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Improving Pest Management in the Australian Lucerne Industry

— A review of management of white fringed weevil, small lucerne weevil and broad-back weevil —

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— A review of management of white fringed weevil, small lucerne weevil and broad-back weevil

by Thomas Barnes and James De Barro

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Foreword

This review of literature on three species of weevils that have been recorded as having negative impacts on lucerne in Australia will enable the Australian lucerne industry to develop proactive measures regarding their management. The known biology of the three weevil species has been compiled, as well as information regarding cultural, biological and chemical control measures in lucerne and other infected crop species.

The Rural Industries Research and Development Corporation pasture seed levy payers as well as pasture growers across Australia, will benefit from this literature review as it is the first time such a concise information base on these three pests has been published. Pasture researchers will be able to utilise the review to support current and future research into the management of these weevil pests in Australian pastures.

The weevils, especially the white fringed weevil, have presented themselves as damaging pests of pastures such as lucerne and sub clover in most states of Australia. The intensity of their damage appears reflective of the conditions under which the pastures are produced. Where pastures are more stressed due to soil types or irrigation, the weevil damage is more acute and causes significant hardship to the producers. The review provides a sound footing for improved understanding of the field observed damage by the weevils and will enable constructive management plans to be developed.

This literature review will enable the pasture seed industry to consolidate its knowledge of the weevils causing damage to pasture and to formulate management approaches that target known aspects of the pests' life histories. In addition the review highlights significant gaps in the knowledge base that need attention to evaluate current management attempts, as well as assist in future management plans.

This report was funded from RIRDC Core Funds provided by the Australian Government.

This report, an addition to RIRDC's diverse range of over 1900 research publications, forms part of our Pasture Seeds R&D program, which aims to deliver on the vision for the future, shared by the industry, RIRDC and the research community, for a profitable and sustainable pasture seeds industry based on a reputation for the reliable supply, domestically and internationally, of a range of pasture species.

Most of RIRDC's publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Peter O'Brien
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Persons that provided useful information not necessarily specific to weevils include; Tim Powell (Department of Land, Water and Biodiversity, South Australia), James Altman (Biological Services, South Australia) and Mike Keller (University of Adelaide). Also Cindy Strachan provided proof reading and grammatical advice.

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What the report is about

This report is a compilation of the relevant literature published throughout the world on three species of weevils recorded as impacting on pasture survivorship in Australia. In particular lucerne is reported as being negatively influenced by the white fringed weevil, the small lucerne weevil and the broad-back weevil. The report has assessed and collated both published and unpublished information as well as documented personal communications with research and field officers pertaining to the morphologies, life histories, methods of spread and control options of the three weevil species.

Who is the report targeted at?

The report is aimed at assisting the pasture industry, and in particular the lucerne industry, in evaluating current control methods and developing future management programs. Publishing concise information about the weevils permits areas where control may or may not be successful to be highlighted. Conversely the review permits industry to focus on knowledge gaps and how these may be breached.

Background

Lucerne is Australia's fundamentally important pasture species and as such it is important to minimise damaging losses due to pest damage. The management of pests is always important and it is of particular importance in the 2009 era of economical and environmental uncertainty. Resources are strained and expensive and in some situations quality is compromised. For example, saline water used for irrigation may stress pasture stands increasing susceptibility to other problems such as pest insects.

Pest weevils are formidable problems in pastures and other crops; typically they are unpredictable, damaging at low densities and patchy in distribution. Furthermore, they are difficult to control and consequently are insidiously spreading in Australia, partly due to the creation of an artificial but ideal environment. Insecticides have largely proved ineffective against weevils with the adults resistant and the larvae difficult to target (especially in perennial crops). Laboratory rearing has also proved problematic further hampering research efforts. Lack of quality published information regarding the weevils has resulted in ad hoc and potentially erroneous management systems being implemented.

Aims/objectives

Pasture growers, lucerne seed producers and their servicing consultants and agronomists require a solid information base from which to develop future weevil management programs as well as permit assessment of existing systems. With no concise reference existing, management practices have been constructed based on a limited and at times misleading knowledge base. Consequently this creates the risk of 'urban myth' based management plans becoming enshrined as standard practice even though there are major gaps in the pasture industry's understanding of the weevils and their relationship in the pasture growing environment.

The objective of the review was to prepare a solid document that current and future work on these weevils could be based on.

Methods used

The world's literature was reviewed by utilising on line searches. In addition key researchers and agronomists in Australia and overseas were interviewed to increase the knowledge base that could be compiled.

Results/key findings

The white fringed weevil (*Naupactus leucoloma*) female produces a large amount of offspring and does not need male mates to reproduce. This rapid production is coupled with a long life cycle often in excess of 18 months. Long term stands of lucerne allow *N. leucoloma* to complete its full lifecycle. All life stages except adulthood are spent underground making timely detection difficult, which is further hampered by their patchy distribution. Most damage to crops is caused by larval feeding on tap roots of legume crops, often causing plant mortality and production losses. As they are underground the larvae are very hard to treat with chemicals, although some success has been achieved using soil fumigants, however these are only suited to annuals which allow application just before sowing.

The small lucerne weevil (*Atrichonotus taeniatulus*) has not been researched greatly, however it is closely related to *N. leucoloma* (both Brachyderini family) suggesting a lot of the research on *N. leucoloma* would also apply. Although there has been limited published research, typical weevil traits have been noted for *A. taeniatulus*. These include females only required to produce a large amount of viable offspring and the underground larval stage causing damage to plant roots, particularly legumes. Further, patchy distribution and chemical resistance is also noted for this species. An important difference of *A. taeniatulus* is severe damage caused by adults feeding on newly emerged plants, not noted as problematic for other weevils in this review.

The third weevil species researched in this review is the Australian native beetle named the Broad-back weevil (*Leptopius duponti*) which belongs to the Amycterinae family. This weevil is increasingly being sampled in lucerne stands in South Eastern South Australia. There is no published literature available on the life history and management of this weevil with minimal literature available on its morphology.

Implications for stakeholders

Advances in biological knowledge of *N. leucoloma* have allowed for more informed management decision making. However, a satisfactory control, especially in perennial pastures, is still not currently available. Gaps in the knowledge of *A. taeniatulus* and *L. duponti* may be where crucial management information lies. As such it is crucial to gain as much life history information on these weevils as possible both through field sampling and laboratory experiments.

A biological control of weevils is likely to be the most beneficial outcome. Currently an economically viable solution does not exist for perennial pastures. However, some encouraging results have been obtained in the laboratory and with other similar weevils in the field. This is an area warranting further investigation. Chemical insecticides although problematic are likely to be an option in the future if combined with improved knowledge on the pesticides themselves and weevil biology. Due to the nature of the pests strict cultural controls have been employed but continued weevil spread suggests success has been limited. It is possible that a combination of biological, chemical and cultural controls may provide the best management solution. In situations where heavy infestation is persistent, legume crops may need to be rotated to less preferred cereal crops.

Recommendations

The pasture industry needs to undertake a cost/benefit analysis of the weevil to determine the level of commitment required to increase the knowledge of the pest as well as management options. At present it is perceived that the pests are a significant problem to individual producers but it is unclear what percentage of the national pasture base is affected.

