

**Using Hippodamia
ladybird in brassica
integrated pest
management**

Brendan Nolan
QLD Department of Primary
Industries & Fisheries

Project Number: VG04017

VG04017

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the vegetable industry.

All expressions of opinion are not to be regarded as expressing the opinion of Horticulture Australia Ltd or any authority of the Australian Government.

The Company and the Australian Government accept no responsibility for any of the opinions or the accuracy of the information contained in this report and readers should rely upon their own enquiries in making decisions concerning their own interests.

ISBN 0 7341 1547 4

Published and distributed by:
Horticultural Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

© Copyright 2007



Know-how for Horticulture™

Final report

Horticulture Australia Project VG04017



Utilise *Hippodamia variegata* (white-collared ladybird) in brassica IPM.
Brendan Nolan
Queensland Department of Primary Industries and Fisheries

Utilise *Hippodamia variegata* (white-collared ladybird) in brassica IPM

Brendan Nolan
Queensland Department of Primary Industries and Fisheries

Project Number: VG 04017

Horticulture Australia Project Number VG 04017

1 March 2007

By Brendan Nolan
Queensland Primary Industries
Horticulture and Forestry Science
Gatton Research Station
M/S 437 Warrego Highway
Gatton Qld 4343

Purpose

This report is an account of the experimental approach used to review and analyse the impact White Collared Ladybird, *Hippodamia variegata*, has on the suppression and management of insect pests impacting on the brassica vegetable industry and recommendations for integrated pest management systems resulting from the work.

Funding acknowledgments

The following collaborating organisations are gratefully acknowledged for their contribution to this project:



Disclaimer

Any recommendations contained in this publication do not necessarily represent current Horticulture Australia Ltd policy. No person should act on the basis of the contents in this publication, whether as to matters of fact or opinion or other content, without first obtaining specific, independent professional advice in respect of the matters set out in this publication.

TABLE OF CONTENTS

| | |
|---|----|
| <i>Media Summary</i> | 5 |
| <i>Technical Summary</i> | 6 |
| <i>Introduction</i> | 7 |
| <i>White collared ladybird biology and ecology</i> | 8 |
| <i>CLIMEX: predicting the geographical range</i> | 11 |
| <i>Annual abundance of white collared ladybirds</i> | 23 |
| <i>Ladybird rearing</i> | 26 |
| <i>Behaviour of unfed ladybird larvae</i> | 28 |
| <i>Foraging efficiency of ladybird larvae on broccoli</i> | 30 |
| <i>Effects of plant surfaces on ladybird foraging</i> | 34 |
| <i>Prey consumption by white collared ladybird</i> | 39 |
| <i>Future direction and recommendations to industry, research peers and HAL</i> | 42 |
| <i>Bibliography</i> | 43 |

Media Summary

The white collared ladybird (WCL) is native to Central Europe and was first discovered in southeast Queensland in early 2000 by Queensland Departmental entomologists. Since this initial discovery, the ladybird has spread throughout Australia.

The goals of this project were to better understand how the white-collared ladybird (*Hippodamia variegata* Goeze) interacts with its food resources and how this influences its ability to be an effective biological control agent in brassica cropping landscapes.

Project results indicate the white collared ladybird (WCL) has the ability to eat a range of brassica insect pests, but this ability comes at a cost. WCL development and survivorship rates vary between prey species consumed.

Experiments were conducted to assess the movement of ladybird larvae on four brassica species; broccoli, cabbage, cauliflower and Chinese cabbage. Results showed that movement of ladybird larvae on Chinese cabbage was not restricted. However, movement of larvae on broccoli, cabbage and cauliflower plants is negatively affected by the characteristics of the plants leaf surfaces.

A computer model was used to assess the climatic suitability of given locations to estimate the geographical range of WCL in Australia. Understanding current and future distribution of WCL in Australia is very important for pest managers who are developing and implementing IPM programs.

The findings from this research will improve our understanding of naturally occurring biocontrol agents, thereby providing information useful for augmenting biological control, improving conservation efforts, and increasing pest management options.

The research showed that the WCL larvae have a generalist feeding behaviour that includes vegetable pests such as aphids, caterpillar and whitefly. While their impact is limited within a brassica crop, due to the waxy leaf surface of the brassica varieties, they still have the potential to play a significant role in controlling insect pests on non-brassica vegetables and weeds. Therefore the role of this predator in managing vegetable pests should be included in further research.

The next step for researchers should include predator/prey assessments that quantify the impact WCL adults have on pest mortality, and to assess the effects a mixed prey diet (i.e. aphids and caterpillar eggs, etc) has on the survival and physiology of WCL larvae and adults. In addition to predator/prey assessments, knowledge of WCL field activity around Australia and during cooler months is needed, particularly if inundative releases of insectary reared WCL are shown to be commercially viable.

Technical Summary

The goals of this project were to better understand how the white-collared ladybird (*Hippodamia variegata* Goeze) interacts with its food resources and how this influences its ability to be an effective biological control agent in brassica cropping landscapes.

Project results indicate the white collared ladybird (WCL) has the ability to eat a range of brassica insect pests, including aphids (*Lipaphis erysimi*, *Brevicoryne brassicae* and *Myzus persicae*), thrips (*Thrips palmi*), whitefly (*Bemisia tabaci*), moths eggs and neonates (*Helicoverpa spp*, *Crocodilomia pavonana*, *Plutella xylostella*, *Pieris rapae*), but this ability comes at a cost. WCL development and survivorship rates vary between prey species consumed. For example, WCL body mass and weight is lower, take twice the time to complete their lifecycle, and have very low survivorship when fed whitefly compared with aphids.

Additional investigations found that hatching ladybird larvae need to search for and find food within 24 hours or they will die. Since current knowledge suggests ladybird larvae perceive their prey visually and tactilely, success in finding food is largely determined by the characteristics of the surface of the plant the food is located on.

Experiments were conducted to assess the movement of ladybird larvae on 4 brassica species; broccoli, cabbage, cauliflower and Chinese cabbage. Results showed that movement of ladybird larvae on Chinese cabbage was not restricted. However, movement of larvae on broccoli, cabbage and cauliflower plants is negatively affected by the characteristics of the plants leaf surfaces.

Two features on the leaf surface were important: leaf venation (the presence, density, distribution and shape) and the texture of the leaves wax-layer. If the latter is thick and slippery the ladybird larvae cannot hold on in the area between veins, confining larvae movement to protruding veins or leaf edges which they can grip with their feet and anal suction disc. It is assumed then that only host prey that have settled near to protruding veins or leaf margins would be caught. The predatory capacity of *H. variegata* is therefore significantly reduced on broccoli, cabbage, cauliflower plants.

The CLIMEX[®] v.1.1b software package was used to develop a model of the climate responses of WCL based upon its distribution in the western Palaearctic and North America to; (i) project the potential distribution of WCL throughout Australia under current climate conditions; and (ii) assess the sensitivity of this distribution to climate change.

Understanding current and future distribution of WCL in Australia is very important for pest managers who are developing and implementing IPM programs as WCL can provide significant control of pest insects in agro-ecosystems.

A survey of the WCL's activity in the Lockyer Valley was conducted during the project. Survey results showed WCL is active all year round. However, populations appear to decline in the cooler winter and hotter summer periods.

The next step for researchers should include predator/prey assessments that quantify the impact WCL adults have on pest mortality, and to assess the effects a mixed prey diet (i.e. aphids and caterpillar eggs, etc) has on the survival and physiology of WCL larvae and adults. In addition to predator/prey assessments, knowledge of WCL field activity around Australia and during cooler months is needed, particularly if inundative releases of insectary reared WCL are shown to be commercially viable.

During the life of the project, various communication activities have been undertaken to facilitate knowledge from the project, and promotion of the funding agencies (HAL, AUSVEG and QDPI&F). In total, eleven publications/media releases have been produced; and sixteen field days/seminars have been given.

Information about the biology and ecology of the WCL in vegetable crops has been produced and made available to industry in the form of a DPI Note. It is available through the Queensland Department of Primary Industries and Fisheries web site (<http://www2.dpi.qld.gov.au/horticulture/18686.html>).

Introduction

Phytophagous insect pests place a major constraint on our ability to grow and harvest crops. Globally, it is estimated that every year, insect pests destroy between 10 to 15% of our potential food, feed and fibre production worldwide. Controlling them has been the aim of much research and can be costly for growers, both financially and environmentally.

The integrated pest management (IPM) strategies currently employed by brassica growers in Australia focus on non-chemical approaches to reduce the incidence of insect pests and associated damage. One approach is to protect and promote the activity of naturally occurring beneficial insects, as they feed on insect pests reducing the need for intervention with disruptive insecticides.

Knowledge of naturally occurring beneficial insects in the landscape is very important for pest managers who are developing and implementing IPM programs.

The goals of this project were to better understand how the white-collared ladybird (*Hippodamia variegata* Goeze) interacts with its food resources and how this influences its ability to be an effective biological control agent in brassica cropping landscapes.

The experiments used to address these goals are described in the following sections with methods, results, recommendations and related technology transfer outlined for each.

White Collared Ladybird Biology and Ecology

Brendan Nolan and Jerry Lovett

White collared ladybirds have a lifecycle that is called a complete metamorphosis, and pass through the following stages: egg, four larval instars, pupa, and adult (**Figure 1**).

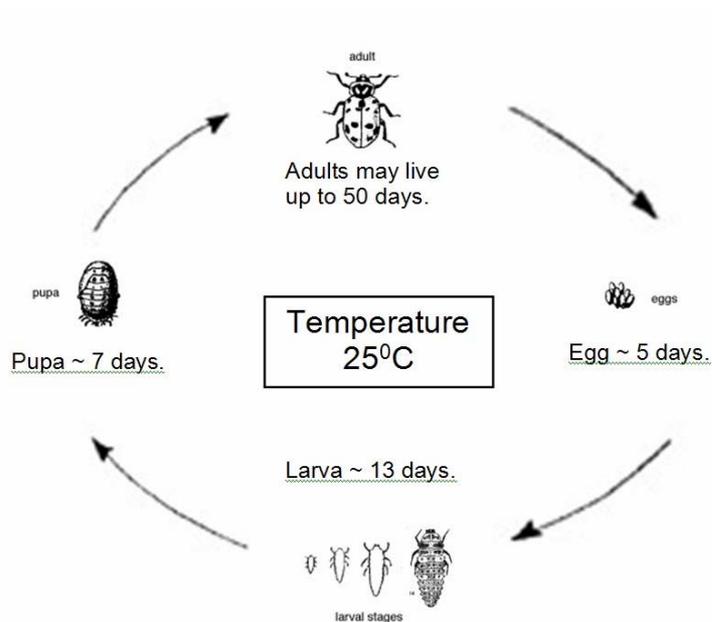


Figure 1. White collared ladybird life cycle.

Adult

The elytra of the emerged adult are soft and light in colour and without pattern. The hind wings protrude from under them and remain unfolded until hardening. The elytra only gradually acquire their normal appearance: the spot pattern appears in a matter of hours, but the red colour may remain a lighter shade for weeks or even months.



Figure 2. White collared ladybird adult.

Adults may live for 40 to 50 days. When temperatures are cold enough during winter WCL will hibernate as adults in protected sites such as leaf litter and the base of grasses and weeds.

Egg

Adult ladybird females may lay between 300 and 400 eggs. Eggs are spindle-shaped, and may vary in colour from yellow to reddish orange (**Figure 3**). Just prior to hatching the eggs become greyish

in colour. The female lays the eggs in clusters (batches) with each egg attached to the substrate by the narrow end, on leaves or stem.



Figure 3. White collared ladybird eggs.

Larva

After hatching from the eggs, the larvae stay on the egg shells for up to one day. During this time they may eat the empty egg shell and often eat nonviable sibling eggs. Then they crawl about in search of their normal food. Ladybird larvae are dark in colour and appear crocodile like (**Figure 4**) with three pairs of legs. Larvae develop from less than 1 mm up to 4.5 mm in length.



Figure 4. White collared ladybird larva.

Pupa

Temperature determines the duration of the pupal stage and may be between 4 and 12 days. During this stage the WCL larvae change into the adult. White collared ladybirds have an uncovered pupa: at the ecdysis to pupa the larval skin is sloughed from the pupa right up to the point where the cauda is attached to the substrate (**Figure 5**). The pupa is not entirely motionless - if irritated the head region is raised several times by upward jerks of the body. When the adults emerge from the pupae they mate and search for prey.



Figure 5. White collared ladybird pupa.

Larval development

The proportion of development time spent in particular larval instars is typical and only slightly varies between species. In the well-being larva the first instar takes in the average 23.7 % of the total development time, the second 16.9 %, the third 19.3 %, and the fourth 39.7 %. The last instar is always longer than other instars even when the time spent as prepupa is not included. Total food consumption of the larva and its final size are largely determined in the fourth instar.

The relative duration of instars may be affected by environmental factors including temperature and food. The variation caused by temperature is relatively small. It is a consequence of the variation of threshold temperatures for development among the instars.

Vegetable crops in which WCL can be found

White collared ladybirds can be found in most crops attacked by aphids, particularly legume crops (beans, peas, etc.), lettuce, brassica crops (Chinese cabbage, broccoli, etc.), tomato, potato and sweet corn.

Insect pests eaten by WCL

Both the adult and larvae are predators. Their food preference is mainly for aphids, including green peach aphid, melon aphid, pea aphid, corn leaf aphid and grey cabbage aphid. If aphids are scarce, WCL will also feed on soft bodied prey such as mites, thrips, scale, leaf hoppers, small caterpillars and insect eggs.

Predatory effectiveness of WCL

White collared ladybirds are usually active all year in southern and eastern Queensland, with peak activity occurring between September and December. They are voracious feeders and may be numerous where prey is plentiful and broad spectrum insecticide use is kept to a minimum or not used.

