CHAPTER 7

DISCUSSION AND CONCLUSION

This thesis is the first to report details of the biology of the Australian ladybird *Stethorus vagans*. Prior to this, *S. vagans* was only known in the literature from its taxonomy, description and occasional references to its presence in the field. While *Stethorus* spp. have been studied in Europe, Asia and USA, only one other Australian species *S. nigripes* (=*S. loxtoni*) has investigated in depth (Richardson 1977). Where possible, this thesis has compared data from *S. vagans* with that reported for *S. nigripes*.

Because of the lack of basic biological data on *S. vagans* the studies primary focussed on the laboratory and semi-field investigations. These concentrated on elucidating information on its development, host location, feeding and reproductive behaviour.

A summary of the major specific thesis outcomes is given in Table 7.1.

Table 7.1 A summary of the major outcomes of the thesis.

Major finding of the thesis	*Chapter/s*	*New*	*Previously reported in S. vagans.*	*Previously reported in other Stethorus spp.*
1. Development of improved rearing method.	2	yes	no	no
2. Calculation of minimal developmental threshold temperature for all stages of *S. vagans*.	3	no	no	yes
3. Calculation of DD for all stages.	3	no	no	yes
4. Confirmation of sex ratio 1: 1.	4	no	no	yes
5. Determination of no diapause in *S. vagans*.	4	no	no	variable
6. Confirmation of description of some stages of *S. vagans* and description of previously undescribed stages, including measurements.	4	no	yes	N/A
7. Mating requirement for oviposition. One mating sufficient for maximum production of viable eggs (for 20 days).	4	no	no	yes

8. Most alternative hosts (live arthropods and substrates) increased longevity, but did not support reproduction.	5	no	no	yes
9. All stages of *S. vagans* have prey preference for eggs of *T. urticae*, but this is influenced by level of starvation.	5	no	no	yes
10. *S. vagans* has type-II numerical response to prey density.	5	no	no	no
11. *S. vagans* show response in time partitioning behaviour between different stages and level of starvation. New activities were identified (ie. walking and drinking water).	5	no	no	yes
12. *S. vagans* adults were shown to be able to locate their prey at low prey densities, provided their normal searching behaviour was not inhibited.	6	no	no	yes

7.1 *S. vagans* and its similarity to other *Stethorus* species

S. vagans is similar to other *Stethorus* species in its morphology and life cycle (Moreton 1969; Daniel 1976; Richardson 1977), its reliance on spider mites as its primary prey and its ability to feed on alternative food sources to maximise its longevity (Putman 1955a; Helle and Sabelis 1985; Majerus 1994). On the other hand, it differs from a number of other species in that is smaller, has a shorter body and has a lower total fecundity (although the rate of oviposition /female /day is approximately the same).

One of the most important characteristics is the conversion of prey (*T. urticae*) eggs into eggs of *S. vagans*. At lower prey densities, this conversion factor was 25-30, but declined to 16-20 at higher densities. The only comparable data has been provided by Richardson (1977) for *S. nigripes* with a conversion factor of 30-40 (although the prey density from which this was determined was not given).

7.2 Evaluation of S vagans as an effective natural enemy

Huffaker *et al* (1969) identified the most important attributes of a natural enemy to be high searching ability, sufficient power of increase to overtake and suppress the prey population, synchrony with the prey and its habitat and a density-dependent response to its prey. *S. vagans* possesses many of these attributes, based on the laboratory and limited field investigations reported in this thesis. It is able to maintain itself at relatively low prey densities, and demonstrates good host location and searching ability. While it has a high preference for one prey species, *T. urticae,* it is also able to survive on alternative food sources likely to be present in the field, including other arthropod species and other organic substrates. Reproduction, however, is severely limited with alternative food. The native spider mite *T. ludeni* may be a possible source of prey for *S. vagans,* although this species was not investigated in the work reported here. However, it is predominantly a tropical species and except for mid-late summer in coastal NSW is unlikely to inhabit much of the known distribution of the predator. *S. vagans* generally appears to be behaviourally and reproductively synchronised with the habitat of its primary prey, except that it does not diapause in conditions where its preferred prey does, including ecosystems primarily composed of deciduous flora. *S. vagans* has many of the qualities expected in a biological control agent. It is able to locate its prey at low prey density and has high powers of increase. It behaviour and reproduction appear to be synchronised with its prey and its habitat (van de Vrie 1972; Readshaw 1975; Bodman 1993; Chapters 4 and 5). It also exhibits a density-dependent response to prey by possessing strongly developed functional and numerical responses to prey density, including intra-specific competition in the form of cannibalism.