It is suggested that there is sufficient information contained in the review to construct meaningful and simplistic research into the field management of the weevils. Such research would be based on an integrated use of several control options including cultural and chemical practices.

In addition it is recommended to develop more information regarding the potential development of a biological control agent that is discussed in the review.

1. Introduction

1.1 The Australian lucerne seed industry

The 2008 RIRDC publication ‘Economic analysis of the Australian lucerne seed industry’ assessed the overall lucerne seed industry in Australia up to and including the 2007 harvest to be valued at A$95 million. 86% of Australia’s annual certified lucerne seed production has an export value of A$28 million with the USA currently being the largest importer of certified Australian lucerne seed. The remainder of the industry’s worth lies in that of the allied industries and their associated inputs (RIRDC Pub. No. 08/103).

The Australian lucerne seed industry produces in excess of 7,500 tonnes of seed per year of which 85% is produced in South Australia with the remaining 15% produced in New South Wales, Victoria, Western Australia and Tasmania. 83% of Australia’s production occurs in a particular region of South Australia extending from Tintinara through to Naracoorte with the focus being the township of Keith (RIRDC Pub. No. 08/103). Other production areas include the mid north of South Australia including the Jamestown region, Forbes and Deniliquin in New South Wales, the Rutherglen region of Victoria and in recent times minor production in the southern areas of Western Australia and north east Tasmania.

1.2 Lucerne

Lucerne (*Medicago sativa*) is a deep rooted perennial pasture legume adapted to a wide range of climatic conditions and soil types, being best adapted to deep, well drained soils (RIRDC Pub. No. 08/023).

1.3 Lucerne seed production

Lucerne seed production is a highly specialised, high value farm enterprise with two thirds of Australian seed being produced under irrigation. Being such an intensive high input pasture seed crop there is an inherent requirement for high yields and grower returns (RIRDC Pub. No. 08/023). Seed yields can vary considerably with crop management and seasonal conditions and producers aim to maximise returns and limit these variations with sound management practices that include crop protection, irrigation management, pollination and harvest management (RIRDC Pub. No. 08/023).

1.4 Purpose of the review

Anecdotally, one of the major pest problems being faced by lucerne growers in Australia is a complex of weevil species. Whether lucerne is grown for seed, hay or a basic grazing pasture, persistence of lucerne is being challenged by the presence of three weevil species. White fringed weevil, small lucerne weevil and the broad-back weevil have been recorded as killing lucerne plants and significantly reducing the viability of the lucerne stand. This review aims to compile the known, relevant literature regarding these beetle species both in Australia and internationally. The review will assess the literature and develop a suggested pathway to aid in managing this pest. This pathway will be recommended to the Australian lucerne industry for further action as deemed appropriate.

Certain weevils (Coloptera: Curolionidae) can cause economic losses to crop production due to their larvae attacking the roots of host plants (e.g. in New Zealand nitrogen fixation of *Trifolium repens* has been reduced by 92% and productivity losses in *Medicago sativa* (lucerne) stands due to reductions in overall plant dry matter by *Naupactus leucoloma*) (Hardwick and Prestidge 1996; Hardwick 2004). Weevils have proved difficult to eradicate due to protection provided by their environment (soil), irregularities in distribution (spatially and temporally) and high fecundity.

Of the three weevil species that have been considered in this review as threats to lucerne, the white fringed weevil, *Naupactus leucoloma* (Boheman) is the most researched. *N. Leucoloma* was known as *Graphognathus leucoloma* before 1995, and are referred to as *G. leucoloma* in a great deal of the literature (EPPO 1999). Considerable investigation has been applied to this insect due to the damage it causes to a large variety of crops (particularly legumes) and its widespread distribution (e.g. South America, North America, New Zealand, Australia, Africa), despite quarantine regulations at ports in developed countries (e.g. North America and Australia) (EPPO 1999; Dixon 2003). In Australia this weevil has been recognised as a pest since the 1930s (pers. comm. with Adrian Nicholas, New South Wales, Department of Primary Industries). In North America entomologists have long recognised the potential of this pest but despite internal phytosanitary regulations its distribution has spread from Florida to states further north and west (EPPO 1999).

There is a paucity of available literature on the other two weevils, small lucerne weevil, *Atrichonotus taeniatulus* (Berg) and the broad-back weevil, *Leptopius duponti*, but a great deal of research on *N. leucoloma* is likely to be relevant to these species due to similarities in biology. Much of the research was carried out in the mid 20th century and of which some aspects are not relevant today, i.e. various attempted chemical controls are now banned. A suite of insecticides was employed or tested to control *N. leucoloma* (e.g., DDT, carbaryl , diflubenzuron , cryolite , dieldrin, aldrin, and chlordane), but many of these are no longer legal for use, even by licensed applicators in Australia, New Zealand and North America (Dixon 2003). Chemical management of weevils is not ideal due to difficulties such as targeting the larval stages, lack of efficacy as well as environmental and economic reasons which has resulted in research into biological methods.

There is a need to find an effective control of weevil larvae and this review aims to highlight what has been attempted in the past and give direction to future research and management. The review will summarise biology and life history aspects of these pests to aid in management decision making. Although lucerne production in Australia is of particular interest all control options for all crops have been researched on a worldwide scale.

2. White fringed weevil (*Naupactus leucoloma*)

2.1 Background

N. leucoloma are indigenous to South America, but they have spread to other countries such as Africa, United States (U.S.), Australia and New Zealand (EPPO 1999). Traditionally they have been associated with moist warm conditions found in the sub tropical and temperate areas such as North Eastern Australia and South Eastern U.S. (Matthiessen and Learmonth 1992). However, *N. leucoloma* more recently have been discovered in drier areas such as South Eastern Australia, Southern California and South Africa, but normally in association with irrigation (De Jager *et al.* 1989; Matthiessen and Learmonth 1992). On a local scale *N. leucoloma* are rapidly colonising pastoral areas (irrigated and dryland stands) such as Tamworth (pers. comm. with Adrian Nicholas, N.S.W DPI), Keith (southeast South Australia) and Jamestown (mid north South Australia) (pers. comm. with James De Barro, Alpha Group Consulting).

N. leucoloma cause problems in agriculture due to larval feeding damaging roots of crops (as do the other two weevil species documented in this review), such as irrigated lucerne (also known as alfalfa in North America) (Matthiessen and Learmonth 1992; Zehnder 1997; Matthiessen and Shackleton 2000). It is also possible that root damage could leave the plant susceptible to root infections (Larson *et al.* 2007). *N. leucoloma* larvae have also been reported to damage underground plastic irrigation piping by chewing, but this is not considered as problematic as root damage (pers. comm. with Adrian Nicholas, N.S.W DPI).

N. leucoloma larvae are recorded to be hosted by at least 385 species such as sweet potato, white clover, sugarcane and cotton (Young *et al.* 1950; Chalfant *et al.* 1990; Zehnder 1997; Dixon 2003). There is no specific published list of what all the 385 recorded hosts are so a list of hosts found in the literature has been compiled in Table 1. The polyphagous behaviour by adults and larvae has contributed to their wide geographical spread. (Lanteri and Marvaldi 1995; Zehnder 1997). However, as the proportion of broadleaf and legume material decreases in pastures the number of fully formed eggs ready to be laid in *N. leucoloma's* reproductive tract decreases (the distribution curve of the data tends to be more skewed as well) (pers. comm. with Scott Hardwick, AgResearch New Zealand).