The larvae may consume approximately 90 aphids per day, whereas the adults consume between 170 and 200 aphids per day. Once all of the aphids have been consumed the adults and larvae will search for additional food. Ladybird adults are very mobile and they are generalist predators. They will not remain on the plant, or crop, once the readily accessible prey has been consumed.

Technology Transfer

The information developed about the biology and ecology of the White Collared Ladybird in vegetable crops has been produced and made available to industry in the form of a DPI Note. It is available through the Queensland Department of Primary Industries and Fisheries web site (<http://www2.dpi.qld.gov.au/horticulture/18686.html>).

DPI Notes provide extensive information that growers can use to improve their production systems.

CLIMEX: predicting the geographical range of *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae), in Australia

Brendan Nolan and Myron Zalucki

Introduction

Coccinellid ladybirds play an important role in controlling phytophagous insects in many agricultural, forestry and horticultural settings (El-Hag 1992; Gordon 1985). Several characteristics, such as a high searching capacity (Hodek and Honek 1996), an ability to occupy all the habitats and niches of their prey, a polyphagous adult diet enabling them to survive food shortages and high consumption rate (Hofsvang 1990), revealing why they have been widely used in biological control for over a century (Obrycki and Kring 1998). Cormier *et al.* (2000) suggests ladybirds are one of the most important groups of beneficial insects.

In 2001 an exotic ladybird, *Hippodamia variegata* (Goeze) (Colioptera: Coccinellidae), was discovered in Australia (Franzmann 2002). The ladybird was first detected at Gatton, Queensland in November 2000. It's not known how it entered Australia, but researchers suspect that it was either accidentally introduced or deliberately for pest control. *Hippodamia variegata*, referred to as *Adonia variegata* (Goeze) in older United States and some current European literature (Gordon and Vandenberg 1991), is a small to medium-sized (3.75-5.60 mm) coccinellid (Fig. 1) indigenous to the Palaearctic region (Fig. 2).



Fig. 1 Adult *Hippodamia variegata* ladybird (left) and larvae (right).



Fig. 2 Palaeartic region where *H. variegata* is indigenous.

The Palaeartic landscape has a climate which ranges from a temperate zone in the north to a southern subtropical zone, suggesting *H. variegata* may function and survive in a large climatic range (Michels and Flanders 1992). Honek (1979) comments that *H. variegata* is a temperature-tolerant species, found in regions where the yearly average temperature ranges from 30°C in Northern Africa to -10°C in Russia.

The temperature tolerance displayed by *H. variegata* has enabled it to expand its native range and colonise new locations. For example, Hamid *et al.* (1977) identified *H. variegata* had become an important predator of aphids in Pakistan during 1967-70. Butani (1972) reports *H. variegata* was recorded for the first time as being associated with cotton in northern India. *Hippodamia variegata* was accidentally introduced into South Africa, Zimbabwe, Ethiopia and Kenya and has become the most abundant coccinellid in wheat (Obrycki and Orr 1990).

Within a few years of introduction into South Africa in 1967, *H. variegata* had spread throughout the country (Aalbersberg, Westhuizen *et al.* 1988). It was deliberately introduced into Chile in 1975 (Zúñiga S., Suzuki S. *et al.* 1986) and successfully established (Araya, Arretz *et al.* 1997). Gordon (1987) suggests *H. variegata* was intentionally introduced into Canada, becoming established at Montreal, Quebec before 1984. Numerous attempts were made to establish *H. variegata* in the USA from 1957 to 1983 and from 1987 to 1993 (Ellis, Prokrym *et al.* 1999). The first indication of its establishment was its discovery in the north-east of the USA in 1992, most likely from a range expansions from Canadian population (Wheeler and Stoops 1996). Between 1987 and 1993, the United States Department of Agriculture released more than 500 000 individuals in the mid-west and west of the country (Franzmann 2002), apparently without achieving establishment there (Mohamed, Lester *et al.* 2000). Difficulty to colonise central USA suggests *H. variegata* has certain climatic preferences, which may limit its geographical distribution in Australia.

The success of *H. variegata* to colonise the Australian environment will depend on its ability to overcome factors such as climate, predators and pathogens, and the availability of food resources (Schowalter 2000). One of the first constraints on an immigrant insect is climate at the time of

arrival (Sutherst 1991). The immigrating insect could either establish itself at the entry point or it could be transported immediately to other areas on the same continent with more favourable climates.

In order to understand the impact an immigrant insect may have in its new environment it is necessary to determine their potential for establishment and dispersal in the area to which they may be introduced (Vierbergen 1995) and whether the climate will enable the species to build up into economically damaging populations. Simulation models are now widely accepted by scientists as being valuable tools to help create an early synoptic view of a potential species invasion (Rastetter 1996; Sutherst 2002).

This study used the CLIMEX[®] v.1.1b software package (Sutherst, Maywald *et al.* 1999) to develop a model of the climate responses of *H. variegata* based upon its distribution in the western Palaearctic and North America to; (i) project the potential distribution of *H. variegata* throughout Australia under current climate conditions; and (ii) assess the sensitivity of this distribution to climate change.

Methods

Ecoclimatic Index

CLIMEX uses long-term averages from meteorological sites to derive a weekly and annual population Growth Index (GI) describing the potential for growth of a given species' population during the favourable season. Four Stress Indices (cold, hot, wet and dry), and their interactions, describe the probability of the population surviving through an unfavourable season. These Growth and Stress Indices are combined into an Ecoclimatic Index (EI), which gives an overall measure of the suitability of a location for permanent occupation by a particular insect species (Sutherst *et al.* 1999).

Fitting parameters to current climate

The climatic requirements of *H. variegata* were derived from literature (Cormier, Forbes *et al.* 2000; Ellis, Prokrym *et al.* 1999; Hodek 1973; Honek 1981; Lanzoni, Accinelli *et al.* 2004; Michels, Flanders *et al.* 1997; Obrycki and Orr 1990; Pekin 1996), personal communication with Ivo Hodek (Coccinellidae specialist, Institute of Entomology, Czech Republic), Sutherst (CLIMEX specialist, CSIRO, Australia) and Meron Zalucki (Insect Ecologist, University of Qld, Australia).

The CLIMEX[®] parameters for *H. variegata* were estimated from its climatic requirements and then tested against its known distribution in western Europe (Afonina, Tshernyshev *et al.* 2001; Atakan and Ögür 1994; Ferrari and Nicoli 1994; Gruber, Poprawski *et al.* 1991; Hodek and Honek 1996; Schmid 1992; Thalji 1994; Voicu, Mateias *et al.* 1992), North Africa (El-Habi, Sekkat *et al.* 2000; El-Hag and Zaitoon 1996; Hodek 1973; Jafari, Zadeh *et al.* 2002; Saharaoui and Gourreau 1998) and North America (Cormier, Forbes *et al.* 2000; Ellis, Prokrym *et al.* 1999; Evans 2000; Gordon 1985; Gordon 1987; Gordon and Vandenberg 1991).

Empirical data pertaining to *H. variegata*'s temperature-dependent development (Ershova 1981; Jafari, Zadeh *et al.* 2002; Lanzoni, Accinelli *et al.* 2004; Michels and Bateman 1986; Michels and Flanders 1992; Wang, Liu *et al.* 1984) and morphophysiological adaptations (Michels, Flanders *et al.* 1997; Pekin 1996) were similarly used to clarify climatic preferences. When the parameter values returned a close match with its known distribution in Europe and North Africa (Fig. 2), and North America they were fixed (table 1) and used to make projections of its distribution in Australia.

Table 1. CLIMEX[®] parameter values giving the best visual fit to the distribution of *H. variegata* in Europe, North Africa, North America and Australia.

| Index | Parameter | Value |
|-----------------|--|---------------|
| Temperature | DV0 = lower threshold | -2.0°C |
| | DV1 = lower optimum temperature | 18.0°C |
| | DV2 = upper optimum temperature | 30.0°C |
| | DV3 = upper threshold | 35.0°C |
| | PDD = degree-day threshold | 230.13°C days |
| Moisture | SM0 = lower soil moisture threshold | 0.2 |
| | SM1 = lower optimum soil moisture | 0.4 |
| | SM2 = upper optimum soil moisture | 1.2 |
| | SM3 = upper soil moisture threshold | 2 |
| Cold stress | TTCS = temperature threshold | -5.0°C |
| | THCS = stress accumulation rate | 0.0004 |
| | DTCS = cold stress day-degree threshold | 0 |
| | DHCS = cold stress day-degree rate | 0 |
| Heat stress | TTHS = temperature threshold | 35°C |
| | THHS = stress accumulation rate | 0.01 |
| | DTHS = cold stress day-degree threshold | 0 |
| | DHHS = cold stress day-degree rate | 0 |
| Dry stress | SMDS = threshold soil moisture | 0.1 |
| | HDS = stress accumulation rate | 0.0001 |
| Wet stress | SMWS = threshold soil moisture | 1.25 |
| | HWS = stress accumulation rate | 0.007 |
| Cold/Dry stress | DTCD = Cold-dry degree-day threshold | -10 |
| | MTCD = Cold-dry moisture threshold | 0.1 |
| Cold/Wet stress | DTCW = Cold-wet degree-day threshold | -10 |
| | MTCW = Cold-wet moisture threshold | 0.2 |

Influence of climatic factors on the value of stress indices

In CLIMEX[®], stress indices indicate negative population growth potential and vary between 0 and ∞ , where a value of 100 or greater indicates lethal conditions (Sutherst, Maywald *et al.* 1999). When threshold conditions are exceeded, stresses accumulate on a compounding weekly basis. The stress thresholds and accumulation rates set in table 2 are user-defined parameters.

1. Temperature

Hippodamia variegata is a very temperature-tolerant species, found in regions where the average winter temperature ranges from 30°C in North Africa to minus 10°C, in the Yakutsk region of Russia (Hodek and Honek 1996). Wang *et al.* (1984) determined the optimum temperature range for

development was 18-25°C, and the development period from egg to adult in the 1st, 2nd and 3rd generations lasted 39.9, 27.2 and 25.9 days, respectively. Mean adult lifespan lasted 65.5 days for females and 46.6 days for males. Similarly, Jafari *et al.* (2002) determined the thermal development threshold for egg, larvae, prepupa, pupa, and egg to adult stage were 11.16, 13.4, 12.96, 13.48, and 12.76 deg C, respectively. The heat unit requirements for the egg to adult stage was 230.13 degree days (El Habi, Sekkat *et al.* 2000). Field studies carried out in Jiuquan Prefecture, Gansu Province, China, in 1979-81 identified *H. variegata* completed 3 generations a year (Wang, Liu *et al.* 1984).

- **Cold**

Michels *et al.* (Michels, Flanders *et al.* 1997) clearly demonstrated that *H. variegata* could successfully survive very cold winter conditions (av. min. temp of -15 °C), a crucial physiological adaptation needed if it was to successfully establish itself in the Texas High Plains, USA. Honek (1979) reports that it is frequently found in temperate climates in Europe. A threshold value of -5°C for TTCS (Table 1) and a weekly accumulation rate of 0.004 for THCS were used.

- **Heat**

Hodek (1973) notes that *H. variegata* can tolerate temperatures of up to 40°C. Setting the heat stress threshold long-term average (TTHS) to 35°C would include days when the maximum temperature approaches or exceeds 40°C.

2. Moisture

- **Wet**

Hodek (1973) observed *H. variegata*'s natural geographical range had a predominately a temperate climate, which experiences periods of snow and ice during winter months. During these winter months *H. variegata* adults usually selected a dry location for hibernation. Increasing soil moisture levels may impact on *H. variegata* populations during cooler months. The wet stress threshold was set to equal SM3, and the wet stress accumulation rate was adjusted so as to stress populations of *H. variegata* in wet conditions similar to those experienced in Palaearctic locations.

- **Dry**

Hippodamia variegata has a resistance to desiccation, a developed adaptation to dry conditions that occur during arctic winters (Pekin 1996). This morph-physiological characteristic is due to an increase in its ability to endure dehydration (up to 40% of its final weight). The mechanism of transpiration in this species is ineffective, but the release of relatively large amounts of water probably allows it to effectively regulate its body temperature and occupy xerophytic habitats. For this reason the dry stress threshold (SMDS) was set at a lower level than the SM0, using the rationale that *H. variegata* can tolerate lower moisture levels than higher levels.

Fitting parameters to future climate

- **Temperature**

After the CLIMEX[®] parameters were fitted under present climate averages, a climate scenario was performed that reflected a possible temperature increase (greenhouse effect) predicted to occur between now and the mid-to-late 21st century. According to the 'Climate Impact Group' (Kriticos, Sutherst *et al.* 2003) global average daily temperatures are expected to rise in the order of 2°C sometime during this period. Therefore the climate change scenario was used to test the response of *H. variegata* to a 2°C increase in daily minimum and maximum temperatures (Fig. 3).

| | | | | | | |
|------------|------------|----------------------------|------------|-----------|----------|----------|
| Name | | Equatorial Margin Latitude | | | | |
| Year 2030 | | 25 | | | | |
| | Min. Temp. | | Max. Temp. | | Rainfall | |
| | (°C) | (°C/*lat) | (°C) | (°C/*lat) | (%) | (%/*lat) |
| Winter | 2 | 0 | 2 | 0 | 0 | 0 |
| Summer | 2 | 0 | 2 | 0 | 10 | 0 |
| Equatorial | 1.5 | | 1.5 | | 0 | |

Fig. 3 Temperature parameters used in CLIMEX[®] climate change scenario analyses.

