NAIL THE SNAILS

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NATIONAL

A PRACTICAL GUIDE TO INTEGRATED SNAIL CONTROL FOR AUSTRALIAN GRAIN GROWERS

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Original concept:
This guide is a revised edition of the manual *Bash'Em Burn'Em Bait'Em: Integrated snail management in crops and pastures* (Leonard et al. 2003). The editors acknowledge Emma Leonard, Geoff Baker and Dennis Hopkins, editors of the original manual on which this update is based. The editors also acknowledge the contributors of data and images to the original edition: Megan Leyson, Suzanne Charwat, Vanessa Cavagnaro, Hemantha Rohitha, Trevor Dillon, Bill Long, Allan Mayfield, Jack Desbiolles, Craig Heidenreich, Salil Sharma and Michael Richards, in cooperation with many growers, advisers and commercial companies.

This team, together with the Grains Research and Development Corporation (GRDC) and the South Australian Grains Industry Trust (SAGIT), are acknowledged for their original vision in developing an integrated management strategy for pest snails. The evocatively named manual was a critical step in promoting adoption of best practice snail management in southern Australia.

Revisions:
This is the second edition. Evolving farming practices, an increase in the pest status of snails in some cropping regions of Australia, and new snail research, were the main drivers for this update. The main revisions in this edition include a greater focus on the key recommended actions and timing of controls, incorporation of more recent research information, reduced focus on some control methods that have become less compatible with modern farming, and a streamlined, updatable format with citation of information sources where possible. There are still gaps in knowledge of pest snails and their management. This update draws together the best available information to provide a nationally relevant guide to current best practice snail management for Australian growers. The editors acknowledge Greg Baker, Michael Nash, Helen Brodie, Kate Muirhead, Nicole Fechner, Valerie Caron, Svetlana Micic and Alaina Smith, for contributing new data and critical review of this edition.

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COVER: Snails on cereal stubble
PHOTO: Kym Perry

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Contents

Introduction

Introduced Mediterranean snails are arguably one of the most important invertebrate pest threats facing the Australian grains industry. Their greater pest status in Australian broadacre crops than elsewhere globally limits the availability of overseas experience for local growers to draw on, but also positions Australian growers as leaders in innovation for pest snail management.

Snails cause widespread feeding damage, particularly to young crops. Even more significantly, their potential to contaminate the grain harvest leads to substantial pre- and post- farmgate losses for affected growers, as well as significant risks to trade for the industry.

The costs of snails to the grains industry are not well quantified, but together with slugs are likely to exceed $170 million annually. These costs are incurred from crop losses, field management costs, harvest and post-harvest cleaning costs, grain rejection or value penalties at delivery, and opportunity costs which are difficult to capture. Opportunity costs may arise from growers' avoiding growing certain crops to avoid snails, or grain being diverted to alternative markets.

Research on the impact of snails in the grains industry has occurred since the 1980s, and GRDC has a history of investment in novel approaches to mollusc control, some of which are ongoing. Twenty-five years ago, the grains industry developed a truly integrated management program for snails, which still underpins best practice snail management.

Mollusc management consists of an integrated, year-round approach comprising cultural, mechanical, and chemical (baiting) methods undertaken in autumn, around the harvest operation, and between cropping seasons. Together these methods help mitigate snail populations but, even when performed exceptionally well, snails continue to pose problems.

With evolving farming practices, modern farms provide a generally favourable habitat for snails, with retained stubble increasing the availability of refuges, moisture, and carbon. Some of the earlier snail management practices (e.g., tillage, burning) are now less compatible with conservation farming, with snails also benefitting from reduced disturbance of the system. Meanwhile, invasive snails have continued their quiet spread between paddocks, farms, and districts, through movement of infested feed, vehicles, and equipment.

Together, these factors have contributed to an increased pest status of snails in existing and new geographic regions, which has been concurrent with tightening of grain delivery standards for snail contamination. Conical snails have emerged as a particular problem due to their small size, often high populations, preference for hiding in shelters, and the difficulty separating them from grain at harvest. Effective snail management has become more important than ever before for enhancing grower profitability.

Collective research efforts have led to the development and adoption of improved integrated control programmes for snails and some very promising approaches for further research, but no single 'silver bullet'. The impact of snails will continue to be problematic without an integrated 'systems' approach.

Ongoing research and development of novel monitoring and field control methods is required to better manage the risks of snails in our farming systems. This is likely to require multidisciplinary problem-solving approaches in the supply chain (field, harvest, postharvest), including AI based monitoring, engineering, robotics, biological control, movement interception, and agronomic strategies. But at the heart of successful management must be an ever-more comprehensive understanding of pest snail biology and ecology, to better know these enemies and their vulnerabilities.

GRDC has and will continue to investigate the most effective integrated snail management tactics for the grains industry.

Improved management of snails and slugs remains a priority to improve growers' profitability and ensure Australia's market access is maintained.

This revised and updated booklet *Nail the snails: A practical guide to integrated snail control for Australian grain growers*, is designed to guide and support growers and advisers in tackling snails. It draws heavily on the original research but homes in on the most relevant management strategies and key actions to consider throughout the crop management cycle.

Revisions to the manual include new and updated information on bait timing and application, harvest and postharvest practices, incorporation of newer research information available nationally, and a streamlined updatable format.

This guide provides a national resource to help growers make informed snail management decisions. The key message is that correct timing of controls, as well as patience and persistence, underpin successful snail control. The core management points are:

1. Practise farm biosecurity to prevent snails spreading

2. Reduce snail survival over summer

3. Bait snails before they breed

4. Minimise snail contamination at harvest

5. Clean infested grain after harvest

6. Encourage biocontrol of conical snails

Dr Leigh Nelson

GRDC Manager - Pests

GRDC™

Theba pisana **aggregation on a fenceline.**

Image: Kym Perry

Section 1 – Quick start guide

Pest snails in Australia

Introduced Mediterranean snails are major pests of grain crops and pastures in Australia. The following two round-shaped and two conical-shaped species are the focus of this manual:

- **Round snails:**
  - Vineyard snail, *Cernuella virgata*
  - White Italian snail, *Theba pisana*
- **Conical snails:**
  - Conical snail, *Cochlicella acuta*
  - Small pointed snail, *Cochlicella barbara*

These species feed on crops and contaminate grain at harvest. All four species share many biological characteristics, but vary in their abundance and pest status in different cropping regions. There is no single solution for snail control. An integrated management program is required, which targets key stages in the snail life cycle (Table 1.2, Figure 1.1 and Figure 1.2).

How to use this manual

This manual contains seven sections:

To use this manual, keep the **Quick start guide (Section 1)** handy and follow the **Key actions (Table 1.2)**. For more details, refer to **Sections 2 to 7** (Pages 10–34) and follow the **Key actions**.

Table 1.1: Identification of the four pest snail species covered in this manual.

Round snails		Conical snails	
Vineyard snail, *Cernuella virgata* • Open circular umbilicus (central depression) • Feeds on plants and dead plant matter • Can damage crops and contaminate grain		**Conical snail, *Cochlicella acuta*** • Elongated shell (ratio of length to maximum diameter greater than 2:1) • Feeds primarily on dead plant matter, but sometimes on plants • Can contaminate grain	
White Italian snail, *Theba pisana* • Partly closed umbilicus (not circular) • Feeds on plants and dead plant matter • Can damage crops and contaminate grain		**Small pointed snail, *Cochlicella barbara*** • Broader shell (ratio of length to maximum diameter less than 2:1) • Feeds on plants and dead plant matter • Can contaminate grain • Pest of lucerne	

Images: Herbert Zell

Core management actions for pest snails

- Monitor snails at key times of year (Section 3, and Figure 1.1) and assess management options (Figure 1.2).
- Manage snails in all infested crop and pasture paddocks in all years (Table 1.2).
- Practise farm biosecurity (Section 6) to prevent snails spreading between paddocks and farms.

Table 1.2: Key actions and considerations for snail management.

Management practices	Considerations
1. Practise farm biosecurity to avoid spreading snails (Section 6)	
Ensure vehicles and equipment are free from snails, especially at harvest, in summer and at planting	• Snails dislodged in summer readily climb onto equipment
Do not move infested fodder	• If snail removal is difficult: consider harvesting snail-infested areas last, then thoroughly clean equipment
Limit access to farm	• Erect farm biosecurity signage at all entries • Ensure contractors do not bring infested machines onto property
2. Reduce snail survival over summer (Section 5)	
Control summer weeds	• Removing weedy refuges limits snail survival and increases the efficacy of cabling and burning
Use cables or chains to dislodge snails from stubble on hot days and kill them	• Cable on sunny days with maximum temperature more than 35°C • Using two passes at least one hour apart is most effective • May be less effective against conical snails
Use rollers to flatten stubble and crush snails	• Heavy flat steel rollers are more effective than rubber-tyred or steel-ribbed rollers • Roll in summer or autumn when snails are resting on stalks • May be less effective against conical snails
Consider burning to manage excessive stubble and kill snails	• Kill weeds; roll stubble and turn over rocks prior to burning • A slow, hot, even burn kills most snails • Consider soil health and erosion risk
3. Bait before egg-laying to suppress snails (Section 4)	
Apply baits as soon as snails commence feeding at the end of summer dormancy	• Monitor movement in late summer and autumn • Apply bait as soon as snails commence feeding • Monitor and re-apply bait as required • Apply bait evenly at recommended rate • If both round and conical snails are present: consider a second bait application around sowing time due to later onset of conical snail activity
4. Minimise snail contamination at harvest (Section 6)	
Harvest early	• Snails are more easily dislodged earlier in spring
Consider windrowing or direct heading	• Windrowing dislodges mostly larger round snails; can reduce snail intake when harvested soon after • Direct heading canola may reduce the intake of conical snails
Harvest and store snail-infested grain separately from cleaner grain	• Use separate storages for post-harvest cleaning
5. Clean infested grain after harvest (Section 6)	
Clean infested grain using a combination of snail crushing rollers, screening and scalping	• Tailor cleaning systems to your individual farm situation to maximise snail/grain separation and minimise grain loss • Calculate the cost and benefits of different solutions to clean snails from grain • Storing grain for at least one week can increase cleaning throughput
6. Encourage biocontrol of conical snails (Section 7)	
In regions where the fly is established: Promote flowering native vegetation on property perimeters to enhance biocontrol	• The parasitoid fly, *Sarcophaga villeneuveana*, attacks both conical and small pointed snails, but also requires floral nectar and pollen resources

Figure 1.1: Snail life cycle and key monitoring times.