Table 1: Host plants of white fringed weevil

Common Name (if supplied)	Life stage	Scientific Name (if supplied)	Geographic Location	References
Alfalfa/ lucerne	Adults, larvae	*Medicago sativa*	U.S., Australia etc	(Young *et al.* 1950; Lanteri and Marvaldi 1995)
Beans	Larvae		U.S.	(Young *et al.* 1950; Lanteri and Marvaldi 1995)
Beautyberry	Adults		U.S.	(Young *et al.* 1950)
Beggarweed	Adults		U.S.	(Young *et al.* 1950)
Blackberry	Adults		U.S.	(Young *et al.* 1950)

Common Name (if supplied)	Life stage	Scientific Name (if supplied)	Geographic Location	References
Camphor	Adults		U.S.	(Young *et al.* 1950)
Carelessweed	Adults, larvae		U.S.	(Young *et al.* 1950)
Carrot	Larvae		U.S.	(Young *et al.* 1950)
Chrysanthemum	Larvae		U.S.	(Young *et al.* 1950)
Chufa	Adults		U.S.	(Young *et al.* 1950)
Cocklebur	Adults, larvae		U.S.	(Young *et al.* 1950)
Coffeeweed	Adults		U.S.	(Young *et al.* 1950)
Corn	Larvae	*Zea mays* L	U.S.	(Young *et al.* 1950; Zehnder 1997)
Cotton	Adults, larvae	*Gossypium hirsutum* L	U.S., Australia etc	(Young *et al.* 1950; Zehnder 1997)
Cowpea	Larvae		U.S.	(Young *et al.* 1950)
Curled dock	Larvae		U.S.	(Young *et al.* 1950)
Irish potato	Larvae		U.S.	(Young *et al.* 1950)
Dahlia	Adults		U.S.	(Young *et al.* 1950)
Dewberry	Adults		U.S.	(Young *et al.* 1950)
Gallberry	Adults		U.S.	(Young *et al.* 1950)
Kudzu	Adults		U.S.	(Young *et al.* 1950)
Lespedeza	adults		U.S.	(Young *et al.* 1950)

Common Name (if supplied)	**Life stage**	**Scientific Name (if supplied)**	**Geographic Location**	**References**
Lettuce	Not specified		Not specified	(Lanteri and Marvaldi 1995)
Lima bean	Adults		U.S.	(Young *et al.* 1950)
Lupine	Larvae		U.S.	(Young *et al.* 1950)
Mustard	Larvae		U.S.	(Young *et al.* 1950)
Oat	Larvae		U.S.	(Young *et al.* 1950)
Okra	Adults		U.S.	(Young *et al.* 1950)
Peanut	Adults, larvae		U.S.	(Young *et al.* 1950)
Peas	Larvae		U.S.	(Young *et al.* 1950)
Peppers	Not specified		Not specified	(Lanteri and Marvaldi 1995)
Ragweed	Adults, larvae		U.S.	(Young *et al.* 1950)
Soybean	Adults, larvae		U.S.	(Young *et al.* 1950)
Strawberry	Adults, larvae		U.S.	(Young *et al.* 1950)
Sugarcane	Adults, larvae		Australia	(Chalfant *et al.* 1990)
Sweetpotato	Larvae	*Impomoea batatas* L.	U.S.	(Young *et al.* 1950)
Teaweed	Adults		U.S.	(Young *et al.* 1950)
Tobacco	Larvae		U.S.	(Young *et al.* 1950)
Velvet bean	Adults, larvae	*Mucuna deeringiana*	U.S.	(Young *et al.* 1950; Zehnder 1997)

Common Name (if supplied)	Life stage	Scientific Name (if supplied)	Geographic Location	References
White clover	Larvae	*Trifolium repens* L.	N.Z.	(Hardwick 2004)
White clover	Not specified	*Melilotus alba*	U.S.	(Zehnder 1997)

2.2 Morphology

Adult females are light to dark grey or brown, they have a lighter band along the outer margins of the wing covers, with two paler longitudinal lines on each side of the thorax and head, one above and one below the eye; their total length is approximately 8-12 mm (see Figure 1) (Lanteri and Marvaldi 1995; EPPO 1999; Dixon 2003). Typically adults are 4 mm in width across the abdomen, which is covered in short white hairs gaining in length towards the elytra (EPPO 1999). For a more detailed description of the adult stage (including male) a key has been produced by Lanteri and Marvaldi (1995).

Figure 1: White fringed weevil adult (arrow line representing approvimate actual size (Dixon, 2003)).

The pupa is about 10-12 mm long and colour transforms from white to brown as the body changes to the adult stage (EPPO 1999). Larval pupation occurs in oval chambers 5-15 cm deep in the soil during late spring or early summer (EPPO 1999).

Mature larvae are approximately 12 mm long and 6 mm wide; creamy yellowish-white; C-shaped with a strong thoracic swelling (see Figure 2) (EPPO 1999; Dixon 2003). Only the black mandibles protrude from the head which is light brown and tucked into the prothorax (EPPO 1999). The 12 segments are interrupted by two sub lateral longitudinal grooves along the length of the body (EPPO 1999). Different stages of the 11 instars can be determined based on the width dimensions of the head capsule, which ranges from 0.26 mm for the 1st instars to 1.90 mm for the 11th instars (Zehnder 1997). For more details on instars stage identification see (Gough and Brown 1991; Lanteri and Marvaldi 1995).

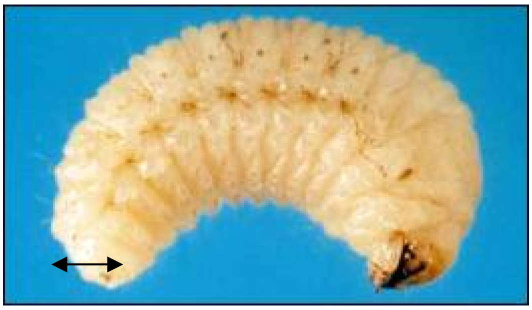

Figure 2: White fringed weevil larva (arrow line representing approximate actual size (Dixon, 2003)).

Eggs are approximately 0.9 mm long by 0.6 mm wide; recently laid eggs are white then turning light yellow after four to five days (Lanteri and Marvaldi 1995; Dixon 2003). Eggs are bonded together with a sticky, hyaline, gelatinous material, which hardens into a protective film, slowing desiccation and possibly aiding in drought survival (EPPO 1999). The gelatinous material causes soil to adhere to egg masses making detection difficult (Lanteri and Marvaldi 1995; Zehnder 1997; EPPO 1999; Rattray 2005).

2.3 Life History

Parthenogenic females are only found outside of South America and even within South America males are rare (Lanteri and Marvaldi 1995; Zehnder 1997; EPPO 1999; Rattray 2005). The fact *N. leucoloma* only needs females to reproduce increases the destructive potential of this pest. From 5-25 days after emerging from the soil mature univoltine females lay large amounts of eggs (> 1500) in clumps over two months (Zehnder 1997; EPPO 1999; Dixon 2003). The number of eggs laid by *Naupactus peregrinus* (a separate species) can be affected by the host plant, which is also the case with *N. leucoloma* (Ottens and Todd 1979). Eggs are deposited in groups of 12-60 in the soil or on the roots, in plant litter under plants or on stems and lower leaves of plants. In addition they are also laid on hay, firewood, timber, tools and machinery if in contact with the soil, and these habits aid the beetle's distribution (Lanteri and Marvaldi 1995; EPPO 1999; Dixon 2003).