- **Rainfall**

There is considerable uncertainty surrounding the effects of climate change on rainfall in Australia (Kriticos, Sutherst *et al.* 2003) . However, the irrigation scenario was used to test the response of *H. variegata* to a 25mm rainfall increase (**Fig. 4**).

| | |
|--|---|
| Specify Irrigation: | |
| <input checked="" type="radio"/> by Season | <input type="radio"/> by Month |
| Winter: 25 | Jan/Jul* <input type="text"/> Jul/Jan* <input type="text"/> |
| Summer: 25 | Feb/Aug* <input type="text"/> Aug/Feb* <input type="text"/> |
| | Mar/Sep* <input type="text"/> Sep/Mar* <input type="text"/> |
| | Apr/Oct* <input type="text"/> Oct/Apr* <input type="text"/> |
| | May/Nov* <input type="text"/> Nov/May* <input type="text"/> |
| | Jun/Dec* <input type="text"/> Dec/Jun* <input type="text"/> |
| ALL values are specified in mm/week | * Southern hemisphere locations |
| <input checked="" type="checkbox"/> OK | <input type="checkbox"/> Cancel <input type="checkbox"/> Help |

Fig. 4 Rainfall parameters used in CLIMEX[®] climate change scenario analyses.

Results and Discussion

The CLIMEX[®] model produces a series of indices for *H. variegata* at each location. The main one is the Ecoclimatic Index (EI). The higher the value of the EI, the more suitable is the location. A marginal EI value above 15 may allow the ladybird to survive, but population growth may be limited due to fluctuating stress indices (R. Sutherst *pers comm.*). An EI value above 35 is considered very favourable and would allow the ladybird to successfully survive and increase its population free from the effects of stress indices.

Current climate scenario

CLIMEX[®] was used to calculate a current climate scenario EI value to describe how favourable the climate of a particular location in Australia is for *H. variegata* (Fig. 5).

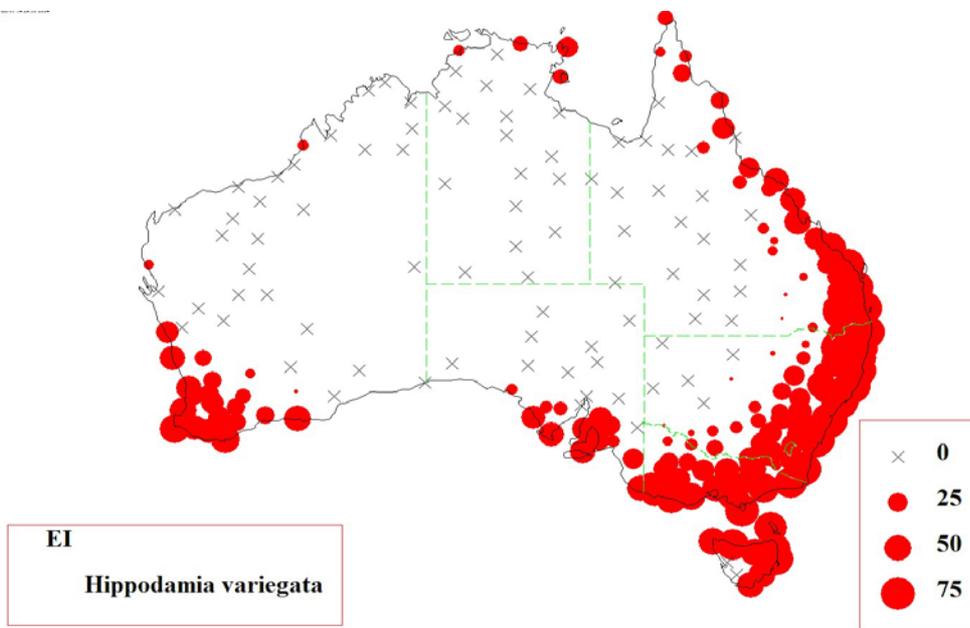


Fig. 5 Ecoclimatic indices for *H. variegata* in Australia under current climate conditions. The relative climatic favourableness of each location for permanent colonisation by *H. variegata* is proportional to the area of the circles. Locations with a cross have indices of zero.

Hippodamia variegata distribution is restricted to a coastal band, between 100 and 800km wide. The band extends from Carnarvon to Esperance in Western Australia (WA), and from Ceduna (SA) to Bega (NSW) to Cape York (Qld). *Hippodamia variegata* also occurs in much of Tasmania and a few coastal locations in the Northern Territory and WA. The band of distribution is thickest in the southern half of Australia, tapering off to a few locations as it extends into northern Australia, suggesting *H. variegata* prefers a temperate climate. The ladybird does not tolerate very hot and dry climates because there is no distribution into the interior of Australia.

The north-western boundary of the potential distribution is limited by hot climatic conditions and monsoonal rainfall events. The CLIMEX[®] model suggests that *H. variegata* entering Australia at locations within this band would experience a climate that would allow it to successfully colonise and increase its population. However if *H. variegata* entered a location outside this climatically suitable range it would have difficulty establishing itself.

The CLIMEX[®] model analysed the suitability of a total of 229 locations in Australia and found 16% had a marginal EI value (15 to 35%), and 36% that had a suitable EI value (> 35) (Table 2). Fifty-four (54) percent of locations had an EI value <15 indicating population growth by *H. variegata* could not occur due to influences by one or more stress indices. Surveys have identified *H. variegata* at locations such as Emerald in Queensland (Franzmann 2002), which experiences an EI value of 5. Migration by *H. variegata* from coastal locations that EI value >15 may explain their occurrence.

Table 2. Current climate conditions: - number and percentage of EI values for 229 locations in Australia.

| EI Value | Number of locations | Percentage |
|--------------|---------------------|------------|
| 0 | 88 | 38 |
| 1 to 15 | 36 | 16 |
| 16 to 35 | 40 | 17 |
| 36 to 60 | 40 | 17 |
| 61 to 100 | 25 | 12 |
| Total | 229 | 100 |

Four main stress indices (dry, heat, cold, and wet) are factored into the CLIMEX[®] model's EI value (Fig. 6). The hot and dry stresses are the main limiting factors affecting the distribution of *H. variegata* in Australia. Hot temperature prevents population growth in semi-arid and arid landscapes that occur in central and northern Australia. Dry stress reduces the growth of *H. variegata* in all locations with exception of Tasmania and the coastal fringe in Eastern and Southern Australia. The combination of heat and dry stress is the major reason preventing *H. variegata* from surviving in central Australia. Wet stress index impacts on the ladybird growth in south west of Western Australia, west coast of Tasmania, Snowy Mountain Region, northern NSW coast, far north Queensland and the Northern Territory. Cold stress does not impact on *H. variegata*.

To determine if *H. variegata* is able to establish itself at the point of entry the weekly growth, temperature and moisture indices of the eight most likely cities for entry in Australia were assessed (Fig. 7). The graphs indicate the climate is very favourable in Brisbane and Sydney. Melbourne and Hobart have a moderately favourable climate, with *H. variegata*'s growth is limited for a short period during mid summer due to moisture stress.

Monsoonal rainfall in Darwin and Townsville during summer severely impacts on *H. variegata*'s ability to survive in open environments. Dry conditions during summer in Perth and Adelaide, and in Townsville during winter impact *H. variegata* at these locations. Rainfall levels may be either inadequate (e.g. Perth during summer) or excessive (e.g. Darwin during summer). Brisbane and Sydney are the only cities, which are highly suitable, with both the temperature and moisture indices being favourable for most of the year.

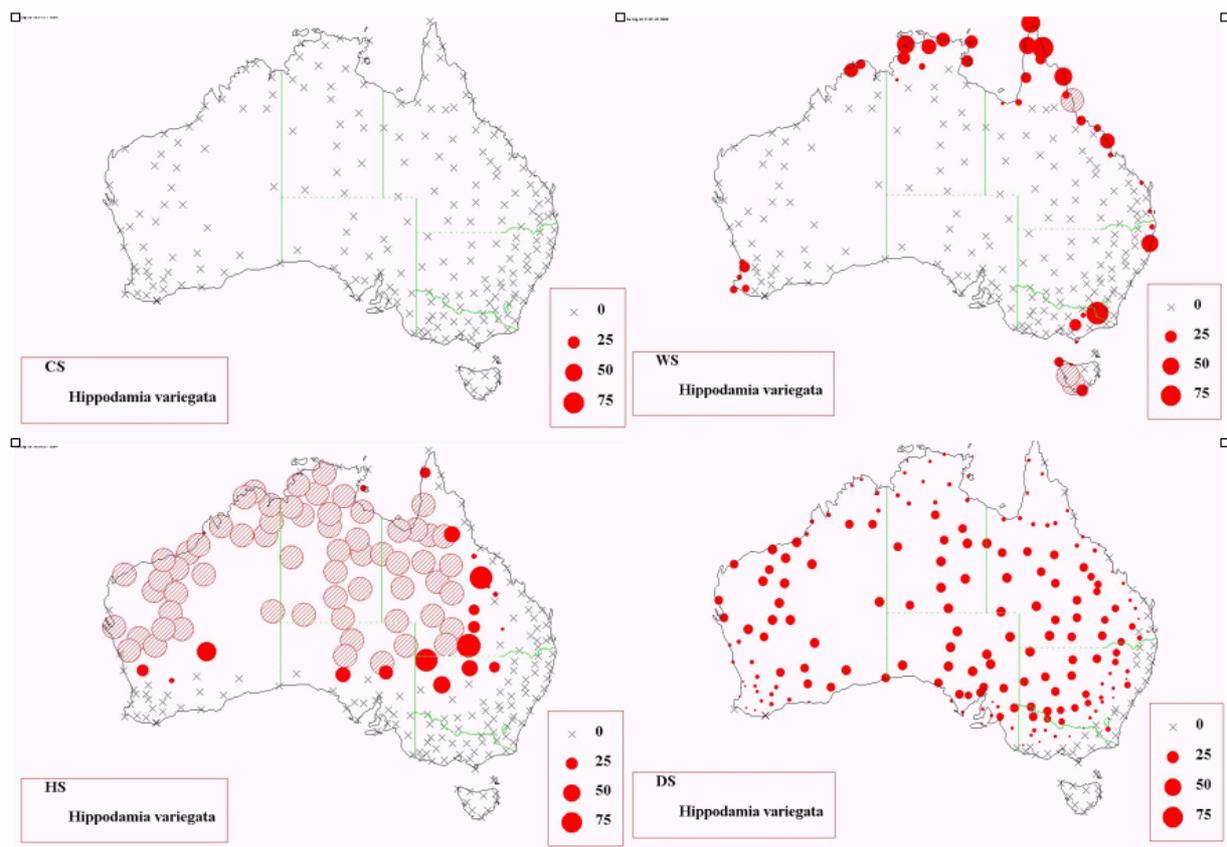


Fig. 6 Current climate scenario stress indices for *H. variegata* in Australia: (CS) cold stress (WS) wet stress (HS) hot stress (DS) dry stress. Open circles with stripes indict locations whose index exceeds the maximum tolerable level of 100. Locations with a cross have indices of zero.

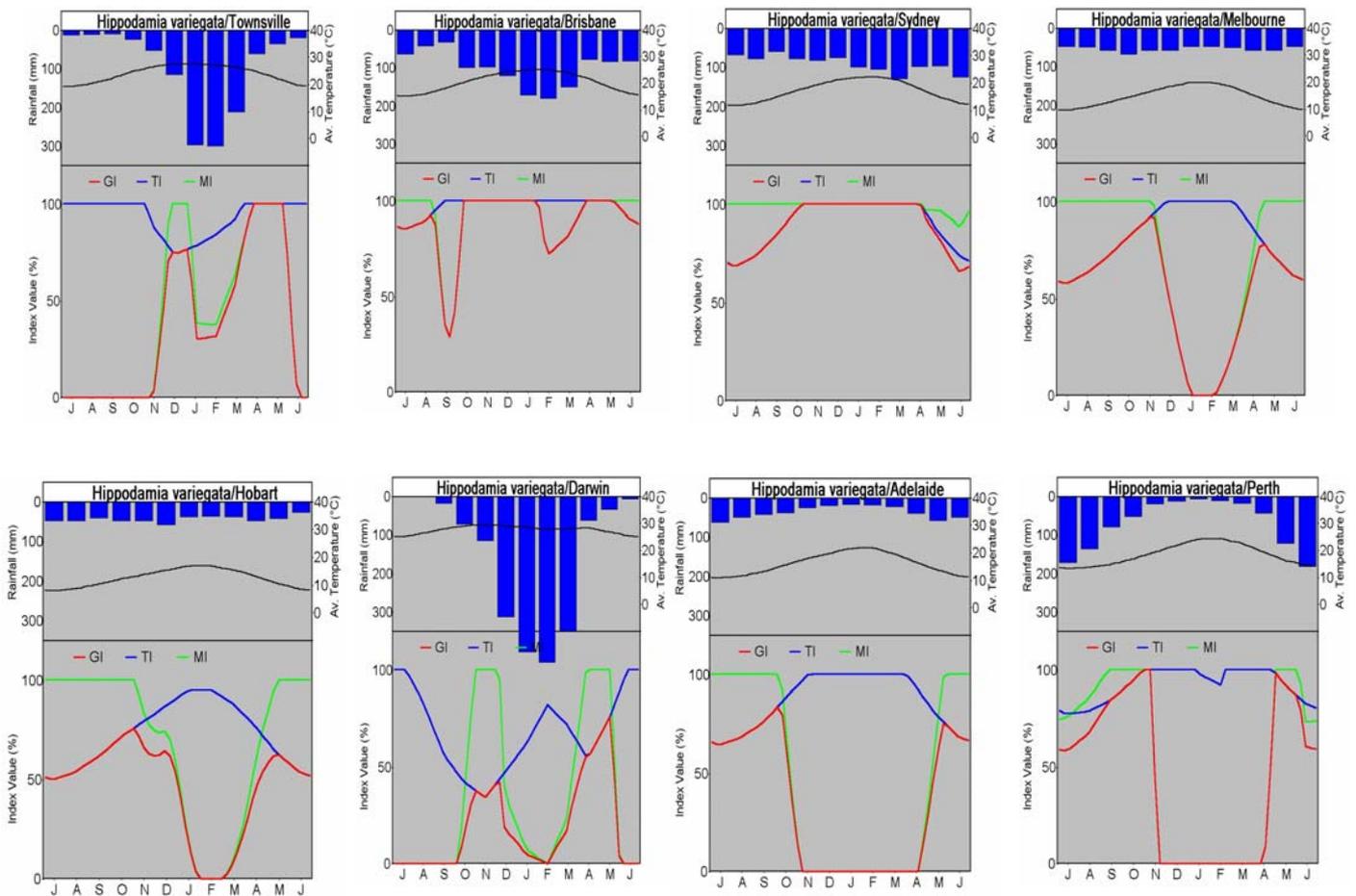


Fig. 7 Long-term weekly growth, temperature and moisture indices for major Australia cities.