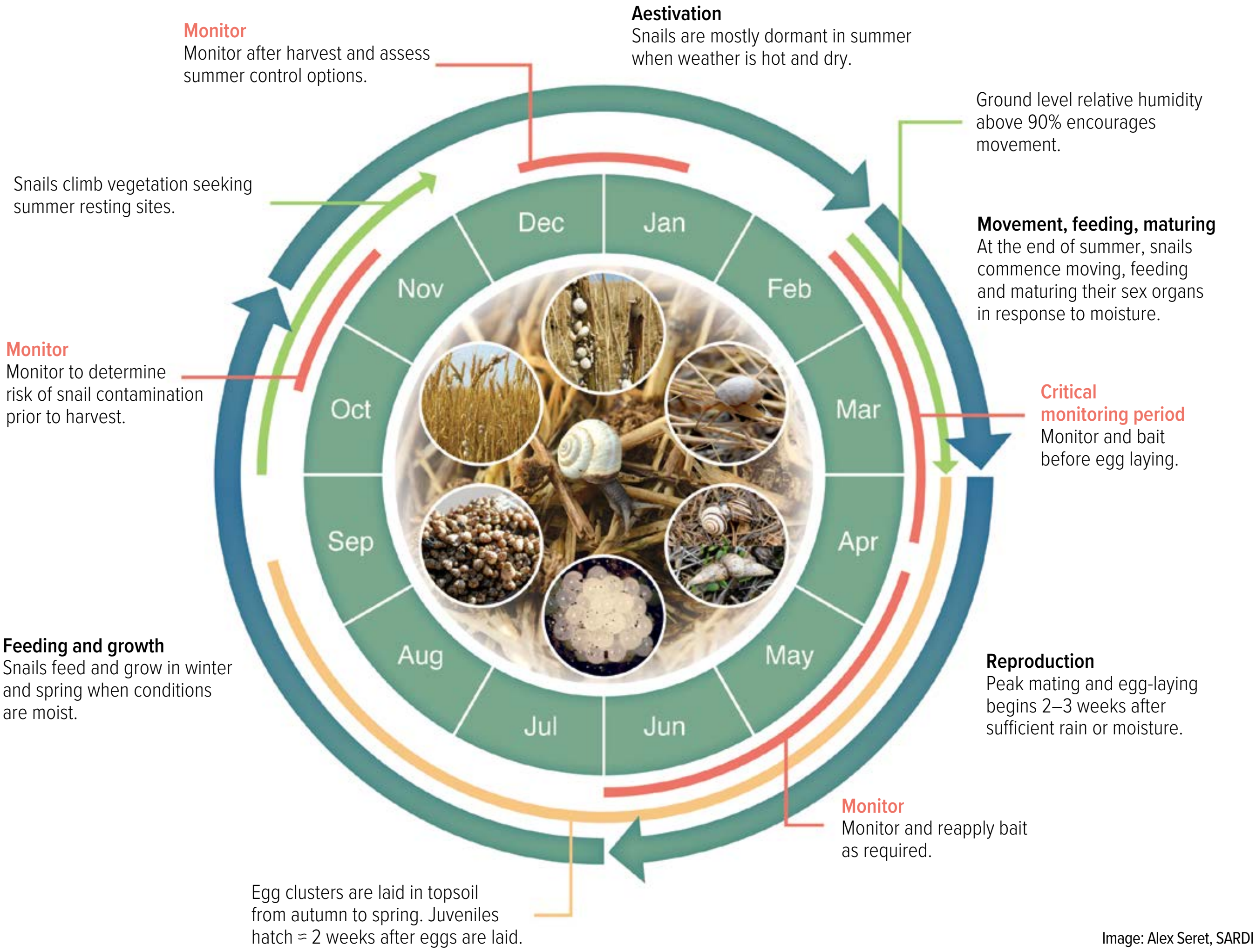

Image: Alex Seret, SARDI

Figure 1.2: Snail management timeline.

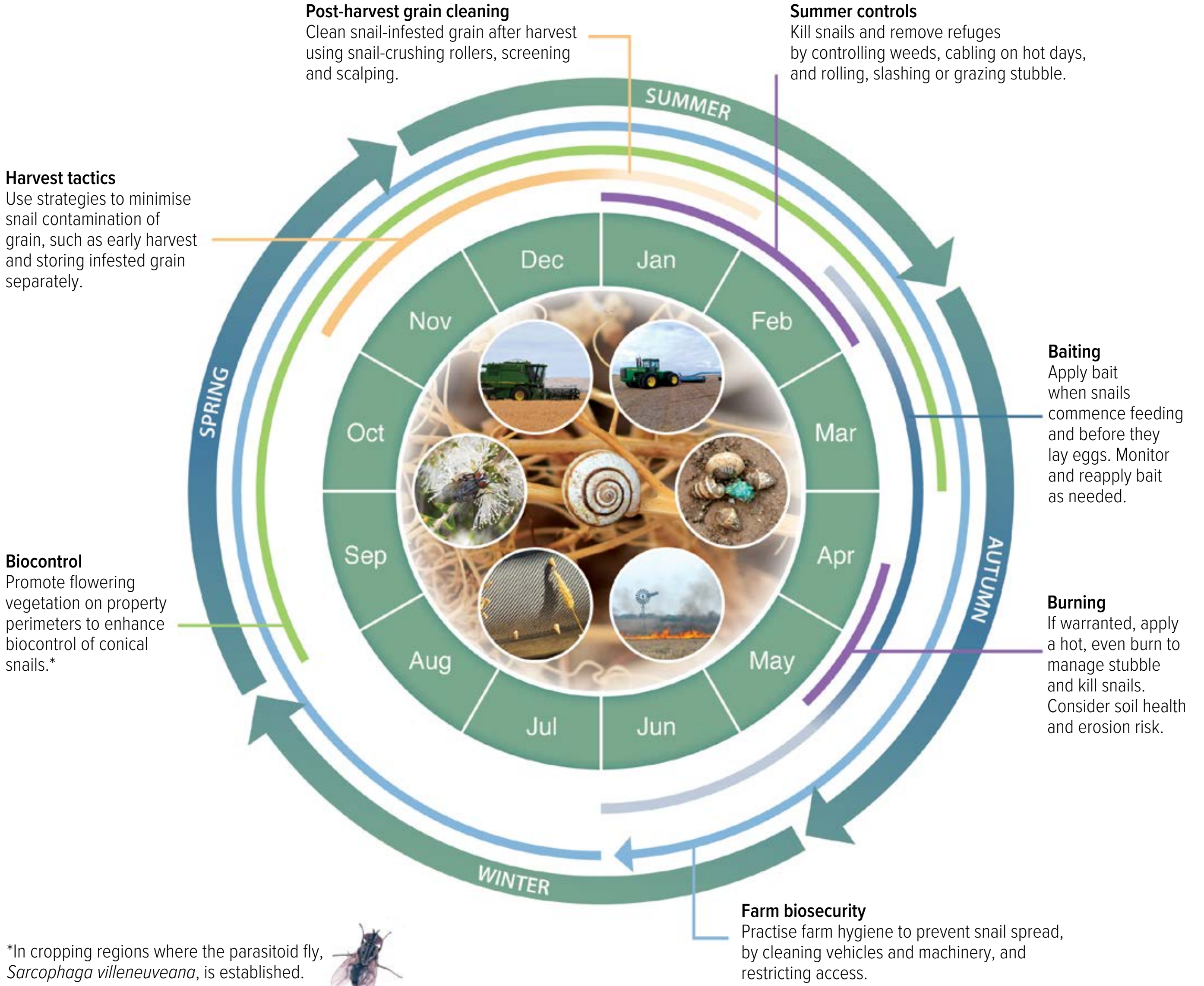

Image: Alex Seret, SARDI

Section 2 – Biology and ecology of pest snails

Overview

Four species of introduced snails are significant pests of grain crops, pastures and other crops in Australia, and are the focus of this management manual:

- the vineyard snail, *Cernuella virgata*;
- the white Italian snail, *Theba pisana*;
- the conical snail, *Cochlicella acuta*; and
- the small pointed snail, *Cochlicella barbara*.

As they share many characteristics, a general understanding of snail biology can facilitate management of all four species.

Damage

The four pest species feed on dead and living organic matter. Snails damage crops by direct feeding (Figure 3.10). Establishing crops and pastures are most susceptible to damage. Contamination of harvested grain is the most widespread problem caused by snails. Snail contamination of grain can clog harvest machinery, downgrade grain quality and threaten export markets. Livestock reject pastures heavily contaminated with snail mucus[1].

Origins and distribution

The pest snails featured in this manual originated in the Mediterranean Basin in Europe. They are now found in all grain-producing regions in the southern half of Australia (ala.org.au). Introduced pest snails have not yet colonised all potentially suitable sites in Australia.

Pest snails can be found on all soil types but often reach high abundances on alkaline soil types where calcium carbonate is freely available, either naturally or where lime has been applied to acidic soils[2]. Snails require calcium for shell growth and reproduction[2,3,4]. Abundance is strongly correlated with soil moisture levels and the amount of soil organic matter[5]. Stubble-retention farming practices provide a favourable habitat for snails.

All species have expanded their Australian distributions by hitchhiking on vehicles and farm machinery, and have become locally abundant in agricultural areas. Aestivating (dormant) snails resting on farm equipment are readily transported to new sites when equipment is moved. This has important implications for farm-level biosecurity, even from paddock to paddock.

Seasonal activity

Snails display a seasonal pattern of activity. Key monitoring times for snails depend on the snails' life cycles and time of year (Figure 1.1). They are mostly inactive in summer and active when soils are moist throughout the rest of the year. Breeding typically commences shortly after sufficient rain has fallen in late summer or autumn. Activity is significantly affected by rainfall, humidity and evaporation, so the actual timing of snail activity is dependent on local conditions that differ each year.

Moisture and snail behaviour

Moisture and humidity levels strongly influence snail behaviour and reproduction. Snails are highly susceptible to dehydration but have adapted to minimise this risk in several ways. Movement usually occurs when the ground is wet, but not saturated[5]. Snails are inactive when conditions are dry and hot, and restrict activity when moisture and humidity levels are low[5]. They absorb water through their skin when humidity exceeds 95 per cent[6].

Aestivation, or dormancy, is an adaptation that allows snails to survive unfavourable conditions in spring and summer[5]. Snails pass this period of dormancy in various ways, depending on the species. Round and conical snails rest above the ground on stubble, tree trunks, fence posts and other objects. They also shelter under rocks, fallen trees and other objects, at the base of plants or on plant roots, or burrow into the soil. Conical snails display more cryptic behaviour than round snails, and hide in cooler, dark refuges near ground level. Snails often aggregate during aestivation.

Prolonged periods of dryness and high temperature trigger aestivation or dormancy in late spring or early summer. Snails attach their shells to the substrate, seal the shell aperture, withdraw into their shell and remain inactive. As the shell aperture is sealed during aestivation, little water is lost[6,8]. This is a survival strategy against desiccation, as even when food is present, it is not available to snails unless the ground is sufficiently moist to permit activity[9,10]. Mortality over summer is thought to be primarily due to starvation[9] or exposure to heat extremes[11], but not dehydration[9], indicating the effectiveness of dormancy in preventing water loss.

Summer survival is enhanced where crop stubble has been retained (Figure 1.1). Stubble allows snails to rest in a cooler location above ground level, and escape potentially lethal soil surface temperatures in summer[12]. Summer rains can trigger short periods of activity, but no breeding occurs until the end of summer or early autumn[13]. In autumn, snails begin feeding and their reproductive organs mature. Mating typically starts two to three weeks after the first rains in late summer or autumn[12–16].