7.3 The strategy of *S. vagans*

Natural enemies of invertebrate pests have generally been classified as **r** or **K** strategists MacArthur and Wilson 1967, Pianka, 1972, Matthews 1976) although Greenslade (1972) has also introduced the concept of **beyond K** selection in specific environments. R strategists have a rapid intrinsic rate of increase to exploit the situation of high food density with few other constraints. They are usually tolerant of a broad range of physiological conditions, but are poor competitors, avoiding competition by emigration or other behavioural mechanisms when the prey density is low. They are typically opportunists that arrive early and quickly become numerous in disturbed or unstable ecosystems such as agro-ecosystems. In contrast **K** strategists are generally less voracious and less responsive to changes in prey density and have a narrow tolerance of environmental conditions, including food source. They are, however, good competitors. In general, the relative influence of **r** or **K** selection depends on the degree of stability of the environment (Matthews 1976). It has been argued that the most suitable biological control agents are **r** strategists. In biological control programs, agents are typically imported, mass reared and released into the target area, aiming at long-term establishment in the environment and exertion of some level of suppression on the target species (pest) over time. This has been referred to as "Classical Biological Control". In more recent years, there has been the development of "Inundative Biological Control" in which agents are mass-reared and released in higher numbers in specific target areas, frequently on a regular schedule or in response to pest levels, to achieve rapid reduction of the target species (Broadley & Thomas 1995). In this case, the agent is akin to a biological pesticide. In classical biological control, long-term survival of the agent in the field is essential to its success although this is less important with inundative strategies.

Thus, a natural enemy should exhibit attributes of a **r** strategist when initially introduced, or at times when the prey population may rapidly increase due to disruption of the ecosystem. Yet, for its long-term survival in the field, it must also exhibit attributes of a **K** strategist when pest populations are low. This thesis reports that *S. vagans* exhibits both of these attributes. It behaves as a **r** strategist when populations of *T. urticae* are high, but as a **K** strategist when prey density is low.

7.4 Potential for mass rearing *Stethorus* and field augmentation

A number of insect species as well as several families of mites have been recorded as predators of spider mites (especially *T. urticae*) in the field, and several have been mass reared and used in augmentive biological control programs. There has been only one report of successful mass rearing of *Stethorus* spp. for biological control of spider mites (Scriven &

Fleschner 1960), although Richardson (1977) mass reared almost 20,000 *S. nigripes* which were released in Californian strawberry fields, but apparently failed to establish. This contrasts with the common use of predatory mites in the family Phytoseiidae (eg. *Phytoseiulus persimilis*) (Helle and Sabelis, 1985b; Spooner-Hart 1990), *Typhlodromus* = *Metaseiulus* = *Galandromus occidentalis* (Readshaw 1975; Hoy *et al* 1979; Thwaite 1993) and *T. pyri* (Hardman *et al.*1997; Croft *et al.*1998; Courtieux & Pierre 1999).

A number of authors have reported that *Stethorus* spp. are active fliers and are capable of locating and controllling *T. urticae* populations at low prey densities and in isolated patches (Hull *et al.* 1977b; Helle & Sabelis 1985b). We recorded similar results for *S. vagans* (Chapter 6). The ability to of phytoseiid mites to locate isolated prey is at least partially restricted by their relatively limited mobility.

Another of the major differences between phytoseiid mites and *Stethorus spp* is their prey consumption rate. *P. persimilis* consumes 10-12 mites /day /female, while we recorded *S. vagans* consuming 94-143 mite eggs /day /female, and Richardson (1977) reported similar levels of consumption for *S. nigripes.*

Based on our studies, in which a *S. vagans* culture was maintained for a 3 year period, mass rearing appears feasible. However, preliminary investigations to scale up the colony using the culture method described earlier in this thesis (with minor modifications from Scriven & Fleschner [1960]) proved difficult. There seems to be no immediate alternative to the use of *T. urticae* as prey as evidenced by the results of the investigations reported in Chapter 5, in which alternative food sources were able to significantly increase longevity (although this was still much shorter than with *T. urticae* prey), but were unable to support reproduction.

The lack of suitable artificial diets for rearing arthropods is a limit to production of a number of natural enemies. While Singh (1977) and Singh & Moore (1985) reported more than 750 species that had been successfully reared on artificial diets few have been developed for natural enemies (Anderson & Leppla 1992). The likely reasons given were:

i. Many predators eat only living moving prey.

ii. Predators use chemical cues for prey searching.

iii. Nutrients in the diets must be qualitatively and quantitatively appropriate to support normal growth, fecundity, fertility and behaviour.