Climate change scenario

Using the climate change scenario to increase the average temperature by 2°C and rainfall by 25mm, saw a shift in the geographical extent of *H. variegata* (Fig. 8).

The overall impact of predicted climate change upon the potential distribution of *H. variegata* in Australia was to increase the climatically suitable range in an inland direction.

The ladybird distribution moves away from the coast as the climate becomes too wet for it. The most significant effect from increased rain occurs in southeastern Australia, where the eastern coastline between Melbourne and Brisbane, and most of Tasmania becomes unsuitable for *H. variegata*. Increase in temperature appears to have little impact on *H. variegata* distribution.

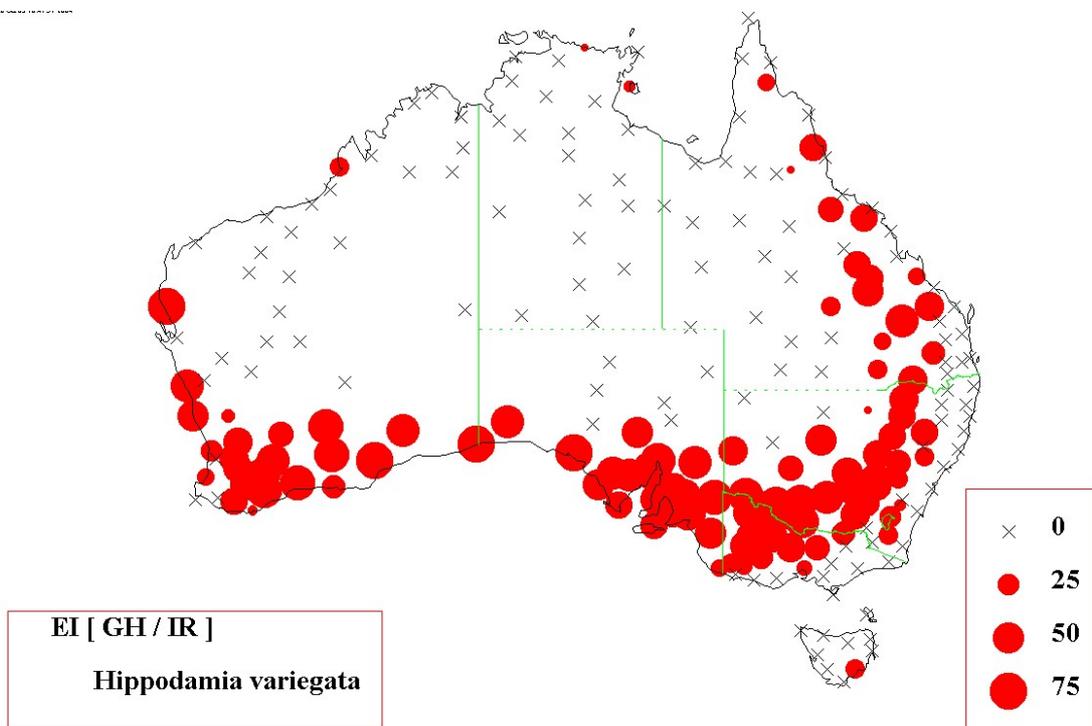


Fig. 8 Ecoclimatic indices for *H. variegata* in Australia using the climate change scenario. The relative climatic favourableness of each location for permanent colonisation by the *H. variegata* is proportional to the area of the circles. Locations with a cross have indices of zero.

The main effect climate change had on the EI values was to cause a 7% increase in the number of locations not conducive (EI < 15) for *H. variegata* survival (Table 4). The number of locations with a suitable climate (EI > 35) for *H. variegata* survival remained constant. However, 7% of locations reduced their EI value below the 60 EI value threshold.

Table 3. Climate change scenario (temperature and rainfall increase): - number and percentage of EI values for 229 locations in Australia.

| EI Value | Number of locations | Percentage |
|--------------|---------------------|------------|
| 0 | 127 | 55 |
| 1 to 15 | 14 | 6 |
| 16 to 35 | 20 | 9 |
| 36 to 60 | 56 | 24 |
| 61 to 100 | 12 | 5 |
| Total | 229 | 100 |

The changed climate scenario dry, hot, cold, and wet stress indices (Fig. 9) were compared with the current climate stress indices (Fig. 6). Heat stress still remains a limiting factor affecting the distribution of *H. variegata* in Australia. The dry stress range no longer impacts on *H. variegata*, its effects are reduced when rainfall is increased by 25mm. However, the effects from wet stress are now significant. The cold temperatures continue to have no effect on population growth. Heat stress is still the major reason preventing *H. variegata* from surviving in central Australia.

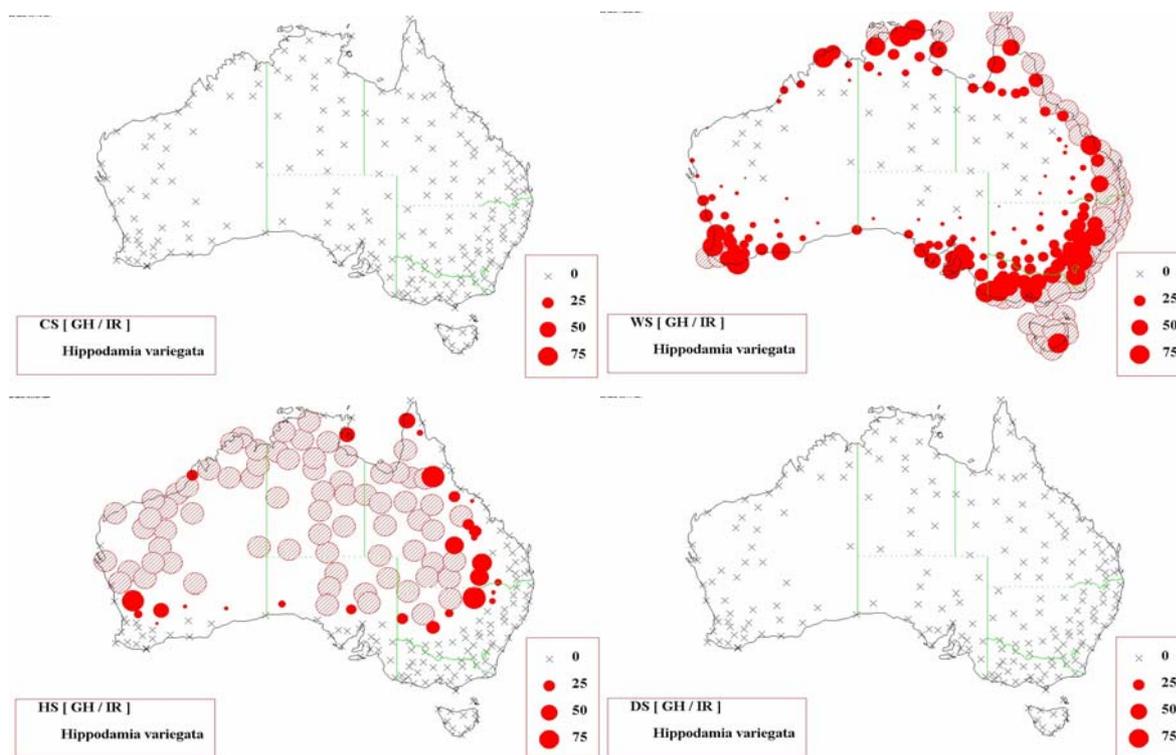


Fig 9. Changed climate scenario stress indices for *H. variegata* in Australia: (CS) cold stress (WS) wet stress (HS) hot stress (DS) dry stress. Open circles with stripes indicate locations whose index exceeds the maximum tolerable level of 100. Locations with a cross have indices of zero.

Recommendations

While CLIMEX[®] is a very good model for providing a reasonable assessment of the climatic suitability of a given location's ability to allow a potential invasive insect to be successful (Dentener, Whiting *et al.* 2002), it has some limitations. For example, Suthurst and Maywald (1991) reminds the user that CLIMEX[®], while easy to use, is a scientific tool that incorporates both ecological understanding and assumptions. Failure of the user to understand the scientific basis of the model and the assumptions on which it is built will result in inaccurate predictions.

While the development of most insect species is predominantly influenced by temperature other regulating factors exist. Being climate based, the CLIMEX[®] model ignores non-climatic factors such as soils, species interactions and competition, pest management practices that also determine habitat suitability for a particular species.

The CLIMEX[®] model makes prediction based on data supplied from meteorological weather station. These climate stations are located irregularly across Australia, with marked biases toward the coastal fringes and eastern mountain ranges, and the records are of variable quality (Baker 1996). For this reason they may not provide an accurate picture of climatic conditions experienced by the targeted organism.

Based on the results of this study, CLIMEX[®] has provided a reasonable initial assessment of the climatic suitability of given locations to estimate the geographical range of *H. variegata* in Australia. Understanding current and future distribution of *H. variegata* in Australia is very important for pest managers who are developing and implementing IPM programs as *Hippodamia variegata* can provide significant control of pest insects in agro-ecosystems.

Technology transfer

In May 2006, the results from this experiment were presented to key industry personal at the inaugural '2006 National Vegetable Industry Conference'. Project results and advice was provided to team members of the HAL project "Development of *Hippodamia variegata* and *Micromus tasmaniae* biocontrol agents for use in Brassica and other vegetable crops" at Orange NSW in June 2006.

Two workshops, one in the Lockyer Valley (June 2006) and Chinchilla (August 2006) were used to present project research outcomes to vegetable growers from Chinchilla and Lockyer Valley.

Annual abundance of the predatory ladybird, *Hippodamia variegata*, in lucerne crops grown in the Lockyer Valley

Brendan Nolan

Introduction

Predatory ladybirds, such as the white collared ladybird (WCL) (*Hippodamia variegata* Goeze) are important in vegetable IPM programs, assisting in the natural control of phytophagous insects. However, WCL activity in crops, as is the case with all ladybirds, can be unpredictable in time and space. Consequently biological control by these predators is also unpredictable. Therefore, knowledge about the annual abundance of WCL is very important for pest managers who are developing and implementing IPM programs.

The research presented here provides population estimates of WCL harboring in lucerne crops planted alongside vegetable crops in the Lockyer Valley, Queensland.

Methods

Between September 2004 and December 2005, ten unsprayed lucerne fields growing in the Lockyer Valley were monitored weekly for ladybird activity. Lucerne was chosen because it is a permanent crop allowing continuous sampling from the same location.

ladybird population estimates were obtained from sampling lucerne using sweep nets. The sweep net was judged to be the best device for sampling most species, including a coccinellid, *Hippodamia spp.* (Fenton and Howell 1957). Sweep net sampling was done using a modified version developed by Elliot and Michels (1997).

A 38-cm-diameter sweepnet was used for to collect samples (Fig. 1). Six 25-sweep samples were taken randomly from within each lucerne field. Thus, a total of 150-sweep samples were taken from each field.

Each stroke with the sweepnet was 1.4-m wide, with the hoop of the net completely submerged in the foliage. When the crop was less than 38-cm high the net was submerged to near the soil surface. One pace was taken between each stroke, therefore the total distance traversed in taking a 25-sweep sample was approximately 20m.

After each 25-sweep sample the net was emptied and ladybird adults and larvae were counted. Only adults were identified to species because accurate identification of larvae in the field is difficult.

Results

Five ladybirds beetle species commonly occurred in samples: White Collared Ladybird *H. convergens*, Transverse Ladybird (*Coccinella transversalis*), Striped Ladybird (*Micraspis frenata*), Three-banded Ladybird (*Harmonia octomaculata*) and Variable Ladybird (*Coelophora inaequalis*) were found in the sampled crops grown in the Lockyer valley between September 2004 and December 2005 are shown in figures 1 and 2.

The dominant ladybird during this period was the WCL, followed by the native transverse ladybird. Other native ladybirds (Stripped, Banded and Variable) were periodically observed, but in lower numbers.

Periods of increased activity occurred between September to November and January to March. Outside these periods of activity populations of all ladybirds were significantly lower. Due to health reasons of the collector no samples were collected during August and September 2005, hence the missing data section.

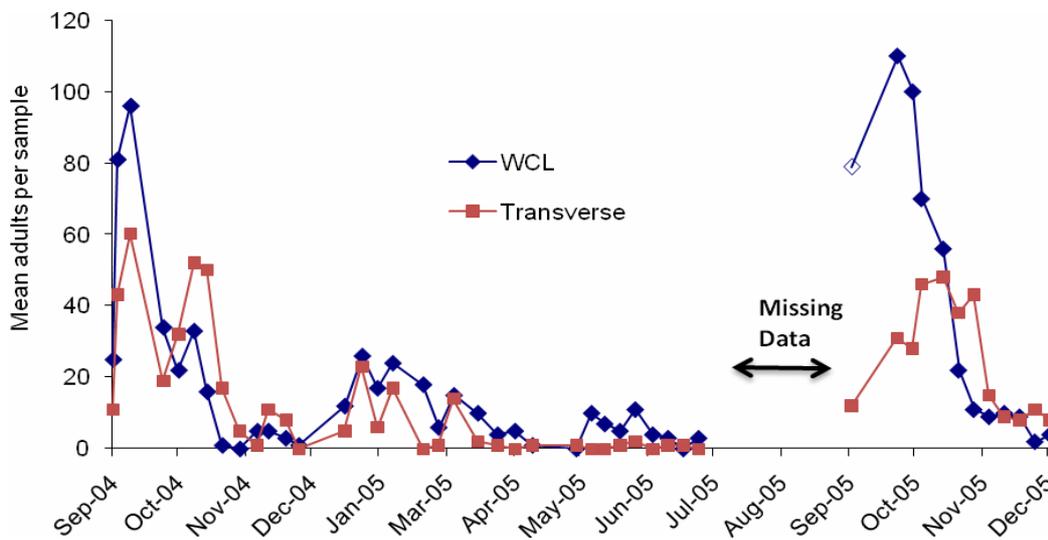


Figure 1: The mean number of adult WCL and Transverse Ladybirds found in lucerne crops grown in the Lockyer valley, 2004-2005.