Movement

Snails move by producing waves of muscular contraction of their sole or 'foot' as they move over their mucus trail[17]. Most movement occurs at night when moisture is present[9] and relative humidity exceeds 80 to 90 per cent (Table 2.1). Snails tend to move at lower relatively humidity levels as seasons change from summer to autumn.

The daily timing of snail movement varies according to season (Figure 2.2). Most snail activity occurs after midnight to soon after sunrise. When timing snail management practices, it is helpful to use predictions of snail movement based on weather conditions.

Table 2.1: Percentage ground level relative humidity predicted to cause high snail movement[13].

Species	Feb	Mar	Apr	May
Vineyard snail	>95%	>90%	>80–85%	>80–85%
White Italian snail	>90%	>90%	>85–90%	>85–90%
Small pointed snail		>95%	>95%	>95%

Reproduction and life cycle

Snails are hermaphrodites, which means they have both female and male reproductive organs, and all snails can lay eggs. They must copulate with another snail before they lay fertile eggs[10].

Snails must grow to a minimum size, typically reached after one year, before they can reproduce. They continue to grow throughout their lifespan.

Soil moisture is crucial for reproduction[18]. Pest snails lay clutches of eggs in moist topsoil[18]. The eggs absorb water and swell as they develop. Laboratory experiments show that egg-laying commences one to six weeks after exposure to moisture, suggesting that similar intervals may occur after natural autumn rains[16,19]. Snail eggs hatch and emerge in autumn about two to four weeks after they are laid. Young snails grow and develop through the winter and spring.

Snails reproduce from autumn to spring, but lay most of their eggs by early winter[13,16,19,20,21].(Figure 2.3). The amount of reproduction varies between locations, possibly in response to different food sources and climate. Most pest snails exhibit a biennial pattern of reproduction, that is, they can survive to reproduce in a second year.

The reproductive potential of pest snails varies among species. The vineyard snail can produce the most eggs, followed by the white Italian snail and the conical snail (Table 2.2). The reproductive potential of the small pointed snail has not been studied.

Snails have an albumen gland that enlarges when they breed. Seasonal variation in the size of the albumen gland indicates how the timing of reproduction varies from year to year (Figure 2.4).

Rainfall affects the onset of reproduction, but this is not well understood. In general, sufficient rain needs to fall at the end of summer or afterwards to stimulate breeding[13].

Population dynamics

Rainfall is a key driver of snail reproduction[20]. Abundance typically peaks in late spring when most snails are immature. Crucially, snail abundance at harvest is not related to snail numbers in the preceding autumn[20,21]. Large numbers are sometimes found at paddock margins, which suggests that local snail invasions arise from dense populations in adjacent pastures.

Recruitment refers to the combined effects of egg production, survival and maturation of immature snails. There is greater recruitment of vineyard snails, white Italian snails and conical snails in pastures than in crops[20,21,22]. Grower observations suggest that conical snails can increase following a canola phase.

Figure 2.1: Effects of wheat stubble (height 15 centimetres) and trash on survival of two snail species over summer[11].

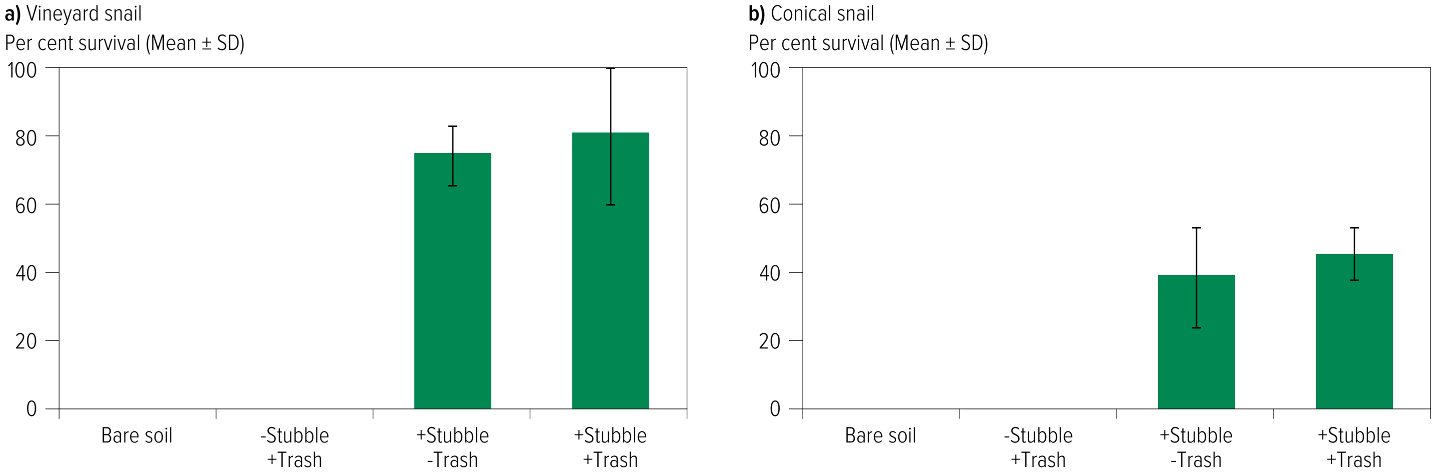

Figure 2.2: Example of distances travelled by white Italian snails throughout one year at a site at Warooka, South Australia. Note the peak of activity after midnight in March, circled in red[13].

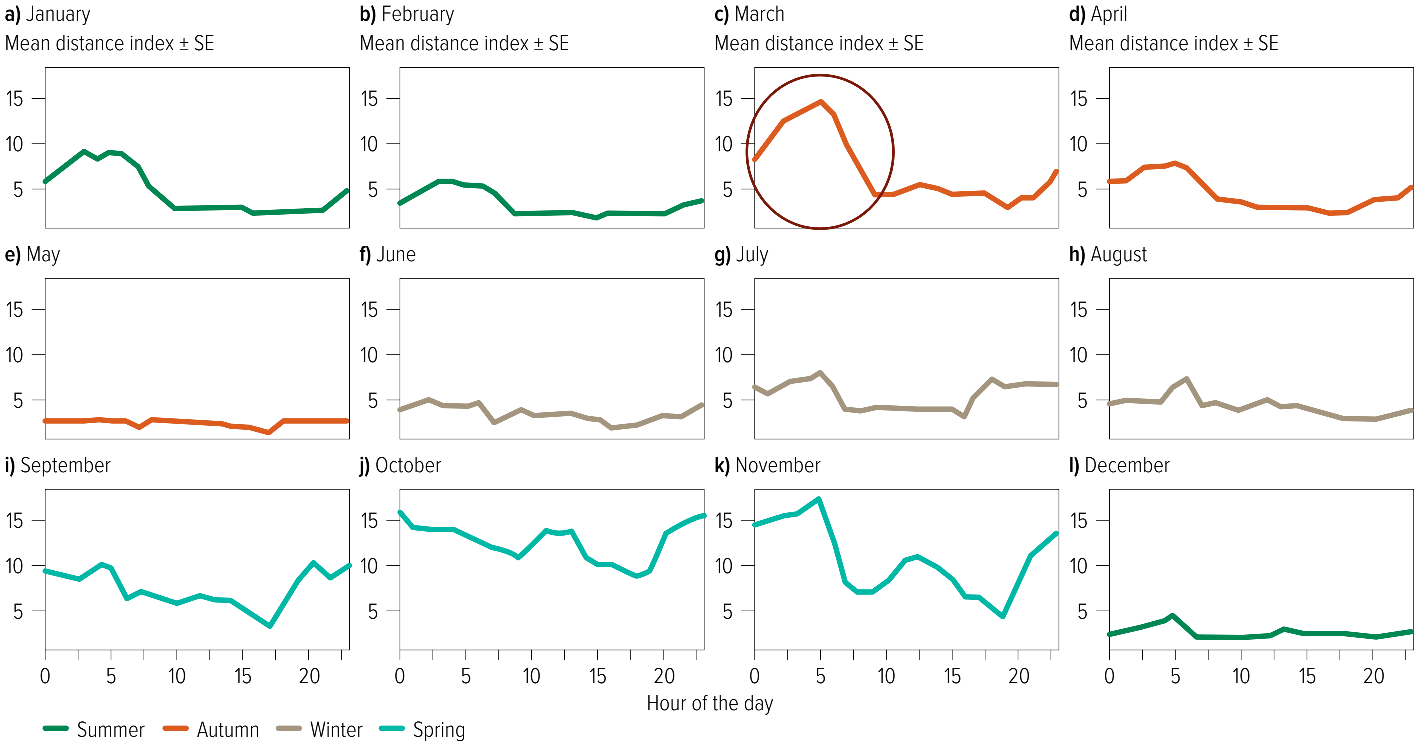

Table 2.2: Reproductive potential of pest snails in Australia. Values shown are ranges of means per pair of snails from different locations.

Species	Weeks to first clutch†	Lifetime egg production	Eggs per clutch	Number of clutches	Reference
Vineyard snail	1–6	2529–3239 (range 50–8268)	60–66 (range 1–257)	42–49 (range 9–96)	Baker 1991
White Italian snail	2–6	1324–3051 (range 694–4566)	70–89 (range 2–225)	19–34 (range 11–46)	Baker 1991
Conical snail	2–5	258–373 (range 117–405)	36–41 (range 29–51)	7–9 (range 2–13)	Baker et al. 1991

†Number of weeks after snails were exposed to wet soil before they laid the first egg clutch.

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Figure 2.3: Seasonal patterns of snail reproduction based on laboratory studies of three snail species. Lines represent separate experiments[16,19].

