larvae. On 1 August 2002 three female butterflies were collected from the Sign of the Kiwi and on 5 September 2002, a further eight females were collected from the same place and from Orton Bradley Park. These butterflies were dissected to check for the presence of mature eggs in the ovarioles (mature eggs have a chorion or egg shell).

On 9 October 2000, 21 pupae, assumed to be parasitized by *E. intricatoria* (given the dark brown, hardened cuticle) were tagged on an *U. ferox* bush at Orton Bradley Park and monitored for the following two months. In August 2002, six parasitised pupae, known to have pupated before mid April 2002, were collected from that site and moved to a controlled-temperature room (18°C with a 10°C range and 55% RH with a 20% range). The purpose of moving these parasitised pupae to higher temperatures and longer daylengths was to determine whether the parasitoids were overwintering in the *B. gonerilla* pupae or if they had died.

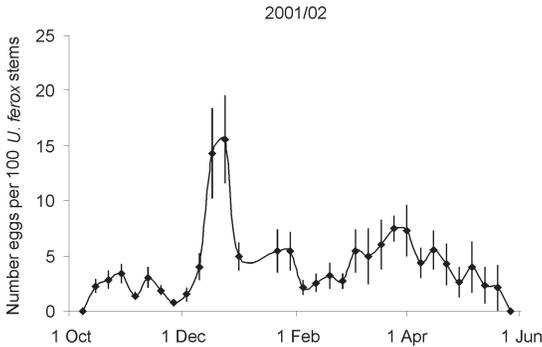
## Results

### Egg phenology

Peak oviposition occurred in late December 2001, with a third smaller peak in late March/early April 2002 (Fig. 1). The earliest date that eggs were found in the field was on 19 August 2000. These eggs



**Figure 2.** Density of *B. gonerilla* larvae at six field sites on the Banks Peninsula, 9 Oct 2000–5 June 2001 and 12 Oct 2001–31 May 2002.



**Figure 1.** Density of *B. gonerilla* eggs at six field sites on the Banks Peninsula, 12 Oct 2001–31 May 2002 (mean of six field sites  $\pm$  S.E.).

hatched when moved to laboratory conditions, but the absence of first instar larvae in the field until late September suggests that ambient temperatures were too low for egg hatch in the field during August.

None of the female butterflies collected on 1 August 2002 had chorionated eggs, although all three contained immature eggs. All eight of the female butterflies collected on 5 September 2002 had chorionated eggs in their ovarioles with a mean egg load of 93.9 ( $\pm 15.4$  S.E.).

### Larval phenology

There were peaks in larval density in November and January/early February in both seasons monitored, but

there was no third peak in May 2001 as there was in May 2002 (Fig. 2). Larval densities were higher at all sites in summer 2001/02 compared with the 2000/01 season.

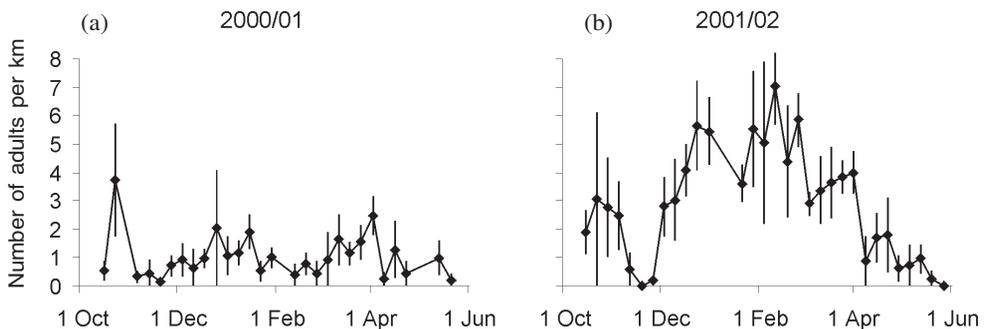
Some third instar larvae were found during winter 2002 in sheltered places at the Ahuriri Valley and Orton Bradley Park field sites but no larvae were found during winter 2001. Late instar larvae (fourth and fifth instar) were also found in early October 2000 and 2002 (but not in 2001), and because they are unlikely to have developed from the egg to late instar larval stage in one month they probably overwintered in the larval stage.

