DEVELOPMENT OF *STETHORUS BIFIDUS* IN RELATION TO TEMPERATURE: IMPLICATIONS FOR REGULATION OF GORSE SPIDER MITE POPULATIONS

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SUMMARY

The relationship between temperature and development rate was linear over the range 12.5 to 27.5°C for eggs, four larval instars and pupae of *Stethorus bifidus* (Kapur) (Coleoptera: Coccinellidae). Development thresholds ranged from 9.4°C for third instar to 11.9°C for eggs, and development from egg to adult took 217 degree days above 12.5°C. As development rates of *S. bifidus* and the gorse spider mite (*Tetranychus lintearius*) (Dufour) (Acari: Tetranychidae) are similar, the implications of this similarity for regulation of gorse spider mite populations are discussed.

Keywords: predation; numerical response, temperature, development rate

INTRODUCTION

Stethorus bifidus is an endemic predatory coccinellid beetle found throughout New Zealand (Houston 1990). It often attacks populations of the gorse spider mite (*Tetranychus lintearius*) recently introduced to New Zealand from Cornwall, United Kingdom. Since their introduction, gorse spider mites have failed to establish at many sites above latitude 39° South and on the west coast of the South Island (Hill *et al.* 1991). One reason for the failure of gorse spider mites at many sites above 39°S may be their inability to compensate for predation by *S. bifidus*.

The predation process is the result of two responses; functional and numerical (Solomon 1949; Holling 1959). The functional response describes the change in predation rate per individual predator as prey density changes. The numerical response describes the increase in the predator population caused by spatial aggregation at the prey (aggregative response), or by predators reproducing close to the prey (reproductive response) (Readshaw 1973).

The reproductive response is measured as the actual rate of increase (r) (Krebs 1985), which depends on the intrinsic rate of increase (r_m) and extrinsic factors like temperature and food supply. Thus estimates of r_m for *S. bifidus* feeding on gorse spider mites at different temperatures help us to understand better the potential of *S. bifidus* to regulate gorse spider mite populations.

In this paper we describe one component of r_m , ie. development rate, for *S. bifidus*. We then compare development of *S. bifidus* and the gorse spider mite and discuss how these results help us understand whether *S. bifidus* could have caused the failure of gorse spider mite to establish in the northern North Island.

MATERIALS AND METHODS

S. bifidus development was measured at 8.5, 12.5, 17.0, 21.0, 24.5, and 27.5°C. To get faster results at 8.5°C we used a split temperature regime; this involved partial development of a given stage at 8.5°C then relocation to a warmer temperature where the duration of development was already known. Lighting was controlled by a fluorescent tube (33 cool white cg instant start 40w) set to a 16:8 L:D photoperiod. Relative humidity was maintained between 65 and 80% with saturated NaCl solutions

Proc. 47th N.Z. Plant Protection Conf. 1994: 103-106

(Winston and Bates 1960) and by enclosing the experimental cages in air-tight 400 X 450 X 750 mm chambers made from cardboard box ends connected with light framing timber and covered in clear plastic bags (drum liners).

Mixed-stage gorse spider mite colonies were prepared by keeping 100-200 adult and deutonymph mites for one generation on 150 mm long gorse shoots cut from living bushes. The shoots were kept healthy by inserting the cut stem through a water-tight plastic cap and into a test tube of water (Hill *et al.* 1989). Shoots prepared like this could be inspected horizontally under a dissecting microscope. Water in the test tubes was changed every 3-4 days. Most shoots kept in this way supported gorse spider mites throughout the duration of *S. bifidus* development.

Female *S. bifidus* were collected from the field near Palmerston North and reared on gorse shoots or in artificial perspex cells. Shoots better simulated field conditions, but cells were essential for first instar larvae at cool temperatures when mortality on shoots was high. To collect eggs, *S. bifidus* were kept in cells modified from the design of McMurtry *et al.* (1974). Sixteen holes (cells) of 15 mm diameter were drilled into a top perspex plate (100 X 100 X 3 mm) and 16 ventilation holes (8 mm dia.) were drilled into a bottom perspex plate of the same size. The plates were separated by builders' paper to allow air to circulate in the cells. Cover slips were used as lids to prevent beetles and mites escaping.

Individual female beetles were left in cells for 12 h at the appropriate temperature with gorse spider mites as food. Any eggs laid during this period were discarded, ensuring that eggs laid subsequently had developed entirely at the selected temperature. Ovipositing beetles were kept until at least 12 eggs had been collected at each temperature within 12 h. At 8.5 and 12.5°C, it took more than 12 h to collect 12 eggs so they were collected over a longer period and kept in chronological order.

Eggs were collected and transferred singly onto shoots or into fresh cells. At each temperature six shoots with mixed-stage populations of gorse spider mites were inoculated with a *S. bifidus* egg and a minimum of six more eggs were reared in cells as replacements in case eggs or larvae died on shoots. At high temperatures *S. bifidus* oviposition was greater so more than six eggs were collected and reared in cells.

Larvae were reared separately to provide individual records and to prevent intraspecific competition. Larvae in cells at each temperature were fed gorse spider mite eggs and larvae until they became second instars; thereafter they were fed protonymph, deutonymph, and adult mites because observation had shown that as larvae grew they preferred larger prey.