The net reproduction rate has been calculated at 156.4 per female per day (Zehnder 1997; Sato *et al.* 2002). Eggs hatch 11 (summer average) to 100+ (winter average) days after oviposition (Dixon 2003). The eggs need soaking in water for several hours to begin hatching, supporting the hypothesis that irrigated pastures such as lucerne favour colonisation (Matthiessen and Learmonth 1992). Fecundity, high survival rates and rapid growth is aided also by the unseasonal availability of high quality food such as legumes e.g. crops such as lucerne are perennial providing a year round food source (Matthiessen and Learmonth 1992; Zehnder 1997). A long term food source is important as the species is relatively long lived with a mean generation time calculated at 398.4 days (Sato *et al.* 2002). In New Zealand the species has been shown to complete a generation at a minimum of 224 days and at a maximum of 672 days (Hardwick 2004).

Of the 11 larval instars only the first stage does not feed, not surprisingly the most serious damage to legume roots is caused by the larger instars (Gough and Brown 1991; EPPO 1999).

Larvae can spend up to two years feeding on roots within the soil placing feeding pressure on perennial hosts such as lucerne for a long term (Dixon 2003; Larson *et al.* 2007). In early summer larvae pupate, with adults emerging in summer, after a pupation stage of approximately 13 days (longer at cooler times of the year) (EPPO 1999; Dixon 2003). Most larvae spend the entire larval stage at a depth of 1-15 cm (during warmer seasons); however, some do burrow deeper (EPPO 1999). Overwintering larvae (*N. leucoloma* also overwinter as eggs) have been reported at a soil depth of 23 to 30 cm (pupal cells are found at a similar depth) (Chalfant *et al.* 1990; Dixon 2003).

Temperature plays a role in the duration of larval development and when reared in the laboratory at various temperatures 27 ºC provided the fastest larval development compared to 24 ºC and 21 ºC (Sato *et al.* 2002). No larvae pupated during a 12 ºC and 33 ºC trial which are believed to be outside the developmental threshold (Sato *et al.* 2002). Summer soil temperatures under irrigated lucerne are typically between 20 ºC to 30 ºC at a depth of 5cm in south eastern Australia creating good developmental conditions (Rogers 1974). More recent soil temperature data taken from flood irrigated *Phalaris* spp. at 5 to 15 cm at Padthaway, South Australia showed a January average of 21.5 ºC with a mean soil moisture of 7.7 % (pers. comm. with Tim Powell, Department of Water, Land and Biodiversity, South Australia). The Padthaway data is still within the development threshold, although not optimal.

2.4 Dispersal

The inner margins of the elytra (wing covers) of adult beetles are fused and metathoracic wings are poorly developed and as such they do not fly (Zehnder 1997). However, adult dispersal is aided by the female actively crawling (0.4-1.2 km/ lifetime) and due to the clinging behaviour i.e. to crops and agricultural equipment they are often carried by trade (EPPO 1999; Hardwick 2004). Eggs are laid on many parts of plants and thus trade distribution is a key issue (Chadwick 1978; EPPO 1999). Soil transportation can also disperse egg, larvae and pupae stages (EPPO 1999). For example agricultural machinery (also contractors etc) has the potential to disperse this pest at various stages at inter and intra farm levels highlighting the need for cultural and sanitary controls (see below).

Distribution of *N. leucoloma* within infected pastures often displays varied population densities, compared to other insect pests (e.g. *Heteronychus arator*) (Hardwick 2004). However, in some cases whole crops have been reported to sustain damage (pers. comm. with Adrian Nicholas, N.S.W. DPI) (Larson *et al.* 2007). There are a number of possible explanations for uneven density of weevils within pasture crops. The patchiness of distribution is possibly due to crawling and hitchhiking as primary dispersal mechanisms (Hardwick 2004). Although female *N. leucoloma* potentially crawl considerable distances, it has been shown that if suitable host plants are available in the immediate area their dispersal will be very localised (Steven 1980; Hardwick 2004). Hardwick (2004) showed in the establishment of new suitable pastures where *N. leucoloma* populations were initially negligible that colonisation although rapid, was at the greatest density at the edge of experimental pasture blocks (see Table 2). It is likely that emerging adult dispersal will be localised if suitable hosts are present e.g. greater dispersal has been observed in grass swards such as ryegrass compared to legumes such as lucerne (Steven 1980). *N. leucoloma* and other Curculionidae such as *Sitona lepidus* (clover root weevil) have shown a host preference for roots of legumes such as *Trifolium* spp. and other broad leafs particularly lucerne compared to pure grasses (Barratt *et al.* 1998; PrimeNotes 2006). However, Hardwick (2004) concluded that it was soil drainage characteristics (although weak influence compared to some other Curculionidae), presence of shelter beds and adult movement mechanism (e.g. walking) that influenced populations not ryegrass/ white clover (legume) cultivars, although the study was only conducted over two years. Anecdotal evidence from lucerne seed production in Keith in South Australia suggests that white fringed weevil populations are greater and more damaging when ryegrass is not controlled in winter. Irrigated lucerne stands have been terminally damaged by adults and larvae within 20 months of seeding when there has been a high population of annual ryegrass growing in spring (De Barro pers. comm.).

Table 2: Mean numbers/m² (± SEM) at each sampling date of *N. leucoloma* for boundary and internal locations within paddocks in the 1998/99 and 1999/00 growing seasons (Hardwick 2004).

	White fringed weevil
1998/99	
Boundary	5.7± 1.2
Internal	0.9± 0.6
Significance	P<0.001
1999/00	
Boundary	39.8± 3.5
Internal	24.2± 4.4
Significance	P<0.01

Observations have showed that *N. leucoloma* populations increased rapidly under pure swards of legumes (pers. comm. with Scott Hardwick Agresearch NZ). When this occurred the legumes died out and allowed the ingress of weed grass species and the *N. leucoloma* population then went into decline (pers. comm. with Scott Hardwick Agresearch NZ). In mixed legume/grass situations an increase in *N. leucoloma* population resulted in reductions in the legume content of pasture (pers. comm. with Scott Hardwick Agresearch NZ). It is possible that the observed anecdotal effects are due to *N. leucoloma* feeding causing the odd lucerne plant to die out with the subsequent ingress of weedy grass species (pers. comm. with Scott Hardwick Agresearch NZ). Further, *N. leucoloma* oviposition behaviour and larval feeding could be a factor. As grass species are not attractive to *N. leucoloma* adults then it is likely that adults are aggregating on and laying eggs around lucerne plants. When the larvae hatch there is limited evidence from laboratory trials to suggest that they are able to distinguish between a favoured and non-favoured host (Hardwick and Prestidge 1996). If this process occurs in the field then they will preferentially feed on the lucerne plants in a mixed sward situation (pers. comm. with Scott Hardwick Agresearch NZ). This in turn could lead to lucerne plants that are less competitive than the annual grass plants due to heavily damaged root systems (pers. comm. with Scott Hardwick Agresearch NZ). This could lead to plant death resulting in gaps opening up in the sward which are then colonised by weedy grass species (pers. comm. with Scott Hardwick Agresearch NZ). As there become fewer lucerne plants the effect may accelerate until a new equilibrium between the grass and lucerne population occurs (e.g. there are so few lucerne plants that the sward cannot support high *N. leucoloma* populations) (pers. comm. with Scott Hardwick Agresearch NZ).