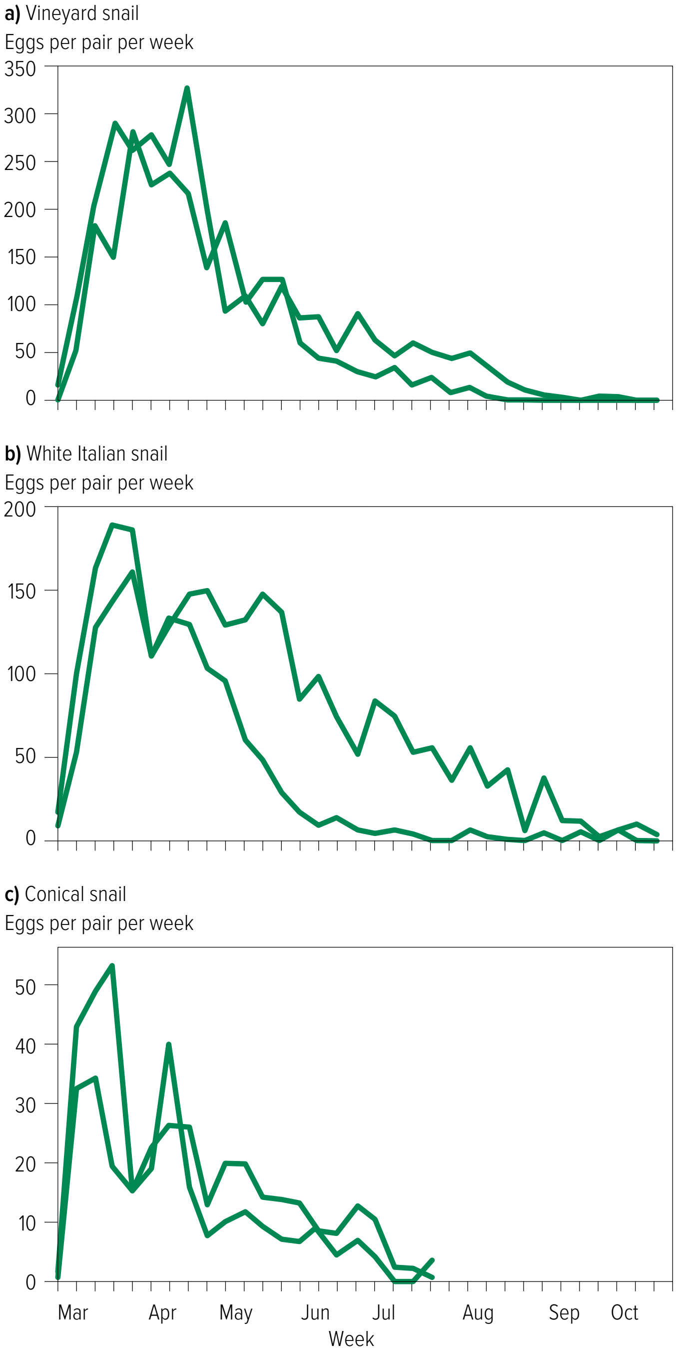
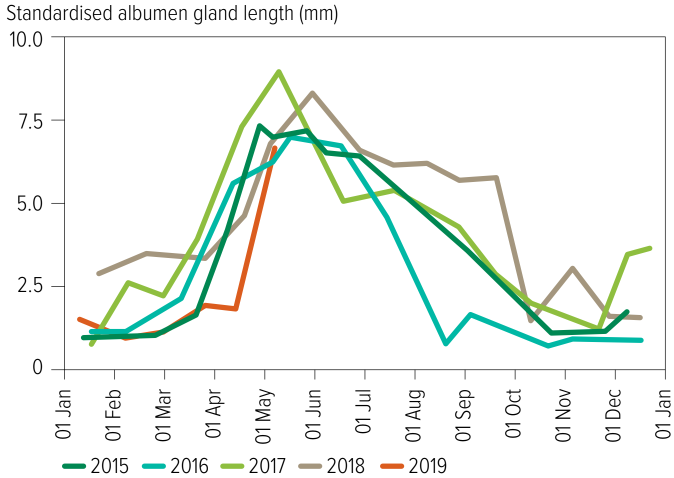


Figure 2.4: Seasonal variation in length of the albumen gland in the vineyard snail at one site. Albumen glands swell when snails are breeding[13].



Identification

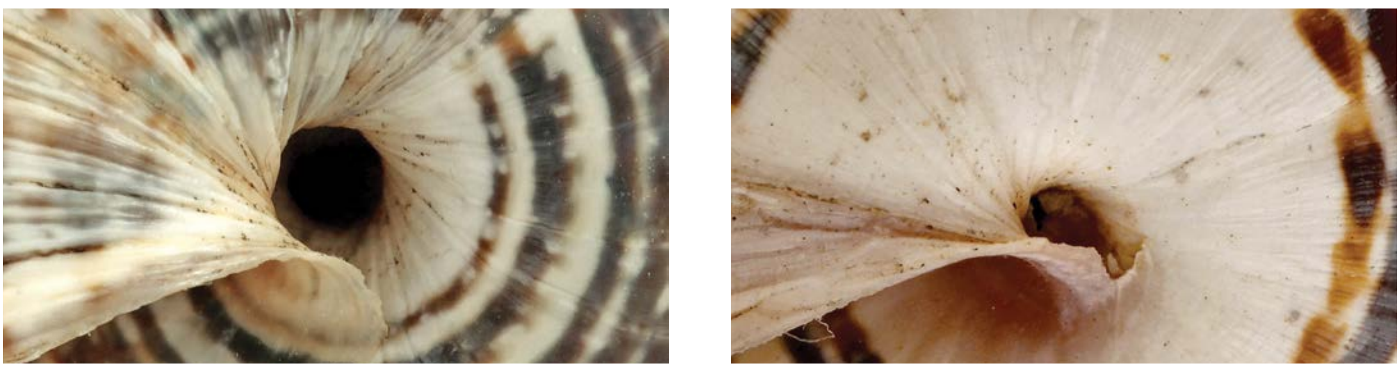
Snails can be identified by their shell shape and size characteristics. The four pest snail species are either helical (a round spiral) or conical (cone-shaped). Snail colour and shell markings vary widely from place to place, so these characters are less useful for identification.

The two round snails can be distinguished by the shape of the umbilicus (central hollow space). The vineyard snail has an open, circular umbilicus (Figure 2.5). It is classified in the family Geomitridae and tribe Cernuellini[23]. The white Italian snail has a semicircular or partially closed umbilicus. It is in the family Helicidae and tribe Thebini[23].

The two conical snails are in the family Geomitridae and tribe Cochlicellini[24,25]. They are distinguished by the ratio of shell length to diameter.

Figure 2.5: Comparison of the shape of the umbilicus in a) the vineyard snail and b) the white Italian snail.

a) Vineyard snail **b)** White Italian snail



Source: Herbert Zell

Vineyard snail, *Cernuella virgata*

Image: Herbert Zell

This species has an open circular umbilicus. Reproductive snails have a diameter greater than 9 to 10 millimetres (mm)[13]. The white shell may have brown bands around the spiral, but there can be considerable variation in shell colour. Under magnification, regular straight etchings can be seen across the shell.

The vineyard snail feeds on green foliage and dead organic matter. It can damage young cereals, canola and pulse crops. This species mainly over-summers off the ground on plants, stubble, fence posts and other objects. The vineyard snail has a biennial life cycle[19].

Conical snail, *Cochlicella acuta*

Image: Herbert Zell

This species is recognised by the shape of its shell. The ratio of shell length to diameter is always greater than 2:1. Reproductive snails have shells greater than 10mm in length[13]. They are fawn, grey or brown in colour.

The conical snail feeds on dead organic matter, and occasionally on green foliage. It mainly over-summers under stones, stumps and plants, as well as on fence posts and vegetation[7]. It contaminates grains and fouls harvest machinery. The conical snail has a biennial life cycle[16].

White Italian snail, *Theba pisana*

Image: Herbert Zell

This species has a semicircular (partly closed) umbilicus. Reproductive snails have a shell diameter greater than 10 to 12mm[13]. The white shell may have broken brown bands around the spiral, whereas some specimens are entirely white. Under magnification, cross-hatched etchings can be seen on the shell.

The white Italian snail feeds on green foliage and dead organic matter. It can damage emerging crops and pastures. This snail mainly over-summers off the ground on plants, stubble, posts and other objects, and is commonly found on green weeds. The white Italian snail has a biennial life cycle[22].

Small pointed snail, *Cochlicella barbara*

Image: Herbert Zell

This species is recognised by the shape of its shell. The ratio of shell length to diameter is always less than 2:1. Reproductive snails have shells greater than 6 or 7mm in length[13]. They are fawn, grey or brown in colour.

The small pointed snail feeds on green vegetation and dead organic matter. It is recorded as a pest of lucerne and also contaminates grains. This species typically over-summers in leaf litter on the soil surface, just below the soil surface, under stones and other objects, and can also be found on posts and vegetation. The biology of this species is poorly understood. It has an annual life cycle in Europe[26], but its life cycle has not been studied in Australia.

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Section 3 – Monitoring

Overview

Regular monitoring of snail populations is essential for successful snail management. It is important to identify the species (round or conical), density, and size of snails present at key times to determine appropriate management options. The rapid sampling method is often adequate for decision-making. More detailed sampling can be performed to guide baiting application rates, assess the efficacy of control or monitor populations over time.

How to monitor

The four key times of year to monitor snail populations and assess the options for management are as follows (Table 3.1; Figure 1.1):

- early summer;
- late summer and early autumn;
- early winter; and
- three to four weeks before harvest.

The different monitoring methods are listed below and described in more detail later in this section:

- **Rapid sampling** – to assess management options at key times of year
- **Quadrat sampling** – to count snail densities before and after control, or monitor over time
- **Monitoring snail movement** – in late summer and autumn, to detect the onset of snail feeding and guide the timing of early bait applications.

Snail behaviour and distribution affect monitoring (Box 3.1). Assessing snail risk and knowing the higher risk areas on the farm allow targeting of monitoring and management. Only live snails need to be counted. Live snails retract into their shell when prodded and are moist if squashed.

BOX 3.1: SNAIL BEHAVIOUR, DISTRIBUTION AND MONITORING

- Changes in snail behaviour throughout the year can affect snail distribution and sampling results.
- In **late spring and summer**, snails are mostly in a dormant state (aestivation) and their distribution becomes extremely aggregated. Aestivating snails commonly cluster together on fence posts or stubble, or in sheltered positions, such as around weeds (Figure 3A), under rocks, logs and surface litter, or inside soil cracks[1,2] (Figures 3.1–3.3).
- Monitoring in summer is useful as snails attached to objects above ground level are visible. However, overall numbers are easily underestimated as many snails shelter in refuges. Conical snails prefer refuges over elevated positions[1]. They often shelter in the root zone and inside the stalks of canola stubble (Figure 3.2).
- Random quadrat sampling can be unsuitable in areas with patchy habitat, such as weedy fencelines or roadsides, when snail distribution is highly aggregated. In summer, checking in refuges such as under rocks or inside plants can reveal many snails (Figures 3.2, 3.3).
- In **autumn to early spring** and when moisture is present, snails are often active and distributed more evenly on the soil surface than in dry summer conditions.
- Snail numbers per metre squared (m^2) can be estimated using quadrat sampling.

Figure 3A. Small conical snails sheltering under green vegetation over summer.

Image: Stirlings to Coast Farmers

Table 3.1: Key monitoring times and recommended methods.

What to monitor	Purpose	Method	Management action
1. Early summer (soon after harvest)			
• Snail species • Snail density	Assess options for managing snails in stubble	• Rapid sampling • Quadrat sampling (to assess control success)	Summer controls: • weed control • cabling • rolling • grazing stubbles with snails
2. Late summer to early autumn (before crop sowing)			
• Snail species • Snail density • Snail movement	Assess areas and timing for baiting Assess options for burning	• Rapid sampling • Monitor movement • Quadrat sampling (to assess bait rates or control success)	• Bait as soon as snails commence feeding and before egg laying • Burn stubble if warranted
3. Autumn to early winter (crop establishment)			
• Snail species • Snail density • Crop damage	Assess the need to re-apply bait	• Rapid sampling • Quadrat sampling (to assess bait rates or control success)	• Re-apply bait as needed
4. Early spring (three to four weeks before harvest)			
• Snail species • Snail density and size class	Assess the risk of snail contamination and options to minimise the risk	• Rapid sampling	• Plan harvest to minimise snail intake and maximise snail/grain separation

Figure 3B. Conical snails at the base of a wooden fence post.