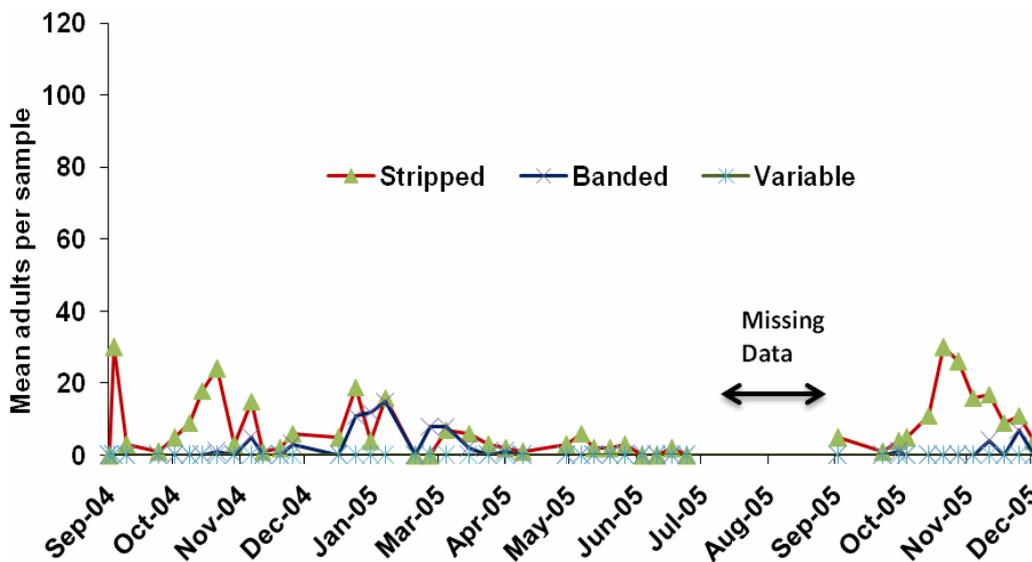


Figure 2: The mean number of adult WCL and Transverse Ladybirds found in lucerne crops grown in the Lockyer valley, 2004-2005.

Recommendations

Populations of WCL appear to be active all year round. However, populations appear to decline during the cooler winter and hotter summer periods. While the relationship between WCL and its prey was not assessed during this survey, the presence of ladybird species during winter, when aphids were not always available as prey suggests other food may be utilised. This is true of some ladybirds in the United States, where predatory behaviour in response to bollworm egg and larval stages and other moth pests has been reported.

The control of other pest species (particularly caterpillar and sucking pests) may influence ladybird abundance. Understanding ladybird activity under a multi-pest management system needs further exploration.

Technology Transfer

There appeared to be close similarities in the seasonal abundance of coccinellids between the ten crops sampled. Suggesting ladybird activity may be similar in much of south-east Queensland.

The results indicate that natural populations of WCL could be supplemented with insectary reared ladybirds; however their behaviour in the absence of prey needs to be assessed.

Acknowledgments

We thank the growers whom provided location on their properties for sampling ladybirds. This assistance is gratefully acknowledged. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

Laboratory technique for rearing the White Collared Ladybird

Brendan Nolan

Introduction

In order to undertake experimentation of the white collared ladybird (WCL) (*Hippodamia variegata* Goeze) during the HAL funded project 'Utilise *Hippodamia variegata* (white-collared ladybird) in brassica IPM' (project # VG04017), it was necessary to develop a practical rearing method for the WCL and its food source, turnip aphids (*Lipaphis pseudobrassicae* [Davis]).

Methods

A colony of WCL's and turnip aphids were reared in a laboratory at the Queensland Department of Primary Industries and Fisheries, Gatton Research Station (27°S'32, 152° E'19) for the duration of the project.

- Temperature controlled rooms

Separate temperature controlled rooms (TCR) were used to rear the WCL's and turnip aphids. The temperature in the TCR used for aphids was set at 26°C ($\pm 1^\circ\text{C}$) and the TCR used for the WCL was set at 25°C ($\pm 1^\circ\text{C}$). Light inside the TCR was illuminated by high pressure sodium lights (SON-T-AGRO 400 Watt) (L:D 16:8). Live plants growing inside TCR were supplied water through capillary matting, lining the floor of predator/parasitoid proof cages.

- Procedure for rearing turnip aphids

Growing Chinese cabbage plants

Turnip aphids feed on brassica plants. Chinese cabbage (*B. campestris* ssp, *pekinensis* cv 'Matilda') was used to rear turnip aphid. The Chinese cabbage were grown from seedlings in small pots (15 cm diameter) in an insect proof screen house. The rooting substrate in each pot consisted of potting mix (Pinebark:peat:sand 2:1:1) and a slow release fertilizer (15:4.4:10 NPK) that was sufficient to meet nutrient requirements. Plants were watered daily through an automatic dripper system.

Plants were ready for inoculation with turnip aphids when they reached the 4-5 true leaf growth stage (Andaloro, Rose *et al.* 1983). When this stage was reached plants were then transferred to a temperature controlled room, inoculated with aphids and then placed in a predator/parasitoid proof cage.

Chinese cabbage plants were continually grown in the shade house to replace plants being removed for aphid inoculation. Any excess plants not required for inoculation were disposed of.

Turnip aphid rearing

In January 2004, wild populations of Turnip aphid were collected from field grown Chinese cabbage. These aphids were transferred to a TCR and deposited onto Chinese cabbage plants. These plants were then placed into an insect proof cage.

For a period of 2 weeks, only 1st instar nymphs produced by these wild aphids were removed with soft fine paint brush and placed onto fresh Chinese cabbage plants. These plants were transferred to a new TCR and placed in an insect proof cage. The reason for this is that the wild field collected

Turnip aphid may have pathogens or parasites that can interfere with a colony. When sufficient numbers of 1st instar nymphs were obtained, the wild turnip aphid colony was destroyed.

Every 10 to 12 days fresh Chinese cabbage plants are placed in the insect proof cages for aphids to colonise.

- Procedure for ladybird rearing

In February 2005, wild populations of adult WCL were collected from lucerne and forage sorghum crops growing in the Lockyer Valley region of south-eastern Queensland. Adults were successfully transferred to a TCR located at the Gatton Research Station.

Copulating adult pairs were isolated and placed into glass vials (25mm x 100mm) lined with paper towelling. Breeding pairs were supplied daily with copious (> 40) turnip aphids. No more than 10-12 breeding pairs were maintained at one time. WCL are voracious feeders. Greater the number of breeding pairs the greater the food and labour requirement will be.

The vials containing breeding pairs were checked daily for eggs. Female usually deposited clusters of eggs on the towelling. Eggs were removed to a new glass vial and incubated for 2 days. After hatching, 1st instar larvae remain clustered around the egg shell, but because of cannibalism it was necessary to immediately separate the newly hatched larvae individually to plastic petri dishes (5cm diameter) using a soft wet paint brush. To reduce cannibalism, no more than 2 larvae are placed in each petri dish. Store larvae in a temperature controlled room (25 ±1°C; L:D 16:8; 60% RH) illuminated by high pressure sodium lights (SON-T-AGRO 400 Watt)..

Feed each larva copious (> 40) amounts of turnip aphids, twice a week, until pupation. Scatter aphids evenly and remove dead aphid skins between feedings if they interfere with a larva's movement. Larvae development takes approximately 22-25 days at 25°C.

Pupae hatch as adults 8-12 days. Adults are able to mate and lay eggs approximately seven days after emerging from pupae.

Technology Transfer

The above procedure describes how to produce and maintain a small colony of WCL adults, eggs and larvae. It is not intended for mass rearing, but rather serves as a template for those who wish to experiment with this insect.

Acknowledgments

We thank the David Schofield (Manager, Gatton Research Station, DPI&F) for technical advice and for laboratory facilities. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

Behaviour of unfed white collared ladybird neonates

Brendan Nolan

Adult ladybirds lay their eggs close to food source (e.g. aphids) so that neonates (newly hatched larvae) can locate and begin feeding quickly. When foraging for prey ladybirds are affected by their habitat (e.g. plant structure), prey location and prey apparency (e.g. odour and visual cues).

The following laboratory experiment assesses the behaviour of unfed white collared ladybird (WCL), *Hippodamia variegata*, neonate larvae.

Methods

Laboratory bioassays were conducted at the Queensland Department of Primary Industries and Fisheries Gatton Research Station between April and May 2005.

A total of 40 WCL eggs, of the same age, were placed individually into plastic petri dishes (7.5cm diameter) with the aid of a soft wet paint brush. Eggs were incubated at 25°C and observed regularly until hatching. All eggs hatched within 1-2 hours of each other.

Apart from the empty egg shell, no food was provided to neonate larvae. The larvae were then observed at 0hrs, 4hrs, 8hrs, 16hrs, 24hrs and 36hrs after hatching. During observation larvae were gently touched with a soft haired paint brush. If the larvae moved they were recorded as alive. If larvae did not move they were recorded as dead.

Results

The survival of 40 unfed WCL neonate larvae is displayed in Figure 1. After hatching, all neonate larva spent a short period on time sitting on the empty egg shell (<8hrs after hatching). Dixon suggest neonates will feed on egg shells before commencing foraging.

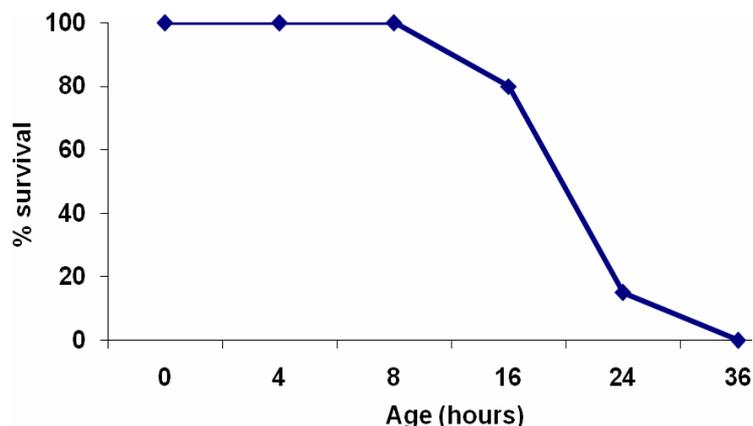


Figure 1: Survival duration of unfed WCL neonate larva.

After 8hrs all larvae had moved away from their empty egg shells and begun to search for food. As time progressed larvae became slower, eventually becoming stationary, before dying. At 24 hours after hatching >80% of the 40 larvae had died. By 36hrs all larvae had died.

Recommendations

The results suggest that WCL neonate larvae will die within 24 to 36 hrs after hatching if food is not found. The longer neonates take to locate food the lower the chance they have of survival. Therefore, eggs not laid by adult females close to food source will have a lower chance of survival compared to ones laid close to food.

Technology Transfer

The results from this experiment were presented at 2 seminars in May 2005. The first seminar was given to members of the Queensland Organics society in Toowoomba. The second seminar was given to visiting NSW fruit and vegetable growers at QDPI&F Gatton Research Station.

Acknowledgments

We thank the David Schofield (Manager, Gatton Research Station, DPI&F) for technical advice and for laboratory facilities. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

Foraging efficiency of white collared ladybird on broccoli plants

Brendan Nolan

Predatory ladybirds, such as the white collared ladybird (WCL) (*Hippodamia variegata* Goeze) have a specialized way of searching and locating prey. When foraging for prey ladybirds are affected by their habitat (e.g. plant structure), prey location and prey apparency (e.g. odour and visual cues).

A following laboratory bioassay was designed to assess the ability WCL larvae to search for and locate turnip aphids on broccoli plants.

Methods

The laboratory foraging bioassays were conducted at the Queensland Department of Primary Industries and Fisheries Gatton Research Station between April and May 2005.

The foraging bioassay had two levels of assessment. Level one assessed WCL neonate larvae and the level two assessed WCL 2nd instar larvae. Both levels of assessment had 5 treatments, containing different rates of WCL larvae (**Table 1**). Each treatment was replicated twice.

Table 1. Number of aphid and WCL larvae per plant per treatment in both levels of the foraging experiment.

| Treatment | Plant type used | No. of WCL larvae / plant | No. of aphids / plant |
|-----------|-----------------|---------------------------|-----------------------|
| 1 | Broccoli | 2 per plant | 10 per plant |
| 2 | Broccoli | 4 per plant | 10 per plant |
| 3 | Broccoli | 8 per plant | 10 per plant |
| 4 | Broccoli | 16 per plant | 10 per plant |
| 5 | Broccoli | 32 per plant | 10 per plant |

Plants

Twenty broccoli plants were grown from seedlings in small pots (15 cm diameter) in an insect proof screen house. The rooting substrate in each pot consisted of potting mix (Pinebark:peat:sand 2:1:1) and a slow release fertilizer (15:4.4:10 NPK) that was sufficient to meet nutrient requirements. Plants were watered daily through an automatic dripper system.

Plants were ready for use when they reached the 5-6 true leaf growth stage . When this stage was reached 10 plants were assigned to each assessment level and transferred to a temperature controlled room (24°C) and placed in a predator/parasitoid proof cage, ready for inoculation with aphids and WCL larvae.