### Adult phenology

Adult numbers were higher in the 2001/02 season compared with the 2000/01 season (Fig. 3). There was a peak in adult sightings in October of both seasons monitored and in the 2000/01 season this was the highest peak recorded over that whole season. In the 2000/01 season there was a second peak in January and a third peak in early April (Fig. 3a). In the 2001/02 season there was also a second peak in January, a third peak in late February then a fourth in early April (Fig. 3b). The third peak in late February 2002 does not correlate with any peaks in egg or larval abundance, whereas the other peaks show some agreement with a developmental timeline.

### Pupal parasitism survey

Pupal parasitism by *E. intricatoria* was high in both years at 67.5% and 82.3% in 2001 and 2002 respectively. Parasitism by *P. puparum* was lower at 16.9% in 2001 and even lower in 2002 at 3.5% (Table 1).



**Figure 3.** Relative density of *B. gonerilla* adults at six field sites on the Banks Peninsula, (a) 9 Oct 2000–5 June 2001 and (b) 12 Oct 2001–31 May 2002 (mean of six field sites  $\pm$  S.E.).

**Table 1.** Species reared from, and percentage parasitism of *B. gonerilla* pupae collected from Banks Peninsula on 28 February–2 March 2001 and March–6 March 2002.

Year	Percent emerging			Failed to emerge	<i>n</i>
	<i>E. intricatoria</i>	<i>P. puparum</i>	<i>B. gonerilla</i>		
2001	67.5	16.9	3.9	11.7	77
2002	82.3	3.5	1.8	12.4	113

### Overwintering of *E. intricatoria* in *B. gonerilla* pupae

Of the 21 pupae tagged at Orton Bradley Park in early October 2000, six yielded *E. intricatoria* which emerged during November and December 2000, whilst the other 15 disappeared. Of the six parasitised pupae collected from Orton Bradley Park in August 2002, three were dissected to reveal *E. intricatoria* pupae. The other three pupae had *E. intricatoria* emerge from them within two weeks of collection. These observations show that *E. intricatoria* is capable of over-wintering as pupae within *B. gonerilla* pupae.

## Discussion

The timing of peaks in the egg, larval and adult stages suggests that *B. gonerilla* is capable of producing two generations per summer in the Banks Peninsula region of New Zealand, with the adults of the first generation emerging around January and the second in April. A third generation was begun in April 2002 and, although most larvae probably perished with the onset of winter due to low temperatures and declining nutritional quality of the *U. ferox* plants, the presence of third instar larvae in the middle of the winter and late instar larvae the following spring suggests that some survived winter in the larval stage. A third generation was not evident in 2001, probably because a severe drought in late summer caused death or leaf loss in many *U. ferox* bushes, limiting larval food resources. A lack of recruitment to a third generation and a cold winter could explain the absence of larvae in winter 2001. Until now, *B. gonerilla* were not known to overwinter as larvae, the adult being the usual overwintering stage. The ability to overwinter as larvae is probably related to the severity of the winter and microclimate around the host *U. ferox* bush. It is possible that at lower latitudes, *B. gonerilla* is able to complete a third generation each summer and/or overwintering in the larval stage is relatively common. The low larval densities going into winter and the low densities of late instar larvae observed the following spring, suggests that the number of overwintering larvae at the Banks

Peninsula study sites is small and thus the contribution of this overwintering generation to the following summer's population dynamics is likely to be minimal.

There was a peak in adult abundance in spring (October) in both years of this study. This phenomenon was observed by Hudson as early as 1883. This spring peak is unlikely to be an absolute increase in adult abundance due to a new generation emerging, because not enough thermal time had passed since the start of oviposition in late September/early October for a generation to be completed. It also unlikely that the development of overwintering larvae could cause this peak because their (estimated) numbers were so few. The number of butterflies counted on transect walks is a function of both abundance and apparency, and apparency can be influenced by weather conditions, time of day, surrounding habitat and seasonal influences (Pollard and Yates, 1993). The peak in red admiral sightings in spring is probably due to their increased activity at this time. The butterflies are just coming out of reproductive diapause and may be concentrated in areas favourable for courtship, mating and egg laying.