Image: Kym Perry

Figure 3.1: Round and conical snails aggregating on *Brassica* weeds in summer.

Image: Nicole Fechner

Image: Kym Perry

Figure 3.2: Conical snails *(C. acuta)* sheltering inside and on canola stubble.

Image: Kym Perry

Image: Kate Muirhead

Figure 3.3: Snails rest on objects above the ground and shelter in refuges.

Image: Helen Brodie

Image: Nicole Fechner

Image: Nicole Fechner

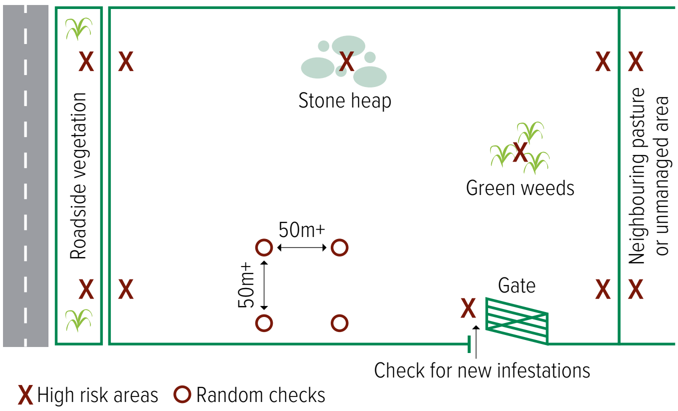
Rapid sampling

Rapid sampling aims to quickly gauge snail populations across the farm to determine options for management. Cover as much ground as quickly as possible, sampling only until a management decision can be made in each paddock. If sampling all paddocks is impractical, sample at least several higher risk and several lower risk paddocks to assess whether snail populations are restricted or widespread.

A suggested strategy for rapid sampling is illustrated below (Figure 3.4). Within each paddock, check higher risk areas. Sample two to several locations along fencelines (for example, adjacent to pastures, roadsides or infested crops). Check outside the paddock to assess the potential for snail reinvasion. Also sample several randomly chosen locations both near the fenceline and farther away (at least 50m).

At each sampling point, turn over any rocks or other refuges, check under weeds and look in surface trash for sheltering snails (Figure 3.3). Visually estimate and record the average numbers of snails (round and conical) per m^2 at each sampling point. Approximate counts are adequate. If desired, also estimate the relative percentage of adult and juvenile snails. As a guide, snails with shells greater than 7mm length or diameter may be adults, or sub-adults that can grow quickly to an adult size, which are capable of reproduction. The minimum reproductive size varies between snail species (page 14). Note any hotspots of higher snail density for targeted management.

Figure 3.4: Recommended rapid sampling points.



Quadrat sampling

Quadrat sampling can be used to estimate the number of live snails per m^2. It is a detailed form of sampling and best used when calculating baiting application rates, to estimate the snail density after a control (for example, baiting or cabling) has been applied, or to monitor populations over time.

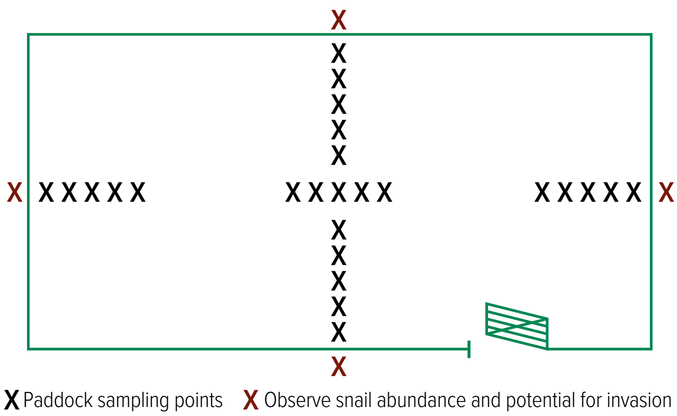
To sample, place a 0.1m^2 quadrat (32cm x 32cm) randomly on the ground and count all live snails within it (Figure 3.5). Record the numbers of round and conical snails separately. It is useful to distinguish two size classes: 1) adult or sub-adult snails that will soon be capable of reproduction, with shell diameter (round snails) or length (conical snails) greater than 7mm; and 2) juvenile snails with shell diameter or length less than 7mm. An example monitoring sheet is provided in Figure 3.6.

Figure 3.5: A 32cm x 32cm quadrat used to count snails.

Image: Kym Perry

To sample a whole paddock, sample five transects (straight lines along which multiple samples will be taken), one at 90° to each fenceline and the fifth across the paddock centre (Figure 3.7). Take five samples (quadrat counts) 10m apart along each transect. For each transect, average the quadrat counts and multiply this figure by 10 to calculate the number of snails per m^2 in that paddock area. Observe habitats and snail numbers outside paddocks to determine the potential for reinvasion. To estimate the efficacy of a control method, sample the whole paddock before and then seven days after application and calculate the percentage mortality.

Figure 3.7: Quadrat sampling points across a paddock.



Monitoring over time

Monitoring snail populations over time in selected areas on the farm has several benefits. Comparing snail populations across years helps to define the level of management effort required each season based on past experience. The data can also reveal the longer term effectiveness of snail management strategies applied on the farm.

For accurate monitoring over time, detailed sampling and record-keeping are required. A suggested sampling strategy is to select two or more cropping paddocks to be sampled. Sample these same paddocks each year in autumn and spring around the same dates. Sample the paddock using the quadrat sampling method, taking five transects and five quadrats per transect. Count all live snails on the ground surface and vegetation within quadrats.

Figure 3.6

Snail Monitoring Sheet

Paddock name:	Date:	Crop:	Temperature:
Name of sampler:	Time:	Count: before / after treatment	Rain (mm) in last 7 days:

	Round Snails		Conical Snails	
	Circle species present: *Cernuella virgata* / *Theba pisana*		Circle species present: *Cochlicella acuta* / *Cochlicella barbara*	
Transect 1	< 7mm diameter	> 7mm diameter	< 7mm diameter	> 7mm diameter
1				
2				
3				
4				
5				
Total				
Average				
Snails/m²				
Transect 2	< 7mm diameter	> 7mm diameter	< 7mm diameter	> 7mm diameter
1				
2				
3				
4				
5				
Total				
Average				
Snails/m²				
Transect 3	< 7mm diameter	> 7mm diameter	< 7mm diameter	> 7mm diameter
1				
2				
3				
4				
5				
Total				
Average				
Snails/m²				
Transect 4	< 7mm diameter	> 7mm diameter	< 7mm diameter	> 7mm diameter
1				
2				
3				
4				
5				
Total				
Average				
Snails/m²				
Transect 5	< 7mm diameter	> 7mm diameter	< 7mm diameter	> 7mm diameter
1				
2				
3				
4				
5				
Total				
Average				
Snails/m²				
All Transects	**< 7mm diameter**	**> 7mm diameter**	**< 7mm diameter**	**> 7mm diameter**
Av. Snails/m²				

Relative percentage of round snails:	***Cernuella virgata***	eg. 80%	**Relative percentage of conical snails:**	***Cochlicella acuta***	eg. 100%
	Theba pisana	eg. 20%		***Cochlicella barbara***	eg. 0%

In autumn, sample in March or April at the end of the snails' summer dormancy, soon after they have commenced activity on the ground (Box 3.1). Even better, sampling these paddocks both before and seven days after the first bait application each year could give an overall indication of baiting success. In spring, sample before harvest, around October or November. Record the weather conditions during sampling and keep consistent records of sampling data.

Sampling at these times measures the population both before (early autumn) and after (spring) the peak breeding season, to help guide management.

Monitoring snail movement

The critical time to monitor snail movement is in late summer and early autumn, to guide the timing of bait applications. Bait should be applied as soon as snails commence movement and feeding activity, at the end of their summer dormancy (Section 4). Accurate timing of bait application is essential for control. Snails must be moving and feeding to encounter and consume a lethal dose of pellets (Figure 3.8 and Box 4.1).

Snail movement is dependent on weather (Box 3.2). Movement can be monitored using a time-lapse camera placed along a fenceline with high snail numbers (Figure 3.9). Alternatively, check the ground for snail trails in the morning. Feeding can be detected by placing small areas of bait in infested areas and checking after a few days. The presence of dead snails around baits indicates that they are feeding, and widespread bait application may be warranted.

BOX 3.2: SNAIL MOVEMENT AND WEATHER

- Snail movement is dependent on weather. Most movement occurs overnight or in the early morning when moisture is present [5].
- In summer, snails are mostly inactive when conditions are hot and dry. Summer rainfall can trigger short periods of snail movement but there is no breeding at this time.
- In late summer and early autumn, snails become more active in response to moisture. At this time, they commence feeding and maturing their sexual organs in preparation for reproduction. This is the ideal time to apply bait (Section 4).
- Snail movement is greatest when relative humidity at ground level exceeds 90–95% in summer and 80–95% in autumn (Table 2.1).

Figure 3.8: Round snail moving.

Image: Kym Perry

Figure 3.9: Time-lapse camera and weather station for monitoring snails.

Image: Helen Brodie

Figure 3.10: Snail feeding damage to canola seedlings (left and middle) and vegetative cereals (right).

Image: Kym Perry

Image: Kym Perry

Image: Martyn Chandler

Feeding damage

Snails have rasping mouthparts that they use to graze on the surface of plant tissues and other foods. Feeding creates irregular holes or ragged edges in leaves (Figure 3.10). In canola, whole cotyledons, leaves or seedlings can be lopped. Maturing cereal crops can be surface grazed, creating leaf striping. Surface grazing of pods in maturing pea crops can cause some grain shattering. Monitoring for snail damage symptoms during crop establishment can inform the need to re-apply bait (Table 3.1).

Assessing snail risk

Areas at risk of higher snail densities include those with previously high snail densities, calcareous soils or acid soils with lime applied, summer weeds and paddock margins (Table 3.2). Adjacent roadside verges, stone heaps, pasture paddocks and heavily infested crops are often sources of invading snails. Noting areas with high snail contamination the previous harvest can identify snail hotspots. Weather also affects seasonal snail risk. Good growing conditions and wet summers generally favour snail populations. Retained stubble and trash provide a favourable environment for snails.

Table 3.2: General and seasonal risk factors for snails.