Aphids used in the foraging experiment

Laboratory reared turnip aphids were used for this bioassay. Ten small aphids were deposited, with aid of a soft fine paint brush, into a small plastic clip cage (5cm X 5cm). The clip cage was then attached to the bottom side of the 5th youngest true leaf of each broccoli plant. The aphids were left for 24 hours prior to the bioassay commencing. This allowed the aphids to establish in a small zone on the bottom of the leaf.

This procedure was repeated for each broccoli plant. These plants were then placed into an insect proof cage.

WCL larvae used in foraging experiment

WCL eggs were collected from laboratory reared adult WCL females (see rearing section pp28-29). A total of 124 eggs, which were of the same age, were collected using a soft wet paint brush and placed individually into plastic petri dishes (5cm diameter). Eggs were incubated at 25°C and observed regularly until hatching. All eggs hatched within few hours of each other. Of the hatched larvae, half (62 in total) were assigned to assessment level one. The remaining larvae were assigned to assessment level two.

- Assessment level one

Sixty-two neonate larvae were used immediately in the foraging bioassay. Apart from the empty egg shell, no food was provided to neonate larvae. A soft fine paint brush was used to gently transfer larvae to the same plant as the aphids. Larvae were placed onto the 4th youngest true leaf of a broccoli plant, which was one leaf below the aphids. Neonate densities per plant were determined by treatment requirements (see **Table 1**). Neonates used in the foraging experiment were <6 hours old.

The entire surface of each broccoli plant was observed at regular intervals and the density and location of WCL larvae and aphids were recorded.

- Assessment level two

The remaining sixty-two neonate larvae (see rearing section above) were supplied daily with copious (> 20) turnip aphids until larvae reached 2nd instar lifestage. When the 2nd instar lifestage was reached, the larvae were ready for use in the level two assessment. Method of establishing 2nd instar larvae on broccoli plants followed the same procedure listed in level one assessment above. Second instar larvae were starved for 12 hrs prior to use in the bioassay.

The entire surface of each broccoli plant was undertaken at regular intervals and the density and location of WCL larvae and aphids were recorded.

Results

The results from both assessments showed aphids populations did not change during the experiment (**Figure 1 and 2**). All treatments in both levels of assessment showed a similar decline in WCL larvae on the broccoli plant over time.

An inspection of the soil surface below each plant showed that the WCL larvae had fallen from the plant and were searching the soil surface.

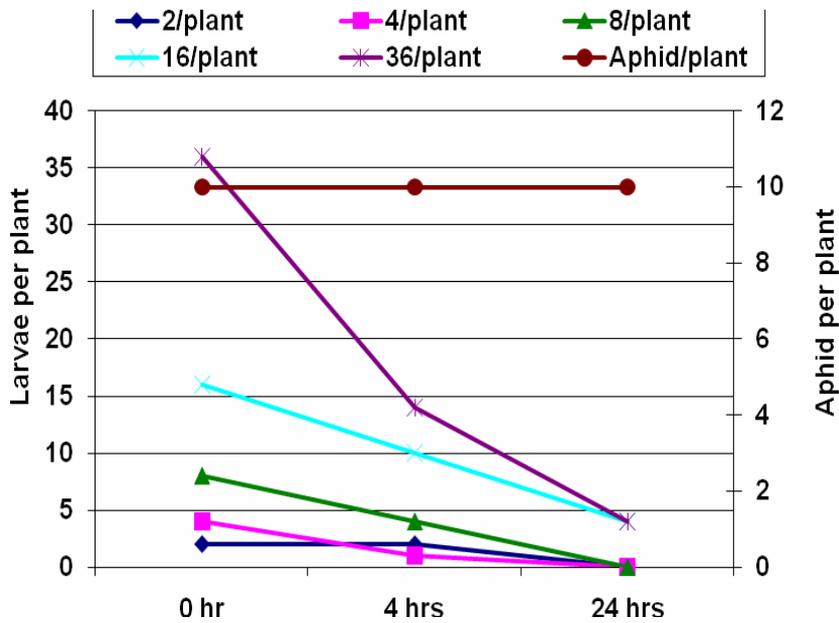


Figure 1. The mean number of WCL neonate larvae and aphids observed in the laboratory on broccoli plants at various time intervals.

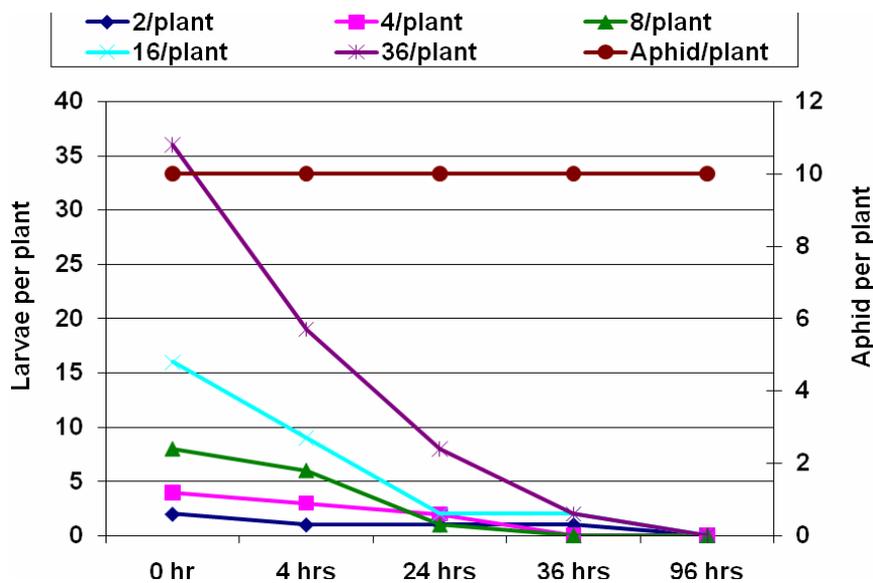


Figure 2. The mean number of WCL 2nd instar larvae and aphids observed in the laboratory on broccoli plants at various time intervals.

Recommendations

The aim of this experiment was to assess the searching time by larvae and give indications of threshold numbers required for reducing aphid numbers on brassica plants. However, serendipitously, it was shown that all neonate larvae did not remain on the plant. Observation during the experiment suggested that the larvae found it difficult to hold on to the plants waxy surface. This phenomenon may have negative implications for the WCL's ability to search, find and

consume prey on brassica plants. Therefore, additional testing is needed to assess the effects plant surface has on WCL foraging.

Technology Transfer

Two field days were held in the Lockyer Valley and Stanthorpe in October 2005 where the results of the experiment were presented to the Brassica industry. Two national media articles were written in October 2005. The first was for Dijana Jevremov detailing the projects objectives for inclusion in the November edition of the 'Brassica IPM Newsletter'. The second article was written for Simon Adams detailing the projects objectives for inclusion in the AusVeg publication 'Vegetables Australia'.

Acknowledgments

We thank David Schofield (Manager, Gatton Research Station, DPI&F) for technical advice and for laboratory facilities. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

Brassica plant surfaces affects movement and biological control potential of coccinellid larvae

Brendan Nolan, Myron Zalucki and Mary Firrell

Introduction

Coccinellid females decides where an egg batch is to be laid (Hodek and Honek 1996). Hatching neonate larvae spend 12-24 hours on the empty egg shells (Michels and Flanders 1992) before they disperse to search for food. If food is not found within 25-35 hours they will die. Since current knowledge suggests coccinellid larvae perceive their prey using visual and tactile stimuli, success in foraging is largely determined by the characteristics of the substratum of the host plant as well as the density of food.

The following paper assesses the influence leaf surfaces of four different brassica plants may have on the larvae of *Hippodamia variegata* Goeze.

Methods

The movement ability of coccinellid larvae were tested in small arenas in the laboratory at the Queensland Department of Primary Industries and Fisheries, Gatton Research Station (27°S'32, 152° E'19) between April and October 2005. Arenas consisted of either a single brassica leaf or a whole brassica plant.

Plants

Four brassica species were tested during the experiments, (1) broccoli (*Brassica oleracea* var. *Italica* cv 'Babylon'), (2) cabbage (*B. oleracea* var. *Capitata* cv 'Kamaroon'), (3) cauliflower (*B. oleracea* var. *Botrytis* cv 'Discovery') and (4) Chinese cabbage (*B. campestris* ssp. *pekinensis* cv 'Matilda'). They were grown from seedlings in small pots (15 cm diameter) in a screen house to the 11-12 true leaf growth stage when used (Andaloro, Rose *et al.* 1983). The rooting substrate in each pot consisted of potting mix (Pinebark:peat:sand 2:1:1) and a slow release fertilizer (15:4.4:10 NPK) that was sufficient to meet nutrient requirements.

Insects

For our experiment we used laboratory-reared larvae *H. variegata* established from wild populations collected from a lucerne crop growing at the Gatton Research Station. Copulating pairs were isolated in glass vials (25mm x 100mm) for 48 hours; fertilised females were then removed and placed in new glass vials lined with paper towelling. Isolated females were supplied daily with copious (> 40) green peach aphids (*Myzus persicae*) collected from Chinese cabbage.

The vials were incubated at 25°C for 3 days during which time the fertilised females deposited clusters of eggs on the towelling. Eggs were removed to a new glass vial and incubated for further two days. After hatching, 1st instar larvae remain clustered around the egg-shell, but because of cannibalism it was necessary to immediately separate the newly hatched larvae individually to plastic Petri dishes.

Larvae were supplied daily with copious (> 40) green peach aphids until they reached 4th instar larvae. Both 1st and 4th instar larvae were used during the experiments. All larvae were starved for 4 hrs prior to use in the experiments.

Leaf surface experiment

One leaf was removed from each of the brassica species (treatment plants) and was placed in glass vial (25mm x 100mm) containing water. A cotton wool plug was positioned to maintain the leaf in a stable position and prevent water escaping from the vial. All leaves were of average age (4th oldest leaf) and size (eg 10cm L x 8cm W). The glass vial was positioned in a clamp, so the leaf was in a horizontally position.

On each leaf, the same seven leaf surfaces were identified (table 1), and used to assess the movement of thirty 1st instar larvae.

Table 1. Seven leaf surfaces used to assess the movement of 1st instar larvae.

| Leaf surfaces |
|---------------------------|
| 1. Abaxial - lamina |
| 2. Abaxial - lateral vein |
| 3. Abaxial - midrib |
| 4. Adaxial - lamina |
| 5. Adaxial - lateral vein |
| 6. Adaxial - midrib |
| 7. Leaf margin |

Thirty different 1st instar larvae were released individually with the aid of soft camel hair brush on to each of the seven identified leaf surface types in each treatment leaf.

Once the larva was established on a leaf surface the glass vial was gently rotated so the leaf surface being tested was facing downwards. Each larvae were observed continuously for 2 minutes or until they fell off the leaf. The length of time on each leaf was recorded.

Climbing experiment

The climbing success of thirty 1st and 4th instar larvae were observed on each treatment plant.

Larvae were released individually with the aid of soft camel hair brush on to the base stem of each treatment plant. Each larva was observed climbing continuously for 10 minutes or until it fell off the plant. The length of time on each plant was recorded.

Results

Leaf surface experiment

The proportion of 1st instar larvae remaining on different leaf surfaces varied between brassica plants (figure 1 to 4). On Chinese cabbage, 1st instar larvae were able to successfully remain on and move on all leaf surfaces tested. The opposite effect was seen on the broccoli, cabbage and cauliflower. Larvae on the leaf surfaces of these plants had difficulty holding on and moving. Successful movement of 1st instar larvae on these plants was limited to leaf margins and on protruding veins which allow larvae to clasp or hold with their legs.

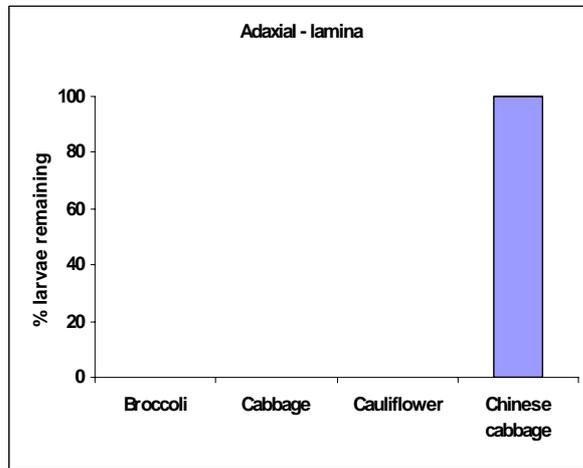
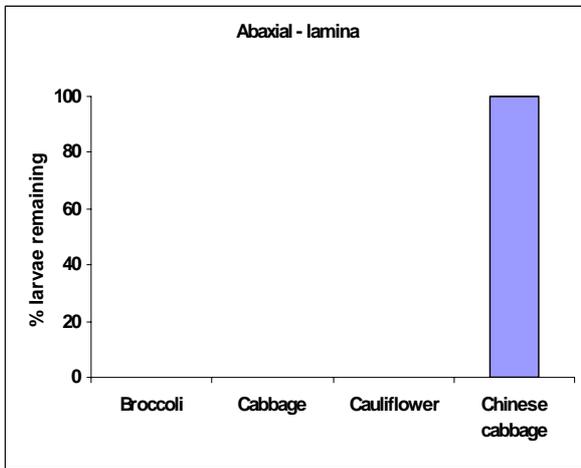


Figure 1. Proportion of larvae remaining on the abaxial (left) and adaxial (right) lamina in each treatment leaf.