The New Zealand red admiral appears to overwinter in a state of reproductive diapause and, judging from egg laying in the field, this period of diapause lasts from late May to late August. Reproductive diapause in other nymphalid butterflies is induced in the larval stage by environmental cues such as decreasing daylength, fluctuating and/or low temperatures and declining host-plant quality (Pullin, 1986a; Nylin, 1989; Pieloor and Seymour, 2001; Goehring and Oberhauser, 2002). It is clear that at least some of the second generation adults produced in late March-early April 2002 were reproductively mature because there was a peak of eggs and early instar larvae around the same time. However some of the females collected in late winter 2002, presumably also from this second generation, had no chorionated eggs in their ovarioles. Thus it appears that the second generation of adults emerging is a mixture of reproductive and non-reproductive adults and, given that a single generation will experience a similar photoperiod, local effects such as host plant quality and microclimate may be important in determining the proportion in each reproductive state.

Both larval and adult abundance was higher in the summer of 2001/02 compared with 2000/01. This was probably a result of higher larval survival in the summer of 2001/02 (M. Barron, *unpubl.*), although the proximal cause of this enhanced survival is unknown. A 20-year data set on population abundance of the nettle-feeding nymphalid *Aglais urticae* showed a strong negative correlation between summer rainfall and the population size of the subsequent (autumn) generation (Pollard *et al.*, 1997). This effect was probably mediated through host-plant effects on larval

survival as it has been shown that reduced nitrogen and water levels result in longer development times in the nettle-feeding nymphalid, *Inachis io* (Pullin, 1986b). It is possible that the higher larval mortality in the summer of 2000/01 was caused by an increased exposure to predation due to longer development times on drought-stressed *U. ferox* plants.

The pupal parasitism survey showed that parasitism levels by the introduced biocontrol agent *P. puparum* are low (3.5–16.9%). Life table analysis has also shown that mortality by *P. puparum* is minimal relative to mortality caused by egg parasitoids (*Telenomus* sp.), larval predation, and pupal parasitism by *E. intricatoria* (Barron *et al.*, 2003). Thus the non-target impact of *P. puparum* appears to be small although this study looked only at direct effects on one species; other studies investigating multiple host-parasitoid interactions in Lepidoptera communities have identified potential indirect effects such as the displacement of native parasitoids (Henneman and Memmott, 2001; Munro and Henderson, 2002). In contrast, parasitism levels by *E. intricatoria* were high (67.5–82.3%) and it is a potentially important mortality factor for *B. gonerilla*. The current study has shown that *E. intricatoria* overwinters as pupae in *B. gonerilla* pupae and is therefore capable of parasitizing the first and all subsequent generations of *B. gonerilla* over the following summer.

This study monitored *B. gonerilla* populations on Banks Peninsula for two summers and, whilst it did show a difference in abundance between a drought (2000/01) and non-drought (2001/02) season, more monitoring is needed to detect long-term trends in *B. gonerilla* abundance. In Britain, long-term butterfly data are collected by the butterfly monitoring scheme which was started in 1976 and is based on weekly transect walks conducted throughout Britain by both professional and amateur naturalists. This scheme has provided many and valuable long-term data on butterfly distribution, trends in abundance, and local extinctions and colonisations (Pollard and Yates, 1993). In New Zealand there is no such scheme and monitoring is restricted to non-standardised counts or simply noting presence or absence. This seriously compromises our ability to make judgements about the status and appropriate management of New Zealand butterfly populations. In the absence of any long-term data, population models are currently being constructed, in part based on the data presented here, to quantify the impact of the two introduced parasitoids, *P. puparum* and *E. intricatoria*, on *B. gonerilla* populations.

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