Risk factor	Lower risk	Higher risk	Explanatory notes
General risk factors			
Cropping region	• Low snail abundance in the region	• High snail abundance in the region	• Snails are more abundant in some coastal regions
Soil type	• Acid soils not limed	• Calcareous soils	• Available calcium benefits snail populations [6, 7]
Liming	• No liming	• Lime applied	• Liming can increase snail populations and shell strength[7]
Previous history of snail populations in the paddock/area	• Low previous snail populations	• Recurring high snail populations • Presence of juvenile snails • Snail contamination during prior harvest	• Snails recur in the same areas • Presence of juvenile snails indicates breeding areas
Vehicle traffic	• Low vehicle traffic	• Vehicle entry points, high traffic areas, parking areas	• Snails hitchhike on vehicles
Seasonal risk factors			
Summer weather	• Relatively hot, dry summer weather • Heatwave events	• Relatively cool and/or wet summer	• Hot weather kills many snails[8]
Summer weeds	• Few green weeds, or weeds controlled	• Green weeds not controlled	• Green weeds increase snail survival[9,10]
Amount of stubble and trash in summer	• Light stubble or trash	• Heavy stubble or trash following high yields	• Residue provides cool, moist refuge
Summer management	• Paddock effectively cabled, rolled or grazed	• Ineffective summer management, or lack of suitable weather (hot days for cabling)	• Snails not suppressed
Crop or pasture rotation in paddock last year	• Paddock continuously cropped	• Pasture phase • Canola rotation	• Conical snails may increase following canola rotations • Snails can breed more in pasture phases[3]

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Section 4 – Molluscicide baiting

Overview

Molluscicide baiting aims to kill mature snails before they breed (Figure 4.1). Accurate bait timing and application are essential for control. Bait as soon as snails begin feeding at the end of their summer dormancy and before they lay eggs. Broadcast pellets evenly using a calibrated spreader to deliver the label rate of product. Baiting provides partial control and is best used in combination with other physical controls (Section 5).

Figure 4.1: Snails consuming bait.

Image: Helen Brodie

Image: Kym Perry

BOX 4.1: FACTORS AFFECTING BAITING PERFORMANCE

Molluscicide baiting relies on snails encountering bait pellets and ingesting a lethal dose of toxin. Baiting efficacy can vary widely as many factors are involved in the chance of encounter and bait ingestion, including weather conditions, snail behaviour, bait product attributes and application (see table below). Baiting performance is maximised by accurate timing of bait application, and spreading pellets evenly. Baits are most toxic to snails during autumn and early winter, just before and early in the breeding season[1] (Figure 4.3). Baits kill both adult and juvenile snails, but juveniles are less likely to encounter pellets[2]. Controlling mature snails at the end of summer, as soon as they start feeding, provides the best return on investment in molluscicide baiting. This is after natural mortality and cultural control has already reduced populations and before they lay eggs.

Chance of encounter depends on:

- Level of snail movement
- Weather
- Snail species and life stage

- Attractiveness of bait
- Product formulation
- Amount and type of alternative food (plants, dead plant matter)

- Bait points per unit area
- Application rate (kg/ha and pellets per m^2)
- Evenness of application

- Habitat complexity
- Presence of stubble, trash, crop plants

Ingestion of a lethal dose depends on:

- Snail physiological state
- Time of year
- Snail hunger levels and metabolism

- Bait palatability
- Product formulation
- Product hardness (snails prefer soft pellets)

- Bait points per unit area
- Application rate (kg/ha and pellets per m^2)
- Pellet size

- Active ingredient (a.i.) concentration
- Product formulation (g a.i/kg)
- Product integrity and persistence (a.i. loss via temperature, moisture or microbial breakdown)

GRDC

Table 4.1: Key actions.

Actions	Considerations
Late summer to autumn	
Monitor snail densities	• Monitor snail densities (Section 3) • Identify areas with snails; all infested areas should be baited • Identify hotspots of higher snail density, such as fencelines, that require border baiting or higher application rates
Monitor snail activity	• Monitor snail movement (Section 3) • Relative humidity above 90% encourages movement
Apply bait before eggs are laid	• Apply bait as soon as snails start moving and feeding • Apply bait effectively using a calibrated spreader. See Snail Bait Application Fact Sheet (GRDC 2015) and the SnapBait app. *If mice are present*: • Bait mice prior to baiting snails to avoid mice consuming snail bait
Autumn to early winter	
Monitor and re-apply baits as needed	• Consider live snail densities and observed crop damage • Quadrat counts can be used to assess the efficacy of baiting • After early winter, baiting efficiency declines • Cease baiting at least two months before harvest; there is zero tolerance for baits in grain *If both round and conical snails are present:* • Consider a second bait application around sowing time due to later onset of conical snail activity

Apply bait effectively

Many factors affect baiting efficacy (Box 4.1). To maximise control, ensure effective application by following these steps:

1. **Select a suitable bait product using the product selection guide (Table 4.2)**
2. **Apply bait at the right time**
3. **Apply and re-apply bait to achieve sufficient bait points**
4. **Broadcast pellets evenly using a calibrated spreader; and**
5. **Avoid applying bait in very hot or wet weather.**

The above five points are described further in the remainder of this section.

1. Select a suitable bait product

Three active ingredients are registered for snail control in Australian crops and pastures:

- metaldehyde (15 to 50g/kg)
- chelated iron (60g/kg)
- iron phosphate (9g/kg iron)

Select a bait product according to your preferences (Table 4.2). Always adhere to directions on product labels, including application rates and withholding periods for harvest (including windrowing) and grazing.

2. Apply bait at the right time

Baiting before snails lay eggs is critical to suppress snail populations.

Bait should be applied as soon as snails commence feeding at the end of their summer dormancy. At this time, snails are hungry and feed voraciously as they prepare for reproduction[3], and bait toxins are rapidly metabolised (Figure 4.3). Snails breed from autumn to spring, but most eggs are laid by early winter (Figure 2.4). The onset of peak activity may be two or more weeks later for conical snails than round snails[1]. If conical snails are present, an additional bait application around sowing time may be necessary.

Bait must be applied when snails are moving and feeding.

Effective baiting relies on snails encountering and consuming pellets (Box 4.1) From late summer onwards, monitor weather conditions and snail movement (Section 3, page 21). Snail movement activity is greatest when relative humidity at ground level exceeds 90 to 95 per cent in summer or 80 to 95 per cent in autumn (Table 2.1 and Box 3.2). Most movement occurs at night to early morning when moisture is present. Before widespread bait application, bait can be applied in small areas infested with snails and checked daily. The presence of dead snails indicates feeding activity.

3. Apply and re-apply bait to achieve sufficient bait points

Always apply bait at application rates as stated on the product label. Pellet densities above 30 per m^2 are preferred to maximise the chance of snails encountering pellets[2]. For your selected bait product, consider the pellet density (per m^2) when applied at the label rate (kg/ha) (Table 4.2). Re-apply bait according to product label directions as needed. Re-application may be needed in areas of higher snail density, such as fencelines.

4. Broadcast pellets evenly using a calibrated spreader

Always calibrate the spreader for the selected bait product to ensure even spread. Manually check the spread width and drive at pass widths (swaths) no larger than the effective spread width. See the *Snail Bait Application Fact Sheet* (GRDC 2015). The SnapBait app can assist with estimating bait pellets applied per m^2.

Spreaders calibrated for fertiliser application can result in spread widths of snail bait up to 69 per cent less than expected and distribute pellets unevenly[5]. Uneven spread results in poor efficacy in the underdosed strips. Ute spreaders provide uneven spread[5] and are best limited to fencelines where larger spreaders are unsuitable. Bait fragmentation affects spread. Smaller bait fragments (<1.5mm) fall close to the spreader, are unlikely to deliver a lethal dose of toxicant to an individual snail and will degrade rapidly.

5. Avoid applying bait in very hot or wet weather

Field exposure of bait pellets causes degradation of the physical integrity and active ingredient concentration in pellets. High temperatures can degrade the concentration of metaldehyde, but trials found no effect of UV exposure[2]. Exposure to temperatures above 50°C can cause a 12 to 25 per cent loss of metaldehyde in pellets in seven days[2]. The effect of rainfall varies for different bait formulations. Applying bait prior to light rain (<10mm) can soften pellets and enhance palatability. Heavy rain (>35mm) can rapidly break down bran-based formulations.

Store unused bait as per label instructions, in the closed original container in a dry, cool, well-ventilated area and out of direct sunlight to maintain quality.

Table 4.2: Bait product selection guide†.

Product name	Active ingredient A.I.	A.I. g/kg	APVMA Product No.	Label rate kg/ha	No. pellets / m² at label rates	Pellet type
Sabakem® Metaldhyde Snail and Slug Pellet	Metaldehyde	15	86284/115239	10	25	dry bran
Snailex Slug and Snail Pellets	Metaldehyde	15	68580/110574	5–7.5	13–20	dry bran
SlugOut® All Weather Slug and Snail Bait	Metaldehyde	18	49324/58633	10	88–112	granule
Delicia® SLUGGOFF® Lentils	Metaldehyde	30	60931/0409	3	30	wet extruded
Axcela® Slug and Snail Bait	Metaldehyde	30	87576/118701	5–7	36–51	wet extruded
Metarex Inov® Slug and Snail Bait	Metaldehyde	40	88160/120463	4–5	24–30	wet extruded
Imtrade Metakill Snail and Slug Bait	Metaldehyde	50	64990/117488	5–8	30–60	wet extruded
Imtrade Transcend® Molluscide and Insecticide	Metaldehyde + 1.5g/kg fipronil	50	87832/125262	4–8	28–55	wet extruded
Multicrop® Multiguard® snail and slug killer	Iron EDTA complex	60	60104/0905	5–16	9–38	dry bran
Eradicate® Snail and Slug Killer	Iron EDTA complex	60	68634/58804	5–16	14–45	steam process bran
IRONMAX Pro® Slug and Snail Bait	Iron as iron phosphate	9	89908/126325	5–7	31–43	wet extruded

† Last updated November 2024. Data from testing conducted by Michael Nash and SARDI. Pesticide labels must be consulted for full application instructions. Adhere to all label directions including constraints and withholding periods. Refer to APVMA's PubCRIS database for current registrations and product labels (portal.apvma.gov.au/pubcris). Pellets per m² varies depending on the rate (kg/ha) applied, the number of pellets/kg, and the pellets' ability to remain intact when broadcast as determined by hardness.

Figure 4.2: Mice can consume snail bait (left). Higher bait rates may be needed along fencelines where snails aggregate (right).

Image: Emma Leonard   Image: Nicole Fechner

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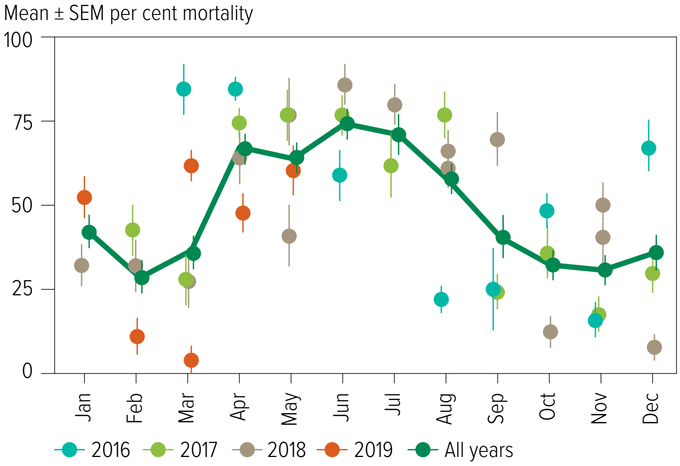
Figure 4.3: Metaldehyde baits were most toxic to vineyard snails from autumn to mid-winter (assay results from Palmer, SA)[1].