Larvae on shoots and in cells were checked every 12 h and their instars recorded. When larvae were needed from cells to replace dead individuals on shoots, their subsequent development was recorded only after they had moulted to the next instar.

Development of *S. bifidus* on shoots was compared to that in cells using analysis of covariance for each development stage. To retain the overall ("experiment wise", (Sokal and Rohlf 1981)) error rate at $\alpha = 0.05$, probabilities from individual tests were adjusted by the Bonferroni procedure (Wilkinson 1990); thus with five comparisons we considered a difference significant only if $P < 0.05/5 = 0.01$.

Because few individuals survived from egg to adult, total development time was calculated by summing the average time to develop for each instar at each temperature.

We compared total development of *S. bifidus* with that of the gorse spider mite (H. Gourlay, unpublished data) by calculating the difference between slopes of the development rate regression equations, and by comparing temperature thresholds for completion of development from egg to adult.

RESULTS

Differences between mean development rates for *S. bifidus* on shoots and in cells ranged from 0.3% for third instars at 12.5°C to 25% for fourth instars at 27.5°C, but none of these shoot/cell comparisons differed significantly ($P > 0.01$).

On shoots, first instar larvae died at 8.5°C, and survival was poor at 12.5 and 17.0°C. First instar larvae were therefore reared exclusively in cells at 8.5°C and mostly in cells at 12.5 and 17.0°C. At 8.5°C no individuals completed their entire

Figure 1: Development rate (DR) of *S. bifidus*. Data from 8.5°C excluded (open circle). Regression equation is: $DR = 0.0046(^{\circ}C) - 0.049$.

development from egg to adult and few survived more than one instar, and so data from this temperature were excluded from subsequent analyses.

Between 12.5 and 27.5°C development rate of *S. bifidus* from egg to adult was adequately approximated by a linear relationship (Figure 1; $R^2 = 0.99$, $n = 5$, $F = 239$, $P < 0.05$). Development thresholds for the pre-imaginal stages of *S. bifidus* ranged between 9.4 and 11.9°C (Table 1), with the threshold for overall egg to adult development being 10.5°C. Development took 217 degree days.

TABLE 1: Development rate of *S. bifidus*.

Stage	Threshold for development (°C)	Degree days	R^2	n
Egg	11.87	52.4	0.93	132
1st instar	9.93	28.9	0.76	102
2nd instar	10.84	18.5	0.65	74
3rd instar	9.43	22.6	0.74	63
4th instar	11.62	29.4	0.81	54
Pupa	10.34	52.9	0.96	33

DISCUSSION

The slope of the regression of overall development rate with temperature for *S. bifidus* was only 2% less than that of the equivalent regression for the gorse spider mite. *S. bifidus* had a development threshold of 10.5°C and took 217 degree days to develop compared with a development threshold of 10.6°C and 213 degree days for the gorse spider mite.

Temperature affects the development rates of *S. bifidus* and gorse spider mites almost identically and it seems implausible to attribute the similarity to chance alone. However, the two species have not co-evolved; *S. bifidus* is endemic to New Zealand and the strain of gorse spider mite originally released in New Zealand is from Cornwall.

A more plausible explanation for the coincidental development rates might relate to similarities between the gorse spider mite and the naturally occurring prey of *S. bifidus*. *S. bifidus* presumably fed on native tetranychids before cosmopolitan tetranychids like two-spotted mite (*Tetranychus urticae* (Koch)) and European red

mite (*Panonychus ulmi* (Koch)) arrived in New Zealand (J.G. Charles pers. comm.). If these native tetranychids develop at similar rates to the gorse spider mite, this may explain the similarity in development rates for gorse spider mites and *S.bifidus*. As no published data exist for the development rate of any native tetranychid we cannot yet test this hypothesis. Nevertheless, the practical conclusion remains unaltered: *S.bifidus* has no developmental advantage over the gorse spider mite in New Zealand.

The linear model has been widely criticised on various grounds, but it still predicts phenological events in the field at least as well as non-linear models (Worner 1992). Therefore we consider it a useful model for comparing the development of *S.bifidus* and gorse spider mites. Certainly, factors other than the linear model's shortcomings are likely to have more influence on the question of whether *S.bifidus* is a major cause of poor establishment of gorse spider mite in the northern North Island.

Development rate is only one aspect of the reproductive response. Natality and longevity are other important components of the intrinsic rate of increase (Krebs 1985). Stone (1986) found that the mean longevity of gorse spider mites decreased by 10 days when temperature increased from 15°C to 25°C, but we do not know how temperature affects longevity of *S.bifidus*. Apart from the innate capacity of *S.bifidus* for increase, other physiological and/or behavioural traits like feeding voracity may vary substantially with temperature allowing *S.bifidus* to regulate gorse spider mite populations more effectively above latitude 39° South. Further investigation could either address the other components of the numerical response or the functional response of *S.bifidus* to temperature.

ACKNOWLEDGEMENTS

We thank Hugh Gourlay for gorse spider mite data, Alison Hayes for constructive suggestions on the manuscript, Richard Hill for help with gorse spider mite rearing and John Charles for helping to identify *Stethorus* spp.

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