If large scale culturing of *S. vagans* using its natural prey was developed, a suitable alternative plant host to French bean for rearing *T. urticae* would be required, because of the presence of leaf trichomes on which larvae become impaled. This contrasts with the rearing of some phytoseiid mites (but not *P. persimilis*) where pollen can be an alternative or supplementary food source, and the presence of pollen and melliferous flowers can prolong their longevity and fecundity in the field (James & Whitney 1993).

Given the absence of diapause in *S. vagans*, this predator provides not only opportunities for continuous rearing, but also for use in field and greenhouse production in winter, where temperatures are able to be maintained above the minimum development threshold of approximately 9.1°C (Chapter 4). In cool areas in Australia and overseas where greenhouse crop production is conducted in winter, houses are frequently heated above this threshold temperature. Rott and Ponsonby (2000a) reported activity of *S. punctillum* against *T. urticae* occurred in heated greenhouse grown crops above 20°C with increased activity to 30 °C.

7.6 The use of *S vagans* in Integrated Pest Management (IPM) Programs

S. vagans is a highly host specific predator. While its target prey *T. urticae* is a major pest in both field and protected cropping (Helle and Sabelis 1985a), it is frequently not the only pest species in the production system, and control measures need to be undertaken for arthropods, pathogens and weeds. The use of a specific biological control agent in such complex ecosystems may therefore, be problematic. The use of pesticides against non-target pests has frequently been associated with resurgence of secondary pests, as a result of their effect on natural enemies.

There appears that *Stethorus* spp may be highly susceptible to a range of pesticides commonly used in agriculture (Charles *et al.* 1985; Hull *et al* 1985; Gurr *et al* 1999; Roy *et al.* 1999). It is possible that there are also sublethal effects of these and other pesticides, such as reduced fecundity or longevity, as this has been reported for other predacious species (Wang & Guo 1995; Wright & Verkerk 1995; Smith & Krischik 1999). The selection of compatible pesticides is therefore a key component of any IPM program involving *S. vagans*.

An alternative option to use of pesticides against other pests is the use of augmentative or inundative releases of biological control agents. In Australia, a number of biological control agents are produced commercially (Broadley and Thomas 1995), and for some crops such as citrus, the naturally occurring biocontrol agents are well documented (Smith et al.) The range of agents available for release is very limited in comparison with Europe (Malais and Ravensberg 1992) and USA (Darr *et al.* 1996). However, there may be sufficient for their incorporation in some IPM programs where they can replace insecticides and acaricides (but not fungicides). In general, it appears that herbicides have less impact on natural enemies than do the other pesticide groups (Nicholas, 2000).

Using a complex of predators against spider mites may also have some validity. Rott and Ponsonby (2000a) demonstrated that in a heated greenhouse, a combination of *S. punctillum* and *Amblyseius californicus* were superior to the commercially available *Phytoseiulus persimilis* in controlling *T. urticae*

Based on the above, the most likely crop ecosystems where *S. vagans* could be incorporated into IPM programs are protected cropping (vegetables, nursery, floriculture, indoor landscapes), pome fruit, berries and hops.

7.5 Future prospects and recommendations

This thesis raises a number of issues that require further investigation. Some key aspects are:

More detailed field studies are required to confirm the data generated from the studies discussed in this thesis, in particular to determine predator-prey interactions under more natural conditions

Prior to any assessment of augmentative field releases, a reliable production system for mass *S. vagans* needs to be developed. Mass rearing on its primary host in the laboratory proved to be difficult, due to production of webbing by heavy infestations of *T. urticae* which impeded movement of all stages of *Stethorus,* and the presence of trichomes on the French bean leaves on which the prey were reared which impaled young *S vagans* larvae. French beans were used because they had previously been identified as the most suitable for mass rearing *T. urticae* for production of the phytoseiid predator *P. persimilis.*

Additional investigations on alternative food sources for *S. vagans*, both in the laboratory but particularly in the field may elucidate the full effect of these on survival and reproduction. The investigations may also provide some suggestions for development of artificial diets.

Further assessment of the host location behaviour is required to clarify the means by which *S. vagans* detects its host, especially at a distance, but also at close quarters. Such studies may identify kairomones or other chemical cues that would assist in understanding this still vexed issue, and provide opportunities to enhance host location or predator aggregation in the field.

7. 6 Conclusion

This thesis concludes that *S. vagans* is likely to be an effective biological control agent of two-spotted mite *T. urticae* based on its attributes elucidated in this thesis. These are its ability to locate hosts in the field at low prey densities, its continuous activity throughout the year, its strong positive functional and numerical response to its primary prey density yet its ability to utilise alternative food and hosts for survival.

However, before this potential can be fully realised, more information is required on its performance in the field, development of reliable methods for mass rearing, and its integration into crop IPM or IPDM programs.