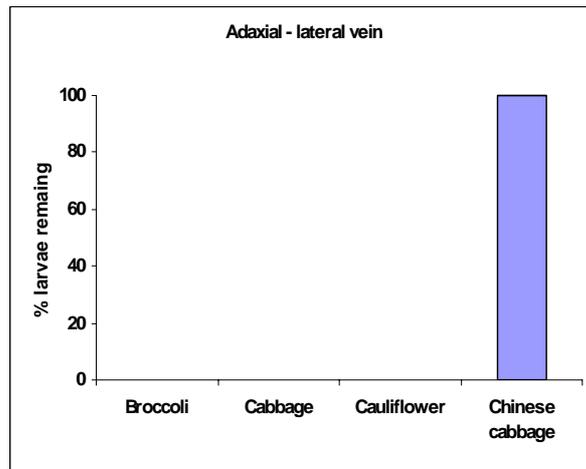
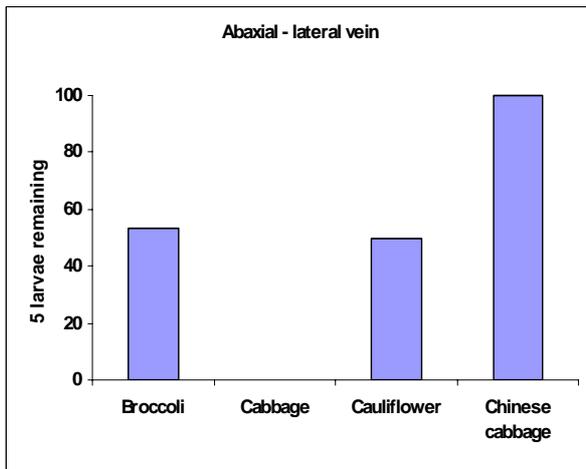


Figure 2. Proportion of larvae remaining on the abaxial (left) and adaxial (right) lateral vein in each treatment leaf.

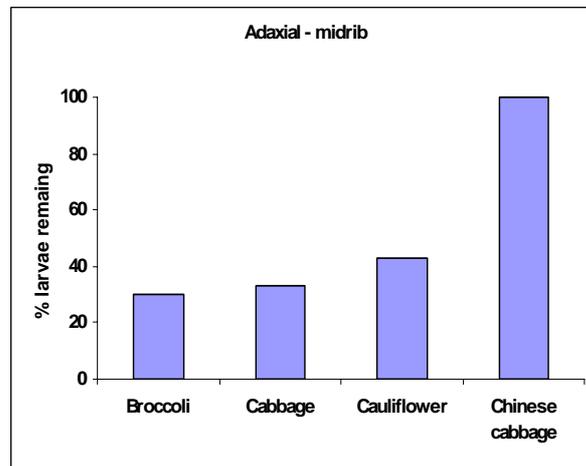
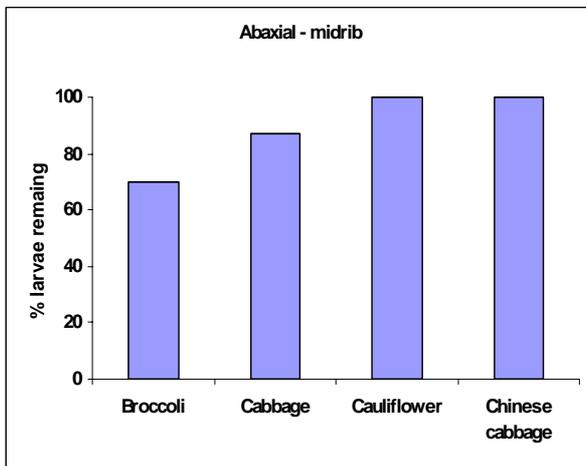


Figure 3. Proportion of larvae remaining on the abaxial (left) and adaxial (right) midrib in each treatment leaf.

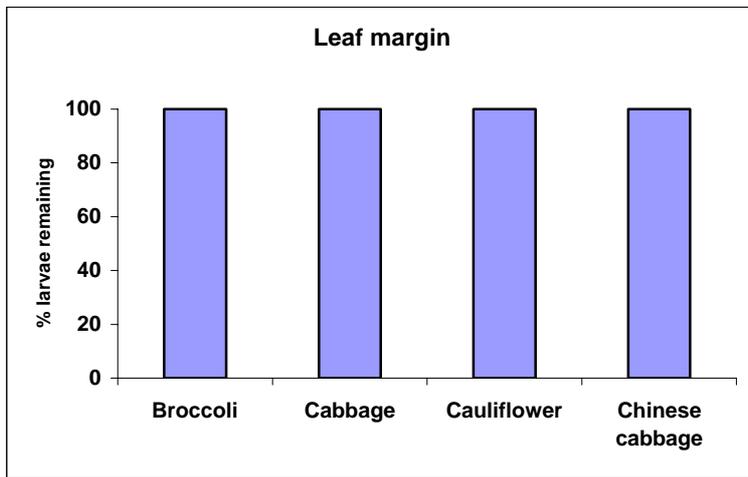


Figure 4. Proportion of larvae remaining on leaf margins in each treatment leaf.

Climbing experiment

The ability of 1st and 4th instar larvae to ascend different brassica plant species and varieties for the purpose of prey searching was assessed (figure 5). Fourth instar larvae were better able to ascend than 1st instar larvae. Larvae ascending broccoli, cabbage and cauliflower were more likely to fall off the plant within 1 to 3 minutes per larvae.

On Chinese cabbage both 1st and 4th instar larvae were able to ascend and search freely over the plant. No larvae fell or had their movement inhibited by the Chinese cabbage plant surface.

On broccoli, cabbage and cauliflower both 1st and 4th instar larvae had difficulty ascending to search the plant. Observation of larvae ascending plants showed the higher they moved the harder it became to hold on as their legs increasingly slipped on the waxy plant surface.

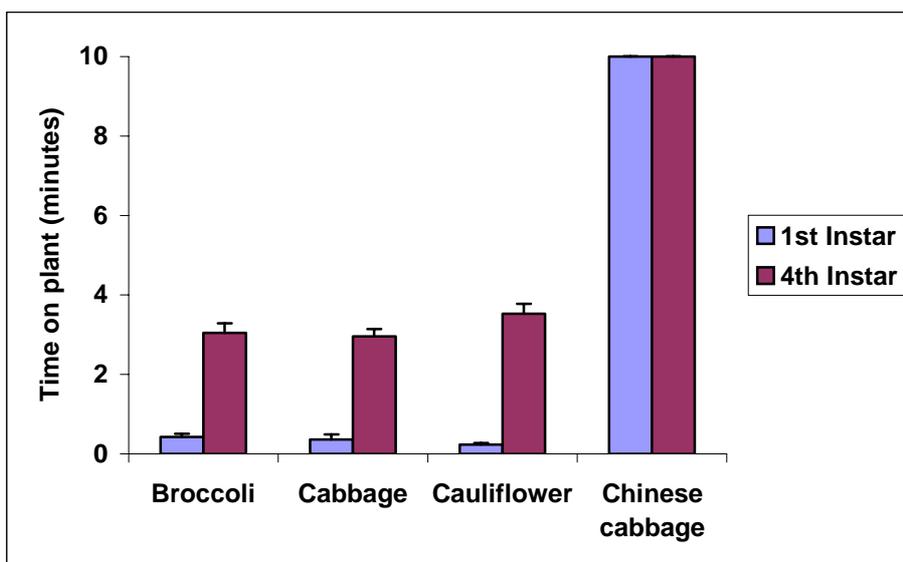


Figure 5. Proportion of time 1st and 4th larvae spent climbing before falling from plants from each treatment.

Recommendations

This study has succeeded in showing that movement of a coccinellid larva on *B. oleracea* is negatively affected by the characteristics of its leaf surface. Two features on the leaf surface were important: the presence, density, distribution and shape of leaf venation and the texture of the wax-layer. If the latter is thick and slippery coccinellid larvae cannot hold on in the area between veins areas and are confined to protruding veins or leaf edges which they can grip with their tarsi and anal disc.

It is assumed then that only aphids which have settled near to protruding veins or leaf margins would be caught. The predatory capacity of *H. variegata* is therefore significantly reduced on *B. oleracea* plants.

Technology transfer

Two field days were held in the Lockyer Valley and Stanthorpe in October 2005 were the results of the experiment were presented to the Brassica industry. Two national media articles were written in October 2005. The first was for Dijana Jevremov detailing the projects objectives for inclusion in the November edition of the 'Brassica IPM Newsletter'. The second article was written for Simon Adams detailing the projects objectives for inclusion in the AusVeg publication 'Vegetables Australia'.

Acknowledgements

We thank David Schofield (Manager, Gatton Research Station, QDPI&F) for technical advice and for providing the trial site. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

White collared ladybird consumption of major brassica pests.

Ladybeetles, such as the White Collared Ladybird (WCL) are considered primarily aphid eaters. However, various laboratory studies focussing on diet have demonstrated that ladybirds will consume non-aphid prey as well, including eggs and larvae of many insects. For this reason, ladybirds are often been considered “generalist” predators.

It is necessary to find out how effective WCL’s are as biological control agents of brassica pests through evaluating predator consumption and the effects the food consumed has on the development and survival of WCL.

Materials and Method

Host insect pests

Table one displays the pest insects assessed for host prey status. The quantities of insects needed for use in this experiment were sourced from either a field grown broccoli crop or from specimens reared in an insectary.

Field specimens were collected from an unsprayed planting of broccoli, grown on the Gatton Research Station for the duration of the project. Insectary specimens (aphids, corn earworm, cabbage white butterfly and diamondback moth) were reared in temperature controlled rooms located at the Gatton Research Station.

Table one. List of the brassica insect pests assessed as host prey for the white collared ladybird.

| Insect common Name | Scientific Name | Life stage |
|-----------------------------|---|------------------------------|
| Aphid | <i>Myzus persicae</i> , <i>Lipaphis erysimi</i> , <i>Brevicoryne brassicae</i> | nymphs |
| Silverleaf Whitefly | <i>Bemisia tabaci</i> | nymphs |
| Cabbage cluster caterpillar | <i>Crocodylomia pavonana</i> | 2 nd instar |
| Centre-grub | <i>Hellula hydralis</i> | 2 nd instar |
| Corn earworm | <i>Helicoverpa armigera</i> | Eggs and neonates |
| Cluster caterpillar | <i>Spodoptera litura</i> | 2 nd instar |
| Cabbage white butterfly | <i>Pieris rapae</i> | Eggs, 1 st instar |
| Diamondback moth | <i>Plutella xylostella</i> | Eggs, 2 nd instar |

Ladybird larvae

Laboratory reared WCL larvae were used for this experiment. Copulating pairs were isolated in glass vials (25mm x 100mm) for 48 hours; fertilised females were then removed and placed in new glass vials lined with paper towelling. Isolated females were supplied daily with copious (> 40) turnip aphids collected from Chinese cabbage.

Vials containing fertilised females were checked daily for clusters of eggs deposited on the towelling. A total of 30 eggs, which were of the same age, were removed using a soft wet paint brush and placed individually into plastic petri dishes (5cm diameter). Eggs were incubated at 25°C and observed regularly until hatching.

All eggs hatched within approximately 2-3 hours of each other. Neonate WCL larvae were used in the experiment with 6 to 8 hours of hatching.

During assessment each neonate WCL larvae was supplied daily with copious amounts of the insect life stage being tested (see table 1). Prior to supply of fresh food the age of WCL larvae was

recorded and if prey had been consumed. Also, each WCL larvae was gently touched with a soft haired paint brush. If the larvae moved it was recorded as alive. If larvae did not move they were recorded as dead.

Supply of fresh food to each was ceased when it began to pupate. When the adult ladybird larvae had emerged after pupation, its length, weight, lifecycle duration (larvae to adult) and fecundity (production and viability) were recorded.

Results

The range of parameters recorded for different brassica insect prey consumed by WCL's indicates mixed results (**Table 2**).

Centre-grub larvae and diamondback moth eggs were the only prey not eaten by WCL. All other prey life stages provided to WCL showed evidence of being eaten. Of these only heliothis neonates were the only prey that did not allow any of the WCL larvae to survive through to adults.

Table 2. Parameters for WCL after consumption of different brassica insect prey.

| Insect pest tested | Was the insect pest eaten? | Ladybird survivorship to adult | Adult Ladybird length (mm) | Adult Ladybird weight (g) | Ladybird development (days) | Adult egg lay | Egg viability |
|--|----------------------------|--------------------------------|----------------------------|---------------------------|-----------------------------|---------------|---------------|
| Aphids | Yes | 100% | 5 | 0.0092 | 19.4 (20 ⁰ C) | Yes | Yes |
| Whitefly | Yes | 17% | 4 | 0.0047 | 48 (20 ⁰ C) | Yes | Yes |
| Heliothis - eggs | Yes | 100% | 4.5 | 0.0071 | 11.1 (27 ⁰ C) | Yes | Yes |
| Heliothis - neonates | Yes | 0% | N/A | N/A | N/A (27 ⁰ C) | N/A | N/A |
| Cluster caterpillar - 2 nd instar | Yes | 25% | 4 | 0.0054 | 37 (20 ⁰ C) | No | No |
| Cabbage white butterfly - eggs | Yes | 100% | 4.5 | 0.0078 | 27.8 (25 ⁰ C) | Yes | Yes |
| Cabbage white butterfly - 2 nd instar | Yes | 43% | 4.5 | 0.0065 | 32.0 (25 ⁰ C) | Yes | Yes |
| Centre-grub - neonates | No | 0% | N/A | N/A | N/A (20 ⁰ C) | N/A | N/A |
| Diamondback Moth - eggs | No | 0% | N/A | N/A | N/A (20 ⁰ C) | N/A | N/A |
| Diamondback Moth - 2 nd instar | Yes | 30% | 4.5 | 0.0069 | 40.0 (20 ⁰ C) | Yes | No |

Recommendations

The results from this experiment show that WCL can predate on a range of brassica insect pests, including aphids (*Lipaphis erysimi*, *Brevicoryne brassicae* and *Myzus persicae*), thrips (Thrips palmi), whitefly (*Bemisia tabaci*), moths eggs and neonates (*Helicoverpa* spp, *Crocodylomia pavonana*, *Plutella xylostella*, *piers rapae*), their rate of development survivorship varies between prey species.