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Section 5 – Physical controls

Overview

Physical controls are best applied over summer and autumn to kill snails and make their habitat less favourable. Strategies include:

- weed control;
- cabling or chaining;
- rolling;
- burning or windrow burning;
- cutting or slashing; and
- grazing.

Physical controls are most effective against round snails, and any snails sheltering on stubble (Box 5.1). Weed control limits survival of all species. As part of integrated control, taking opportunities to drive snail populations down between cropping seasons reduces infestations in the following crop or pasture. Select control methods compatible with your farming operation (Table 5.1).

Weed control

Green weeds provide moist refuges for snails in summer (Figure 5.2). Green weeds can increase snail survival in summer by 50 per cent[6,7] and reduce the efficacy of burning by 40 per cent[8]. Weeds should be desiccated before undertaking other physical controls. Snails harbour in *Brassica* spp weeds[2,6,7], horehound (*Marrubium vulgare*)[2,6,7], onion weed (*Asphodelus fistulosus*) and other green weeds.

BOX 5.1: EXPLOITING SNAIL BEHAVIOUR FOR CONTROL IN SUMMER

- Snails aestivate in summer to avoid moisture loss and heat extremes. They commonly aggregate in clusters attached to objects above ground or under refuges on the ground.
- Conical snails are more likely to shelter under rocks and weeds, in the soil around plant roots, and inside the stalks of canola stubble (Figure 5.1).
- There is high natural mortality of snails during hotter summers and heatwaves[1–3]. In summer, snails have an innate climbing reflex, which causes them to climb onto the nearest resting site immediately after being dislodged[4].
- Cabling, chaining, cutting and grazing stubble in summer dislodges snails and forces them to move across hot soil, killing them or depleting their energy reserves.
- Temperatures of about 60°C kill round and conical snails instantly[5]. On sunny days with ambient temperatures near 40°C, temperatures can be 60°C to 70°C on the ground, but may be 10°C to 15°C cooler at the top of 15cm stubble where snails can rest[1].

Figure 5.1: Snails resting above ground to avoid high ground temperatures.

Images: Kym Perry

Table 5.1: Key actions.

Actions	Considerations
Summer (after harvest)	
Monitor to assess options for summer control	• Choose control options that are compatible with your farming operation
Control summer weeds before undertaking other controls	• Removing weedy snail refuges reduces snail survival in summer and increases the efficacy of other controls
Cable or chain stubble on hot days to kill snails	• Most effective early in summer when there are fewer green weeds • Cable on hot, sunny days when ambient temperature exceeds 35°C and ground temperature exceeds 50°C • Use two passes, at least one hour apart; avoid smashing sensitive stubbles (for example, lentils) to minimise erosion risk • Manage fire risk by threading cables with polythene pipe • Determine the Fire Behaviour Index. • Less effective on conical snails
Roll stubble to crush snails and remove refuge sites	• Heavy flat steel rollers are more effective than rubber-tyred or steel-ribbed rollers • Effective from summer to autumn when snails are resting on stubble • Less effective on conical snails
Consider cutting or slashing stubble shorter to kill snails and remove refuges	• A second pass with the harvester or slashing, when snails are resting on stubble, kills some snails • Shortening stubble exposes snails to hotter ground temperatures in summer • Determine the Fire Behaviour Index.
Consider grazing stubble to dislodge and crush snails	• The impact of grazing in suppressing snail populations depends on stock density and movement
Autumn (before crop sowing)	
Consider burning stubble to kill snails and manage stubble	• A hot, even burn can achieve high snail kill • Kill green weeds, turn over rocks, and roll stubble flat before burning • Consider soil health and erosion risk • Burning canola windrows after harvest can reduce snail numbers while reducing impact on soil health

Cabling

Cabling can be used to knock snails from stubble during hot weather, exposing them to ground temperatures that can kill them. Rocks are also turned over by cabling, which exposes conical snails to heat. Cabling is carried out using a cable of 3 to 5cm diameter, such as a punt cable, strung between two tractors or vehicles driven up to 300m apart (Figure 5.3). A 20 to 25mm diameter chain can also be used. A chain is more aggressive on stubble but turns over more rocks. At the end of each cable, a short length of 0.5cm diameter chain should be inserted as a safety break point. Always maintain radio communication between vehicles.

Cabling is rapid, with 120 hectares per hour (ha/hr) covered using a 150m cable. Repeat passes are possible on the same day. Cabling is best performed on hot, sunny days when ambient temperatures exceed 35°C and ground temperatures exceed 50°C. A laser thermometer can be used to measure ground temperature. Up to 70 per cent kill can be achieved with one pass in suitable conditions[8]. A higher kill rate can be achieved using two passes at least one hour apart. This allows time for dislodged snails that survive the first pass to re-climb the stubble before the second pass.

Cabling can miss fencelines where snail numbers may be higher. Consider the need for internal fencelines if not required for stock. Flat steel rollers can also be used for border passes. Cabling, especially with a chain, can pull out plants by the roots and leave soil susceptible to erosion. Excessively smashing sensitive crop stubbles, such as lentils, can also lead to erosion of lighter soils. Take care to avoid obstacles such as trees or stone heaps.

Fire risk from cabling is minimal but higher in areas with iron stone rocks or when cabling near steel posts. Fire risk can be reduced by threading polythene pipe over the cable. Before cabling, monitor and determine the Fire Behaviour Index.

Figure 5.2: Green weeds provide moisture and shelter for snails in summer.

Images: Kym Perry

Figure 5.3: Cabling or chaining.

Images: Emma Leonard

Rolling

Flat steel, steel-ribbed or rubber-tyred rollers can be used to flatten stubble, which crushes some snails and removes above-ground resting sites (Figure 5.4). Flat steel rollers are most effective for crushing snails, while steel-ribbed rollers help crush rocks. Rolling can cause 50 to 90 per cent snail mortality[8], but is less effective on conical snails.

One pass is generally sufficient to flatten wheat, but two passes in opposite directions may be needed to snap flexible barley stalks. Any upright stems remaining after rolling can provide snail resting sites, reducing effectiveness. If using a disc seeder, rolling in the same direction as seeding can reduce hair-pinning.

Rolling is effective from summer to autumn when snails are resting on stubble. About 15ha/hr can be rolled using a 15m wide triple-section roller (Figure 5.5).

Burning

Burning stubble is an effective control method for round and conical snails. A hot, even burn is important for good control, as poor kill is achieved in unburnt patches (Figure 5.6). Rolling stubble flat first can assist in achieving a thorough burn across the entire paddock.

Snails shelter under rocks and on summer weeds. Rocks should be turned over immediately before burning, by cabling or fire harrowing, and summer weeds should be desiccated. Burning after desiccating summer weeds can reduce numbers of round and conical snails by 95 per cent, but up to 40 per cent survival can occur where green weeds protect snails from fire (Figure 5.6).

Burning has positive and negative agronomic impacts to consider. It can destroy stubble-borne diseases and weed seeds, but reduces soil organic matter and kills soil organisms, with detrimental effects on soil health and crop production[8,10]. Burning is often incompatible with modern farming practices but can be used in some regions to manage excessive stubble loads prior to seeding. Avoid burning in areas prone to soil erosion.

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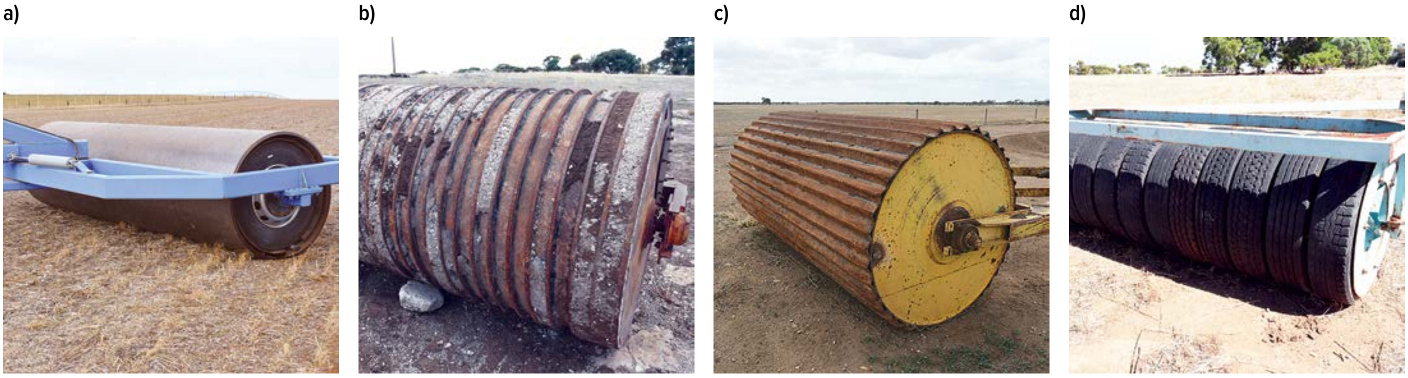
Figure 5.4: a) Flat steel, b) and c) steel-ribbed and d) rubber-tyred rollers.



Images: Kym Perry

Figure 5.5: Triple-section flat steel roller, weighing up to 11 tonnes per section when filled with water.

Image: Nicole Fechner

Windrow burning

Burning windrows created from canola stubble can kill snails and reduce impacts on soil health compared to whole paddock burning (Figure 5.7). In one trial in Western Australia, burning canola windrows reduced the total numbers of small pointed snails by 90 per cent[11]. Movement of snails into windrows, and potential kill rates from burning them, can increase where inter-rows have minimal shelter, such as fallen stubble or weeds[11]. Inter-rows can be rolled to remove tall resting sites. The longer that windrows sit on the ground, the more opportunity snails have to move into windrows before burning.

Cutting stubble lower

Stubble can be cut lower using a second pass with the harvester or a slasher. This can be useful where a stripper front harvester, or higher cutting height, was used to reduce harvest intake of snails, leaving more standing straw. Cutting or slashing flicks snails to the ground and crushes some of them. Dislodged snails can re-climb the remaining shorter stalks but are exposed to hotter temperatures near the ground in summer[1]. Using a 4m slasher is slow, covering about 4ha/hr[8]. Take care in stony paddocks to avoid sparking a fire. Always monitor and determine the Fire Behaviour Index[9].

Grazing

Grazing animals knock snails from stubble and may incidentally trample and consume them (Figure 5.8). Snail mortality from grazing is dependent on stock density and movement. A 32 per cent reduction in snail numbers was recorded in lentil stubble[8]. Grazing is less effective than cabling or rolling, but can contribute to integrated snail management in mixed cropping programs.

Figure 5.6: a) High control of round and conical snails is possible with a hot, even burn[8].
b) Desiccating summer weeds prior to burning substantially increases snail kill (data for conical snails)[8].