Another hypothesis for the patchy distribution of *N. leucoloma* is due to variation of soil types within a given field. A crop of lucerne roots can be assumed to be a constant food source for larvae; therefore, differing soil types are likely to be the only variable (pers. comm. with Stewart Learmonth, Department of Agriculture, Western Australian Government and Adrian Nicholas, N.S.W DPI). The larvae like moist soil, but areas of clay may be too wet for high population densities (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.). *N. leucoloma* do not like areas in flood (pers. comm. with Adrian Nicholas, N.S.W DPI). Well drained soils such as sand or loam that would normally be too dry for larvae to inhabit may be made suitable by regular irrigation. Core sampling for larvae combined with soil type mapping overlay could aid in addressing the distribution of larvae question(s) (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.).

3. Small lucerne weevil (*Atrichonotus taeniatulus*)

3.1 Background

A. taeniatulus was possibly referred to as *Pantomorus taeniatulus* in early literature, such as in Wallace (1941). *A. taeniatulus* is also native to South America (Argentina) and had been introduced to the U.S. in the early 20th century and was first reported in Australia in 1938 where it was found in lucerne and couch grass in Lochinvar (Wallace 1941). The weevil has been reported as a pest in South Australia, Western Australia and New South Wales (Manigano and Severtson 2008). Like *N. leucoloma* larvae have also been reported to feed on the cortex of lucerne tap root (including other pasture legumes) and roots of other hosts such as couch grass (*Cynodon dactylon*) (Wallace 1941). *A. taeniatulus* obviously feed on lucerne and various other plants including some weeds, but there is no published comprehensive list of host preferences. Adult weevils can cause damage to subterranean clover and canola pastures by chewing cotyledons just after germination and feeding on leaves can defoliate plants (feeding is nocturnal) (PestWeb; Manigano and Severtson 2008). Damage to canola has also been caused by chewing plants off at the stem (Manigano and Severtson 2008). Recently this pest has been reported in a wheat crop in the Central Tablelands of N.S.W., but they are an unusual problem in cereal crops, it was noted that this area had been under canola the previous year and the paddock contains some Patterson's curse and clovers (Umina 2008). Like *N. leucoloma* severe damage is caused to lucerne as larvae chew and burrow into the taproot (PestWeb). Channels are carved into the taproot about 4 mm across (PestWeb). Overtime lucerne plant mortality is observed with dead patches in stands increasing each year as the pest infestation intensifies (PestWeb). Most plant damage is noticeable in summer when larvae are at their maximum size causing the most root damage (PestWeb). Like *N. leucoloma* infestations normally start at paddock boundaries (PestWeb; Manigano and Severtson 2008).

3.2 Morphology

A. taeniatulus is very similar in appearance to *N. leucoloma,* however, it is smaller (Wallace 1941). Adult weevils are approximately 10 mm in total length, mainly grey in coloration with some brownish mottling (see Figure 3) (PestWeb).

Figure 3: Small lucerne weevil adult (arrow line representing approximate actual size; picture supplied by Agriculture Western Australia).

A. taeniatulus larvae are creamy white in colour, approximately 8 mm long, with small pointed brown jaws similar to *N. leucoloma* (see figure 4) (PestWeb).

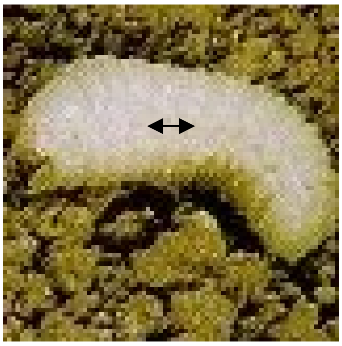

Figure 4: Small lucerne weevil larva (arrow line representing approximate actual size; picture supplied by Agriculture Western Australia).

3.3 Life History

There are no reports of adult males and like *N. leucoloma* females are parthenogenic (PestWeb). It has been reported that the period of greatest activity is January to March with larvae, pupae and adults being abundant in all three months and adults also found in September and May (Wallace 1941). There is no peer reviewed published information on the detailed life history of this species. More recent fact sheet information suggests adults emerge from the soil in late summer (February to March) with most dying by the start of winter in Western Australia (PestWeb; Manigano and Severtson 2008). However, extended periods of late summer and autumn green weeds can reactivate weevils, especially after a hot dry summer (Manigano and Severtson 2008). During the day adults are often found hiding under the soil but it is not uncommon for groups of three to four beetles to be found resting on a single leaf (Umina 2008).

Eggs are laid at the base of plants, hatch in winter when the larvae burrow into the soil and commence feeding on roots; peak larval feeding activity is spring to mid summer (PestWeb). Pupation occurs in mid summer (PestWeb).

3.4 Dispersal

Like *N. leucoloma, A. taeniatulus* metathoracic wings are poorly developed and dispersal mechanisms are confined to crawling and hitchhiking (PestWeb). Patchy distribution has also been noted for this species (Umina 2008).

4. Broad-back weevil (***Leptopius duponti***)

4.1 Background

Very little is published about this insect. It is a native Australian species that is found all over Australia and is the most widely distributed species of its genus (Zimmerman and Oberprielar, unpublished). It is the only species known from Tasmania (Zimmerman and Oberprielar, unpublished). The adults have been recorded as feeding on the foliage of black wattles and have been nicknamed 'wattle pigs' or the 'broad back' weevil. (Froggatt, 1907).

4.2 Morphology

The adults vary in size with the females being significantly larger than the males. Females can grow up to 25 mm in length and double the size of males (Froggatt, 1907). Both sexes vary in colour from black, grey to dark brown and can have a reddish tint on its upper surface (Froggatt, 1923).

The snout is short, stout and rigid, and the thorax is short, small and rounded at the front. They have a broad rounded abdomen, thickest towards the apex, covered with short blunt spines being in three rows on either side of wing covers, (Figure 5) (Froggatt, 1907).

As with the white fringed weevil the adults are flightless but unlike the white fringed weevil there are males. Variations within the species in terms of colour shades and sizes are a reflection of their localised gene pools created by minimal population movement and mixing (Oberprieler, pers. comm.).