For example, WCL body mass and weight is significantly larger, take twice as long to complete their lifecycles and have very low survivorship when fed whitefly compared with aphids.

Results from this experiment suggest that the WCL is predominately an aphid predator, with alternate prey providing limited benefit. In the absence of aphids, it is most likely that ladybird populations would rapidly decline.

Technology Transfer

Results were detailed in two national media articles were written in October 2005. The first was for Dijana Jevremov detailing the projects objectives for inclusion in the November edition of the 'Brassica IPM Newsletter'. The second article was written for Simon Adams detailing the projects objectives for inclusion in the AusVeg publication 'Vegetables Australia'.

The results were also given during a seminar at the at the inaugural '2006 National Vegetable Industry Conference' Brisbane, in May 2006. The results were also provided advice to team members of the HAL project "Development of *Hippodamia variegata* and *Micromus tasmaniae* biocontrol agents for use in Brassica and other vegetable crops" in Orange NSW in June 2006.

Acknowledgments

I thank David Schofield (Manager, Gatton Research Station, DPI&F) for technical advice and for laboratory facilities. This research has been jointly funded by the HAL, QDPI&F and AUSVEG.

Future direction and recommendations to industry, research peers and HAL

The research showed that the WCL larvae have a generalist feeding behaviour that includes vegetable pests such as aphids, caterpillar and whitefly. While their impact is limited within a brassica crop, due to the waxy leaf surface of the brassica varieties, they still have the potential to play a significant role in controlling insect pests on non-brassica vegetables and weeds. Therefore the role of this predator in managing vegetable pests should be included in further research.

The next step for researchers should be quantifying the impact WCL adults have on pest mortality. Resources, time and various constraints prevented efficacy experiments with adult WCL within this project. Future research should be designed to consider the high mobility of adult as they tend to fly away when placed in an experimental arena. Included in these impact studies could be assessing the effects a diet that relies on a combination of prey (i.e. aphids and caterpillar eggs, etc) on WCL larvae and adult survival and physiology.

In addition to predator/prey assessments, knowledge of WCL field activity around Australia and during cooler months is needed, particularly if inundative releases of insectary reared WCL are shown to be commercially viable. Understanding the distribution of WCL in Australia is very important for pest managers who are developing and implementing IPM programs.

Given the apparent role WCL has in managing vegetable pests, it is important that vegetable growers and researchers continue to find ways to first protect WCL activity in vegetable cropping ecosystems, and second to explore ways to enhance their usefulness in IPM systems.

Bibliography

Aalbersberg YK, Westhuizen MCvd, Hewitt PH (1988) Natural enemies and their impact on *Diuraphis noxia* (Mordvilko) (Hemiptera: Aphididae) populations. *Bulletin of Entomological Research* **78**, 111-120.

Afonina VM, Tshernyshev WB, Soboleva-Dokuchaeva II, Timokhov AV, Timokhova OV, Seifulina RR (2001) Arthropod complex of winter wheat crops and its seasonal dynamics. *Bulletin OILB/SROP* **24**, 153-163.

Andaloro JT, Rose KB, Shelton AM, Hoy CW, Becker RF (1983) Cabbage Growth Stages. *New York's Food and Life Sciences Bulletin* **Number 101**.

Araya JE, Arretz P, Lamborot L, Guerrero MA (1997) Natural control by predators of *Rachiplusia nu* (Guenée) (Lepidoptera: Noctuidae) on Phaseolus beans in central Chile. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* **104**, 147-152.

Atakan E, Ögür AF (1994) Effect of natural enemies on the population development of cotton aphid (*Aphis gossypii* Glov.) (Homoptera: Aphididae). In 'Turkiye III. Biyolojik Mucadele Kongresi Bildirileeri, 25-28 Ocak 1994, Ege Universitesi Ziraat Fakultesi, Bitki Koruma Bolumu, Izmir.' Bornova Turkey pp. 459-470. (Ege Universitesi Basimevi)

Baker RHA (1996) Developing a European pest risk mapping system. *OEPP/EPPO Bulletin* **26**, 485-494.

Butani DK (1972) Some new insects associated with cotton (*Gossypium hirsutum*) in northern hirsutum-arboreum region. *Indian Journal of Entomology* **33**, 227-228.

Cormier CM, Forbes TA, Jones TA, Morrison RD, McCorquodale DB (2000) Alien invasion: the status of non-native lady beetles (Coleoptera: Coccinellidae) in industrial Cape Breton, Nova Scotia. *Northeastern Naturalist* **7**, 241-247.

Dentener PR, Whiting DC, Connolly PG, Zydenbos SM (2002) Thrips palmi Karny (Thysanoptera: Thripidae): could it survive in New Zealand? In 'New Zealand Plant Protection Volume 55, 2002. Proceedings of a conference, Centra Hotel, Rotorua, New Zealand, 13-15 August 2002. 2002, 18-24; 39 ref.' (New Zealand Plant Protection Society; Rotorua; New Zealand)

El Habi M, Sekkat A, El Jadd L, Boumezzough A (2000) Biology of *Hippodamia variegata* Goeze (Col., Coccinellidae) and its suitability against *Aphis gossypii* Glov (Hom., Aphididae) on cucumber under greenhouse conditions. *Journal of Applied Entomology-Zeitschrift Fur Angewandte Entomologie* **124**, 365-374.

El-Habi M, Sekkat A, El Jadd L, Boumezzough A (2000) Biology of *Hippodamia variegata* Goeze (Col., Coccinellidae) and its suitability against *Aphis gossypii* Glov (Hom., Aphididae) on cucumber under greenhouse conditions. *Journal of Applied Entomology-Zeitschrift Fur Angewandte Entomologie* **124**, 365-374.

El-Hag ETA (1992) Potential role of indigenous Coccinellidae in regulation of aphid populations in Central Arabia wheat fields. *Tropical Pest Management* **38**, 425-430.

El-Hag ETA, Zaitoon AA (1996) Biological parameters for four coccinellid species in Central Saudi Arabia. *Biological Control* **7**, 316-319.

- Elliott NC, Michels GJ (1997) Estimating Aphidophagous Coccinellid Populations in Alfalfa. *BIOLOGICAL CONTROL* **8**, 43–51.
- Ellis DR, Prokrym DR, Adams RG (1999) Exotic lady beetle survey in northeastern United States: *Hippodamia variegata* and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). *Entomological News* **110**, 73-84.
- Ershova NI (1981) Aphidophagous coccinellids in covered ground. *Zashchita Rastenii*, 29-30.
- Evans EW (2000) Morphology of invasion: body size patterns associated with establishment of *Coccinella septempunctata* (Coleoptera : Coccinellidae) in western North America. *European Journal of Entomology* **97**, 469-474.
- Fenton FA, Howell DE (1957) A comparison of five methods of sampling alfalfa fields for arthropod populations. *Ann. Entomol. Soc. Am.* **50**, 606–611.
- Ferrari R, Nicoli G (1994) Life cycle and natural enemies of *Aphis gossypii* Glover: first observations. *Informatore Fitopatologico* **44**, 59-62.
- Franzmann BA (2002) *Hippodamia variegata* (Goeze) (Coleoptera : Coccinellidae), a predacious ladybird new in Australia. *Australian Journal of Entomology* **41**, 375-377.
- Gordon RD (1985) The Coccinellidae (Coleoptera) of America North of Mexico. *Journal of the New York Entomological Society* **93**, 1-912.
- Gordon RD (1987) The first North American records of *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae). *Journal of the New York Entomological Society* **95**, 307-309.
- Gordon RD, Vandenberg N (1991) Field guide to recently introduced species of Coccinellidae (Coleoptera) in North America, with a revised key to North American genera of Coccinellini. *Proceedings of the Entomological Society of Washington* **93**, 845-864.
- Gruber F, Poprawski TJ, Rey E (1991) Survey for natural enemies of *Diuraphis noxia* (Mordvilko) in Eurasia. *Bulletin SROP* **14**, 102-109.
- Hamid S, Shah MA, Anwar AM (1977) Some ecological and behavioural studies on *Aphis craccivora* Koch (Hem.: Aphididae). *Technical Bulletin, Commonwealth Institute of Biological Control*, 99-111.
- Hodek I (1973) 'Biology of coccinellidae.' (Academia: Prague)
- Hodek I, Honek A (1996) 'Ecology of Coccinellidae.' (Kluwer Academic Publishers: Dordrecht, The Netherlands)
- Hofsvang T (1990) Advantages and disadvantages of parasitoids and predators of aphids when used in biological control. *Acta Entomologica Bohemoslovaca* **87**.
- Honek A (1979) Plant density and occurrence of *coccinella 7-punctata* and *Propylea quatuordecimpunctata* (Coleoptera: coccinellidae) in cereals. *Acta Entomologica Bohemoslovaca* **76**, 308-312.
- Honek A (1981) Aphidophagous Coccinellidae (Coleoptera) and Chrysopidae (Neuroptera) on three weeds: factors determining the composition of populations. *Acta Entomologica Bohemoslovaca* **78**, 303-310.

- Jafari S, Zadeh JH, Sendi JJ, Hoseini R (2002) Effect of temperature on biological factors of *Hippodamia variegata* (Col.: Coccinellidae) in laboratory conditions. *Journal of Entomological Society of Iran* **22**, Pe13-Pe28.
- Kriticos DJ, Sutherst RW, Brown JR, Adkins SW, Maywald GF (2003) Climate change and the potential distribution of an invasive alien plant: *Acacia nilotica* ssp. *indica* in Australia. *Journal of Applied Ecology* **40**, 111-124.
- Lanzoni A, Accinelli G, Bazzocchi GG, Burgio G (2004) Biological traits and life table of the exotic *Harmonia axyridis* compared with *Hippodamia variegata*, and *Adalia bipunctata* (Col., Coccinellidae). *Journal of Applied Entomology* **128**, 298-306.
- Michels GJ, Bateman AC (1986) Larval biology of two imported predators of the greenbug, *Hippodamia variegata* Goetz and *Adalia flavomaculata* Degeer, under constant temperatures. *Southwestern Entomologist* **11**, 23-30.
- Michels GJ, Flanders RV (1992) Larval development, aphid consumption and oviposition for five imported coccinellids at constant temperature on Russian wheat aphids and greenbugs. *Southwestern Entomologist* **17**, 233-243.
- Michels GJ, Jr. , Flanders RV, Bible JB (1997) Overwintering survival of seven imported coccinellids in the Texas high plains. *Southwestern Entomologist* **22**, 157-166.
- Mohamed AH, Lester PJ, Holtzer TO (2000) Abundance and effects of predators and parasitoids on the Russian wheat aphid (Homoptera : Aphididae) under organic farming conditions in Colorado. *Environmental Entomology* **29**, 360-368.
- Obrycki JJ, Kring TJ (1998) Predaceous Coccinellidae in biological control. *Annual Review of Entomology* **43**, 295-321.
- Obrycki JJ, Orr CJ (1990) Suitability of three prey species for Nearctic populations of *Coccinella septempunctata*, *Hippodamia variegata*, and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). *Journal of Economic Entomology* **83**, 1292-1297.
- Pekin VP (1996) Morphophysiological adaptations of Coccinellidae (Coleoptera) to arid conditions. *Russian Journal of Ecology* **27**, 274-277.
- Rastetter EB (1996) Validating models of ecosystem response to global change. *Bioscience* **46**, 190-197.
- Saharaoui L, Gourreau JM (1998) Coccinellids of Algeria: preliminary inventory and food range (Coleoptera, Coccinellidae). *Bulletin de la Société Entomologique de France* **103**, 213-224.
- Schmid A (1992) Investigations on the attractiveness of agricultural weeds to aphidophagous ladybirds (Coleoptera, Coccinellidae). In 'Agrarökologie' p. 122 pp.
- Schwalter TD (2000) 'Insect Ecology - an ecosystem approach.' (Academic Press: California, USA)
- Sutherst RW (1991) Predicting the survival of immigrant insect species in new environments. *Crop Protection* **10**, 331-333.

Sutherst RW (2002) 'National electronic modelling network for pest, disease and weed management.' Rural Industries Research and Development Corporation, RIRDC Publication No 02/030, Canberra, Australia.

Sutherst RW, Maywald GF (1991) Climate modelling and pest establishment. Climate-matching for quarantine, using CLIMEX. *Plant Protection Quarterly* **6**, 3-7.

Sutherst RW, Maywald GF, Yonow T, Stevens PM (1999) CLIMEX: predicting the effects of climate on plants and animals. In '1999, iv + 88 pp.; 8 pp. of ref.' (CSIRO Publishing: Collingwood; Australia)

Thalji R (1994) Occurrence and distribution of aphidophagous ladybirds (Coleoptera: Coccinellidae) on agricultural crops and wild plants in Vojvodina. *Zashacekita Bilja* **45**, 279-291.

Vierbergen G (1995) International movement, detection and quarantine of Thysanoptera pests. In 'Thrips Biology and Management'. (Ed. MS B.L. Parker, and T. Lewis) pp. 119-132. (Plenum Press: New York)

Voicu M, Mateias MC, Pricop M (1992) Contributions to the knowledge of the harmful and beneficial entomofauna in bean crops. *Probleme de Protectia Plantelor* **20**, 3-7.

Wang YH, Liu BS, Fu HZ, Gu LN (1984) Studies on the habits and bionomics of *Adonia variegata* (Goeze). *Insect Knowledge (Kunchong Zhishi)* **21**, 19-22.

Wheeler AG, Stoops CA (1996) Status and spread of the Palearctic lady beetles *Hippodamia variegata* and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae) in Pennsylvania, 1993-1995. *Entomological News* **107**, 291-298.

Zúñiga S. E, Suzuki S. H, Vargas M. R (1986) Biological control of cereal aphids (Hom.; Aphididae) in Chile. III. Mass rearing of introduced predators and parasitoids. *Agricultura Técnica* **46**, 489-494.