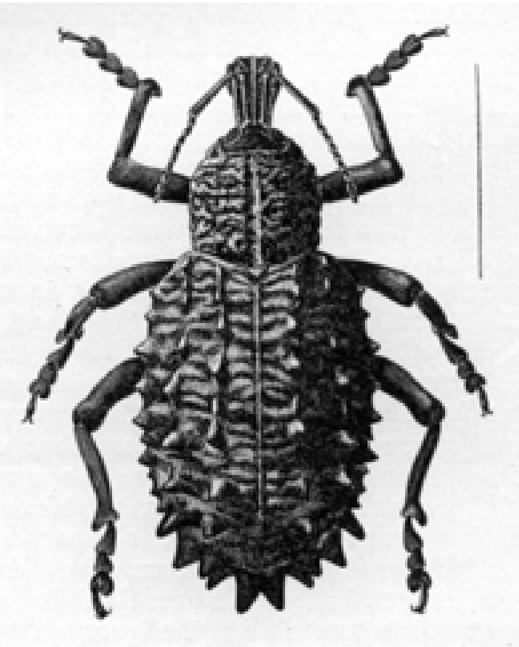

Figure 5: Broad-back weevil adult. (Froggatt, 1907).

4.3 Life History

The larva of this beetle but are similar to the white fringed weevil by being white, soft, legless and subterranean (Zimmerman and Oberprielar, unpublished). When the larvae mature and prepare to pupate they form an underground cell. Sometimes these cells form what is referred to as ‘piccaninny boots’ (Zimmerman and Oberprielar, unpublished).

In the Keith region of South Australia the adults emerge in September/October with the males emerging initially (De Barro pers. comm.).No literature could be found that describes the time duration of the life cycle or its components but only one generation per year has been observed (De Barro pers. comm.).

Adults have been observed feeding on lucerne and grasses such as veldt grass. They have been observed emerging in areas free from Acacia species (wattles) and it is not known if larvae are feeding on roots of eucalypt trees or the roots of perennial species such as veldt grass. Larvae have been found feeding on roots of lucerne (De Barro pers. comm.).

4.4 Dispersal

Like the white fringed weevil the broad back weevil is flightless and dispersal mechanisms are expected to the same.

5. Potential chemical and biological methods of control in lucerne

5.1 Chemical control of white fringed weevil

A suggested method of control of weevils is to target adults with chemical sprays termed adulticides combined with sampling to determine adult emergence (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.). Timing is important to reduce the next generation as oviposition can start five days after adult emergence. Sampling for adult weevils is advised to have an accurate spray timing (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.). Adult *N. leucoloma* prefer to feed on the outer margin of leaves, which results in a characteristic notching appearance which can be used as evidence of their presence (Zehnder 1997). Zehnder (1997) recommended the use of the number of leaves with feeding damage as a practical technique for adult sampling due to notched leaves being easily visible whilst walking through the crop. A potential problem with this sampling method is that there is a complex of weevils that can cause similar damage in lucerne including the *Sitona* spp. weevil (De Barro pers. comm.).

An alternative for sampling surface dwelling invertebrates is to use a purpose built 178 mm diameter Vortis sampler (Burkard Manufacturing Co. Ltd, Rickmansworth, England) (Hardwick 2004). Also due to the crawling nature of adult weevils pitfall traps are effective for adult sampling (De Barro pers. comm.).An appropriate pitfall trap design is described and used by Learmonth and Matthiessen (1994). A teflon coated plastic funnel 21 cm in diameter fitted at ground level into a buried PVC cylinder, the funnel has been found to be slightly more effective than 10 cm diameter PVC (Learmonth 1994). A collecting container consisted of a 2 L plastic jar (Learmonth 1994). Five pitfall traps were equally spaced along transects to determine adult population density, however the dimensions were not specified (Learmonth 1994). Soil core sampling (100 mm in diameter to a depth of 200 mm) combined with a wet sieve is recommended to assess larval density (Zehnder 1997; Hardwick 2004). Another alternative for in crop larval sampling is to dig carefully to approximately 30 cm and the larvae counted as they are observed, however this method was developed for potato crops (Matthiessen and Learmonth 1993). Early detection of late stage larvae and pupae may be beneficial to precisely time adult emergence.

A “Soft” insecticide against adults and getting the sampling/timing of sprays correct is possibly a feasible way to target weevils (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.). Costs are likely to be lower than biological controls such as nematodes (pers. comm. with Stewart Learmonth, Department of Agriculture, W.A.). Foliar insecticides are likely to be less of a threat to soil and groundwater contamination compared to soil insecticides (Zehnder 1997). Also due to the incapability of flight (amongst other possible reasons) weevils may cohabit and feed in a relatively small area making it possible for numbers of notched leaves to be recognised in the first few weeks of colonisation (Zehnder 1997). However, with foliage feeding by other invertebrates a more precise sampling (as discussed above) would be beneficial to give accurate and prompt results. The advantages of control on an as need basis suggest that foliar insecticide applications are worthy of further research. In commercial lucerne seed crops well timed spraying to control adults has given good knockdown but it is not viewed by some researchers as a long term strategy or even sustainable (e.g. Chalfant *et al* 1990) (Hossain *et al*. 2001). This is partly due to the highly fecund nature of *N. leucoloma* which suggests that the species will persist after spraying and the exercise will be population reduction rather than complete eradication. Use of insecticide for white fringed weevil larval control has been trialled by Lucerne Australia in 2007/08 in Keith. Initial control of larvae prior to the first irrigation of the season in December 2007 was effective with chemicals such as chlorpyrifos and fipronil compared to the control. By harvest time in March 2008 larvae were present in all treatments with no differences with the control. This suggests limited control is likely with sole reliance on insecticide but there may be a role in an appropriate integrated pest management plan (De Barro pers. comm.). Further this type of control has not been tested over a substantial temporal period.

A three year test by Zhender *et al* (1998) did demonstrate a short term reduction in larvae from the second year onwards using adulticide type sprays (phosmet or carbaryl) in sweet potato crops. Successful adulticide treatments have been reported in lucerne field tests in New Zealand but reduced plant mortality was confined to non drought years (East and Parr 1977). This result supports the hypothesis that concurrent stresses cause lucerne mortality.

Chemical control of other similar weevils (*Leptopius corrugatus*) by targeting adults has had limited success historically. A field trial of seventeen insecticides by Wicks (1973) found only three (azinphos-ethyl, dieldrin and methidathion at 0.05%) to be more efficacious than the others. Even these three insecticides showed a low mortality rate, for example, in trial 1 azinphos-ethyl provided a "mean % dead" of approximately 1% (Wicks 1973; Sexton and Williams 1981). Wicks (1973) suggested that dieldrin is the only insecticide worthy of further testing, however, this is likely due to it being tested in only one out of the three trials.

5.2 Biological control of white fringed weevil

Insect parasitic nematodes (genus *Heterohabditis*) have been discovered from larvae and pupae of *Heliothis punctiger* Wallengren (Lepidoptera: Noctuidae) in South Australia and in other insects in the U.S.A and New Zealand (Poinar 1979; Sexton and Williams 1981). Natural occurrence of parasitism of *N. Leucoloma* has been reported in Australia as well as other countries (Poinar 1979; Sexton and Williams 1981). The only study on the natural distribution of *Heterohabditis* spp. found a high mortality of *N. leucoloma* within irrigated lucerne crops (Sexton and Williams 1981). Where the parasite was present there was significantly reduced root damage to the crop apparently in response to the reduced *N. leucoloma* population (Sexton and Williams 1981). However, the distribution of the parasites within the tested field was patchy suggesting their ability to spread is limited, possibly compromising their effectiveness as a biological control agent (Sexton and Williams 1981). Unfortunately Sexton and Williams (1981) did not compare parasite and *N. leucoloma* distribution as *N. leucoloma* are known for uneven distribution within crops. However, the parasites can be deliberately spread to overcome the distribution issue. *N. Leucoloma* has been experimentally infected with *Heterohabditis* spp. on at least one occasion by Khan *et al* (1976) in (Sexton and Williams 1981).

Heterohabditis spp. and *Steinernema* spp.have been produced *in vitro* as biological controls of other (Curculionidae) root weevil species (e.g. black vine weevil larvae *Otiorhynchus sulcatus* and sweet potato weevil *Cylas formicarius*) (Smith 1994; Georgis *et al.* 2006). *O. sulcatus* and *C. formicarius* possess similarities to the other weevils in this review, possibly making them a reasonable comparison i.e. they are parthenogenic (Kakouli-Duarte *et al.* 1997). Other Curculionidae species have been described as candidates for future commercial applications (Smith 1994).

The parasitic nematodes *Steinernema carpocapsae* and *Heterorhabditis megidis* have been trialled to control *O. sulcatus* in glasshouse strawberry production by Kakouli-Duarte *et al* (1997). The nematodes have been applied effectively through drip irrigation, which is likely to be successful due to this method's delivery close to the root zone (Kakouli-Duarte *et al.* 1997). An application of *S. carpocapsae* produced a 65% reduction of *O. sulcatus* late instar larvae in the U.K. timed with suitable soil temperatures in spring (Kakouli-Duarte *et al.* 1997; Zehnder 1997). It is possible that flood and centre pivot irrigation used in lucerne production would not be precise enough to be cost effective to control the weevils in question in this review. However, further investigation of nematode application through various irrigation methods should be carried out, especially if they can be produced or purchased at very low expense.

Nematodes, including *Heterohabditis* spp. are produced commercially in Australia by Ecogrow Nematode Facility (eechogro@bigpond.com.au), however when contacted they replied that the CSIRO had tested them on *N. leucoloma* and found them to be ineffective. The CSIRO Entomology Department have been contacted but have not as yet provided any information. There is no published report available describing their trials.

6. Historical chemical and biological control in other related crops

6.1 Chemical

Annual legume crops potentially allow for more control options such as applications of soil-insecticides before planting on a yearly basis. For example, Fonfos an organo-phosphate retailed as the active ingredient in Dyfonate©, is the most effective registered soil applied insecticide for use against *N. leucoloma* damage in Alabama sweet potato (Zehnder 1997). However, it has been reported that even fonfos only provides marginal control of weevil damage (Golden and Bass 1979) in (Zehnder 1997). Similarly, previous studies have demonstrated non susceptibility of *N. leucoloma* larvae to insecticides, suggesting the use of soil insecticides impractical (Todd 1968) in (Zehnder 1997). A possible explanation for the failure of soil insecticides is that even a low survivorship of larvae may be sufficient to generate damaging numbers in the next generation (see biology section above). Further, other factors leading to a loss of efficacy over time include rainfall and irrigation leaching away from the target organism, absorption to soil particles and biodegradation (Chang and Jordan 1983; Zehnder 1997). A previous study has found that *N. leucoloma* can show strong pesticide resistance in the laboratory when trialled against four chemicals (permethrin, cypermethrin, gammexane and DDT) (Chang and Jordan 1983). According to Chang and Jordan (1983) prior exposure to a range of chemicals has resulted in a selection of genes conferring resistance to broad suite of pesticides. It is also possible that natural resistance mechanisms exist due to *N. leucoloma* browsing on a wide range of plant species, enabling the species to cope with many dietary toxins (Chang and Jordan 1983). It is therefore probable that use of soil insecticides when preparing fields for planting of perennials such as lucerne would be a waste of resources and could lead to unnecessary contamination i.e. groundwater. It is thus clear that more research is needed into alternative methods of control, possibly based on seasonal development of the insect and crop damage (Zehnder 1997; Matthiessen and Shackleton 2000). Methyl isothiocyanate is the active ingredient of (sodium *N*-methyldithiocarbamate) soil fumigant used in potato crops in Western Australia (Matthiessen and Shackleton 2000). However, its use is not always viable due to high costs ($A700/Ha) and does not suit perennial crops (Matthiessen and Shackleton 2000). Historically, chlorinated hydrocarbons provided excellent control; however, there are no legally available effective insecticides (Chalfant *et al.* 1990).

Biofumigation has been trialled to control *N. Leucoloma* and other soil dwelling pest species with varying success (Matthiessen and Shackleton 2000). A reduction in the mortality rate of *N. leucoloma* has been linked to highly degrading soils enhancing the biodegradation of methyl isothiocyanate (MITC), the toxin produced by the biocide metham sodium (Matthiessen *et al.* 2004). The limited effect demonstrates the susceptibility of the efficacy of metham sodium for control of soil borne pests due to enhanced soil biodegradation (Matthiessen *et al.* 2004). Clearly the efficacy of biofumigation is dependent on soil and plant type, for example Warton *et al* (2003) used Brassica plants which are known to produce biofumigant chemicals (Pung *et al.* 2004).

6.2 Biological

Soil insect resistant cultivars are available in sweet potato production (Chalfant *et al.* 1990). Lucene may be a suitable crop to develop strains resistant to weevil damage and other stresses but there is no research literature available.

7. Cultural control of white fringed weevil

Due to the lack of successful chemical or biological control thus far the Queensland Department of Primary Industries recommends control of *N. leucoloma* by rotating out lucerne and other broadleaf crops and crop the infested areas to cereals or pure grass pastures, which are not preferred hosts to the pest (PrimeNotes 2006). Similarly in the U.S. control practices include: planting oats or other small grains, which are much less preferred by weevils due to their fibrous root systems; limiting acreage planted to summer legumes (e.g., peanuts, soybeans) and placing leguminous crops on a three to four year rotation (Chalfant *et al.* 1990). Crop rotation has been used effectively to reduce infestation levels (Chalfant *et al.* 1990). The planting of crops which are poor food for adults (oats or other small grains) on heavily affected areas of a farm has been shown to reduce the population (Chalfant *et al.* 1990).

Initially in the United States 30 cm wide by 30 cm trenching was used around farms in an attempt to reduce colonisation (Chalfant *et al.* 1990). Trapped beetles were killed by crushing or by dosing with kerosene (Chalfant *et al.* 1990). Unfortunately Chalfant *et al* (1990) do not expand on the long term success or otherwise of this control, which exploits the crawling behaviour of adult beetles.

Regular cleaning of farm machinery and other items that have been used in affected areas would be beneficial to remove weevils and eggs. Sanitation practices by tillage or seeding contractors as well as general in house on property management is recommended as a means of mitigating spread of the weevil species (De Barro pers. comm.).

8. Chemical control of small lucerne weevil in lucerne

Sprays to control adults as they emerge in late summer may be effective especially if applied twice (PestWeb). The first application is needed approximately one week after weevils are first observed with a follow up spray two to three weeks later (PestWeb). As with *N. leucoloma* timing is critical to prevent egg laying (PestWeb). Unlike *N. leucoloma* sampling must be carried out at night if the first adults are to be observed (PestWeb). Soil core sampling (see above) would be beneficial if pupae could be detected to provide a time of adult emergence.

Due to the crawling nature of this weevil, colonisation of new areas is thought to come from adjoining pastures and bush land border sprays are sometimes beneficial (Manigano and Severtson 2008). Insecticides containing bifenthrin or chlorpyrifos are recommended for bare ground spraying (Manigano and Severtson 2008). Control of weevils that are spread across large areas has been costly in some cases where rates up to 400ml/ha of alphacypermethrin applied to canola seedlings have given low mortalities (Manigano and Severtson 2008). In most cases either 800mL/ha of chlorpyrifos, 400ml/ha of alphacypermethrin or high rates of bifenthrin have worked well against small lucerne weevils (Manigano and Severtson 2008). Alphacypermethrin is most effective when applied onto good vegetative cover (Manigano and Severtson 2008).

9. Cultural control of small lucerne weevil

Crop rotations can be useful to break the weevil lifecycle if all lucerne and tap rooted plants are deceased or removed (PestWeb). Break crops i.e. cereals used in conjunction with dryland lucerne or horticultural crops with irrigated lucerne are effective however a break of at least 12 months is required until lucerne is resown (PestWeb).

10. Future Directions

Weevils are formidable pests in agriculture for a variety of reasons. A greater understanding of their biology will facilitate improvements in their management. Improved knowledge of *N. leucoloma* traits has allowed for some successful treatments although this appears mainly confined to annual crops such as potatoes at this stage. Well timed application of adulticides makes use of the period between adult emergence and oviposition to reduce future generations. Further understanding may allow a characteristic to be exploited that provides control in perennial crops. There is an urgent need to research the biology of *A. taeniatulus* and *L. duponti* to aid in managing these pests as they emerge as a pasture problem.

Standout gaps in the knowledge of *N. leucoloma* include; mixed swards i.e. lucerne and ryegrass causing high lucerne mortality from larval feeding, understanding of natural predators and patchy distribution. The uneven distribution has also been observed in *A. taeniatulus*; to eliminate soil type as a factor core sampling for weevils and substrate type may highlight a significant trend.

Although insecticides have had varied success they are worthy of further research. The adulticide approach has appeared beneficial in some tests, long term testing in perennials would determine if this is an effective management option. Due to the often patchy colonisation small plot trials are not feasible. The fecund nature of weevils suggests that if a few beetles are not treated then infestation could still be significant. Further, it is not clear from the literature if resistance is a confounding problem with some researchers stating that good knock down was achieved on *N.leucoloma* and *A. taeniatulus* whilst others suggesting that *N. leucoloma* quickly showed resistance. Long term monitoring would once again be beneficial due to the costs involved economically and environmentally. A state wide (or national) register of legal chemicals and likelihood of efficacy is needed for researchers and managers alike.

The reasonably successful metham sodium applied to soils between annual crops may have a place in perennials (i.e. before planting new crops) to manage residual weevils. Soil applications could be followed up with other techniques during the crops productive lifetime.

Biological control of weevils with parasitic nematodes could have advantages over insecticides, i.e. some species are native to Australia, there is no risk of groundwater contamination and larvae can be targeted within the soil. At present there have been mixed results when applied to *N. leucoloma*. Some research has found a significant reduction in *N. leucoloma* whilst it is rumoured that the CSIRO have run tests with no positive results (no publications on this have been made available). Resources should be applied to further research nematodes in relation to *N. leucoloma*, *A. taeniatulus* and *L. duponti* (no results on the latter two weevils have been published). Other parasites may produce the desired result, for example in New Zealand a wasp has been developed to target another pest weevil species in lucerne. These parasites appear to be very host specific as such stringent tests should be applied and include their potential effects on other biota.

Resistant cultivars of lucerne could aid in minimising weevil production loss. It is likely that a strain that is unpalatable to weevils will not be discovered. However, strains that can better cope with other stresses (e.g. drought, salinity etc.) could help reduce production losses.

Cultural controls have a substantial role to play. Rotating out lucerne and other leguminous crops to non preferred types (e.g. cereal) crops may be the only option whilst other management techniques are being developed. Due to the life history of *N. leucoloma* infested pastures should not be returned to legumes for a period of at least three years. It has been stated that for *A. taeniatulus* the period should be 12 months suggesting that weevil has a shorter lifecycle (it would be beneficial to have precise information on their lifecycle). Trench type pitfall traps on boundaries can in theory stop colonisation due to the crawling nature of weevils. Design efficacy trials could be reasonably simple and warrant future research due to the potential to stop the spread of weevils from scrub and infected pastures.

Sanitary measures have not stopped weevil colonisation, likely due to controls not being strictly adhered to. It is an achievable goal to prevent weevils being carried by trade but suitable resources must be used within farms, districts, nationally and internationally. Strip farming does not appear to be of benefit as this is usually a measure to enhance the survivorship of natural predators. There is a lack of natural predators reported in the literature.

It is likely that best practice management of weevils would be an "integrated" approach, for example a combination of insecticides, biological control, trapping, sanitary measures and crop rotations. Combined efforts need to be tested (e.g. insecticides may produce nematode mortality) as this approach requires a great deal of resources. Significant effort needs to be implemented against weevils as they are a formidable pest with one beetle having the potential to cause an infestation.

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Glossary

cotyledon: is a significant part of the embryo within the seed of a plant. Upon germination, the cotyledon may become the embryonic first leaves of a seedling.

elytra: plural for elytron is a modified, hardened forewing of certain insect orders, notably beetles (Coleoptera) and true bugs (Hemiptera). An elytron is sometimes also referred to as a shard.

fecund: potential reproductive capacity of an organism or population, measured by the number of gametes (eggs), seed set or asexual propagules.

hyaline: refers to a substance with a glass-like appearance.

metathorax: is the posterior of the three segments in the thorax of an insect, and bears the third pair of legs and bears the hindwings in most winged insects, though sometimes these may be reduced or modified as in flightless beetles (Coleoptera), in which they may be completely absent even though forewings are still present.

oviposition: the process of laying eggs by oviparous animals (no or little embryonic egg development within the mother).

parthenogenic: when reproduction from an ovum occurs without fertilization, esp. as a normal process in some invertebrates and lower plants.

phytosanitary: concerning the health of plants; especially the freedom from pests requiring quarantine

polyphagy: the ability of an animal to eat a variety of food

propagule: a vegetative structure that can become detached from a plant and give rise to a new plant, e.g., a bud, sucker or spore.

prothorax: foremost of the three segments in the thorax of an insect, and bears the first pair of legs.

soft insecticide: a safe and effective way to control pests using natural products that break down quickly after application and have minimal impact on natural enemies and people, e.g., plant extracts, insect disease propagules, mineral oils or commercial material, that are based on natural products.

thorax: a division of an animal's body that lies between the head and the abdomen.

univoltine: referring to organisms having one brood or generation per year.

Improving Pest Management in the Australian Lucerne Industry

— A review of management of white fringed weevil, small lucerne weevil and broad-back weevil —

RIRDC Publication No. 09/172

By Thomas Barnes and James De Barro

This review of literature on three species of weevils that have been recorded as having negative impacts on lucerne in Australia will enable the Australian lucerne industry to develop proactive measures regarding their management. The known biology of the three weevil species has been complied, as well as information regarding cultural, biological and chemical control measures in lucerne and other infected crop species.

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