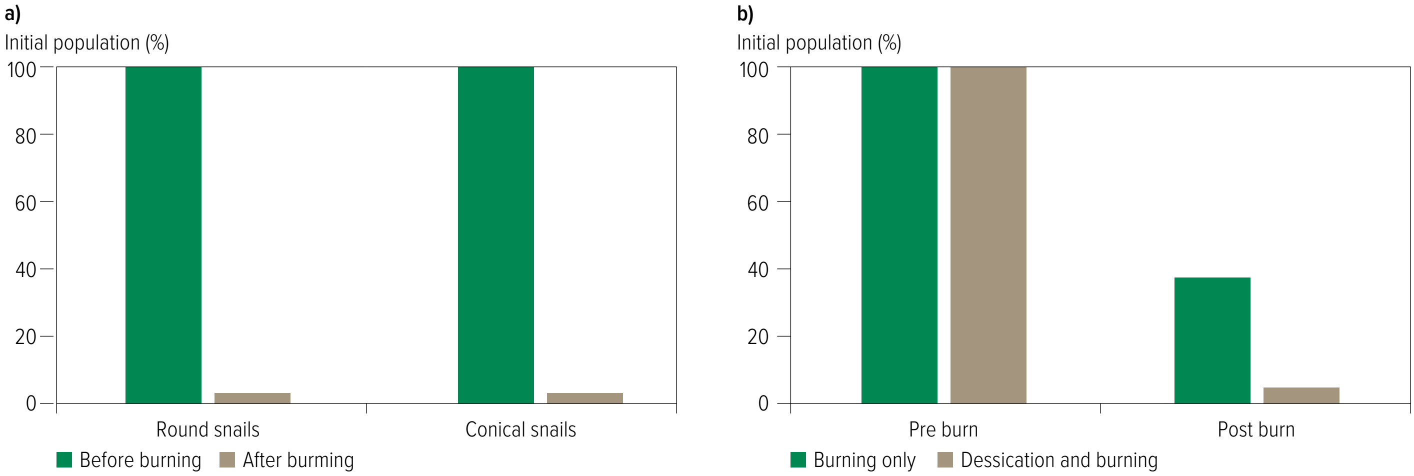


Figure 5.7: Windrow burning canola stubble.

Image: Austockphoto / Jane Worner

Figure 5.8: Grazing animals can trample, dislodge or consume snails.

Image: Emma Leonard

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Section 6 – Harvest and post-harvest control

Overview

Effective snail management in summer, autumn and winter will minimise, but not eliminate, snails present at crop maturity. At harvest, snails resting above cutting height in the plant canopy can enter the harvester, clogging machinery and contaminating grain. Harvest and post-harvest controls involve:

1. Minimising intake of snails into the harvester;
2. Maximising separation of snails and grain within the harvester; and
3. Cleaning infested grain after harvest.

The optimal mix of harvest and post-harvest controls is best determined on individual farms, considering the snails present and the costs and benefits of different cleaning options (Table 6.1). To avoid value downgrades or rejection, all grain must be delivered according to quality standards for snail presence set by Grain Trade Australia and local grain handlers[1].

Snail contamination risk

At harvest, snails resting in the upper crop canopy above the target cutting height can contaminate grain (Figure 6.1). The risk of snail contamination at harvest is difficult to assess as it depends on snail densities, their shape (round or conical) and size relative to grain being harvested, and their location in the crop canopy (Box 6.1). Snails similar in size and shape to grain are most difficult to separate.

Seasonal weather affects the growth rates of snails and their movement into plant canopies. Wetter conditions in autumn and spring can lead to higher populations of juvenile snails in spring[2,3]. Round snails can be crushed by adjusting thresher settings in cereal grains, but are more likely to reach the sample intact in pulse grains. Conical snails are more likely to reach the sample intact in all grains.

Figure 6.1: Snails in a mature pea crop canopy.

Image: Kym Perry

BOX 6.1: SNAIL BEHAVIOUR AND CONTAMINATION RISK AT HARVEST

- More snails rest in the upper crop canopy as harvest progresses. They climb plants seeking resting sites in response to warm and dry weather.
- Smaller snails often remain on the ground later into harvest than larger snails.
- Early in the harvest season, snails often respond to light rain (<2mm) by descending to the ground for a short period. Snails become less responsive to rain as harvest progresses.
- Later in the harvest season, snails become more difficult to dislodge from crop plants.
- Conical snails are often found in sheltered locations on plants (for example, between leaf and stem) or grain heads and are less readily dislodged by harvest operations than round snails.

Minimising snail intake

Early harvest

Early in the harvest season, fewer snails are present in the crop canopy, and they are more easily dislodged with less grain shattering. Early harvesting after light rainfall (<2mm), when snails have descended plants, can reduce snail intake without excessive grain moisture absorption. However, timing the harvest to avoid snails while harvesting at the correct grain moisture content can be difficult.

Table 6.1: Key actions.	
Actions	**Considerations**
Spring (3 to 4 weeks pre-harvest)	
Monitor (Section 3) snail densities to plan harvest tactics and set up the header	• Consider snail densities, shape (round or conical) and size, in relation to grain type • Identify problem areas for early harvest or separate harvest and storage • Set up sieves and screens to maximise snail/grain separation within the harvester
Spring and summer (harvest)	
Consider windrowing or direct-heading	• Windrowing or direct-heading can dislodge round snails and reduce snail intake if harvested before snails invade windrows • Windrowing pulse and canola crops, cut green, may increase snail intake; green windrows are attractive refuges for snails • Direct-heading canola can reduce the intake of conical snails, which often shelter at the plant base
Consider early harvest	• Early harvest can reduce snail intake and dislodge snails with less grain shattering • Harvesting early after light rain (<2mm), when snails move down canopies, can reduce snail intake; ensure correct grain moisture content
Consider cutting height	• Stripper front harvesters can reduce snail intake by 50%; most suitable for even crop canopies on level terrain • Raising cutting height with open-front machines can reduce snail intake • However, more standing straw may require a second pass to cut stubble lower
Harvest and store grain from heavily infested areas separately from clean grain	• Areas of higher snail densities may include fencelines or calcareous outcrops • Avoid contaminating clean grain
Maintain farm hygiene	• Avoid parking in snail-infested areas; snails dislodged in summer readily climb vehicles • Thoroughly clean vehicles and machinery before moving • Restrict property access and erect farm biosecurity signage at all entries • Ensure contractors follow hygiene protocols
Summer (post-harvest)	
Clean infested grain after harvest	• A combination of snail crushing rollers and screen cleaners is usually required to meet delivery standards for snail presence • Estimate costs and benefits of different cleaning solutions • Storing grain for several weeks before cleaning can desiccate snails and increase cleaning throughput

Windrowing or direct-heading

Windrowing (swathing) cereal crops can reduce the number of round snails eventually entering the harvester. Windrowing may dislodge 55 to 75 per cent of round snails[4]. Windrowing cereals early and in cool conditions dislodges more snails[4]. In pulse and canola crops that are cut green and left to dry, snails may move into windrows, resulting in more snails entering the harvester. Leaving windrows for any length of time, or moisture events, can cause more snails to invade windrows. Snails can be dislodged from faba bean windrows immediately in front of the harvester by gently brushing the windrow with a length of iron or flat conveyor belt, which is attached to an extension arm carried by a separate vehicle.

As a last resort in heavily infested areas, crops can be harvested directly behind the windrower to dislodge snails and reduce snail intake, but this dual operation incurs higher costs. When harvesting windrows with open fronts fitted with crop lifters, fitting PVC pipe covers over the cutter bar can mask the unused width of the front. This improves feeding uniformity of material into the machine and minimises intake of snails attached to stubble. Open-raking pick-up designs can reduce snail intake by 50 per cent compared to belt-type pick-ups[4]. In canola, direct-heading can reduce the intake of conical snails, as they often aggregate around the base of plant stems[5].

High cutting height

Using rotary stripper-front harvesters, which mostly harvest the grain heads, is one of the most effective methods of reducing snail intake. Stripper fronts can reduce snail numbers reaching the grain sample by 50 per cent relative to open fronts in wheat crops, and increase harvest capacity by 25 per cent or more[4]. Stripper fronts are most suitable in thick standing cereal crops of even height on even terrain. Drawbacks include higher cost and reduced versatility.

A cheaper, but less effective, method is to raise the cutting height of open fronts to reduce bulk crop intake. Conversely, in crops heavily infested with snails, more straw intake can absorb moisture from crushed snails and facilitate ejection over the chaffer.

Both systems result in more standing straw, which provides snail resting sites and may affect sowing operations. Straw can be cut lower (Section 5) using a second pass with the harvester, or a slasher, to manage stubble and kill some snails.

Dislodger bars

Snail dislodger bars can be used to dislodge snails in front of the harvester. This practice is now uncommon as the benefits of snail removal are often outweighed by high grain losses. However, dislodger bars may be useful as a last resort or for perimeter rounds in areas of high snail density. Dislodger bars are most suited to cereal crops harvested early. A dislodger bar is attached to the windrower, or approximately 2m in front of the cutter bar on the harvester. Rigid steel or lighter flexible PVC can be used. Bar designs and settings are described in the *Bash'Em, Burn'Em, Bait'Em* booklet[4] (pages 27 to 30).

Maximising snail/grain separation

Threshing intensity

Increasing threshing intensity can be used to crush larger round snails. Crushed snails can be removed using air separation. Combining higher threshing intensity with a higher intake of straw can help to minimise recycling as crushed snails attached to straw are ejected as rear losses. These techniques can cause clogging of the grain transfer and sieve components, or physical damage to the grain.

Set-up of sieves and screens

When there is a significant difference in the size of snails and grains, the set-up of sieves within the harvester can be adjusted to maximise snail/grain separation.

Many harvesters are fitted with adjustable louvre sieves in the chaffer (upper sieve) and shoe (lower sieve). These rely primarily on air separation and are most suitable for larger grains, such as faba beans. For smaller and medium grains, replacing louvre sieves with fixed aperture sieves can improve separation. Fixed aperture sieves rely more on physical screening and less on air separation. The set-up of sieve and screens (type and size) can be optimised for the snails and grain being harvested to maximise removal while minimising losses. Recommended settings and specifications are detailed in the *Bash'Em, Burn'Em, Bait'Em* booklet[4] (pages 31 to 34).

Replacing sieves and screens is becoming less common with increased automation and throughput of modern harvesters. Manufacturers can often recommend optimal harvester settings for different conditions. Some growers use blanking plates or shut off concaves to increase grain threshing and snail crushing, although this can reduce throughput and increase screenings[5].

Post-harvest cleaning

Infested grain may require cleaning to meet delivery standards for snail presence[1]. Post-harvest separation relies on differences in the physical properties of snails and grain, such as size, shape, mechanical strength, bulk density and terminal velocity.

Cleaning methods include snail-crushing rollers, screen cleaners, air separation and gravity separation. All methods are a compromise between snail removal and grain losses. A combination of cleaning methods is usually required to clean grain to delivery standards without excessive grain losses (Figure 6.2).

The optimal combination of cleaning systems is best determined on individual farms. Variables to consider include the numbers, types and size of snails present in harvested grain samples, and the costs and benefits of different cleaning options.

Snail-crushing rollers

Rolling grain is an effective method for cleaning round and conical snails from all hard grains (cereal and pulses) without excessive grain damage[4,6–9]. Cereal and pulse grains have a high mechanical strength compared to snails. Canola seed can be rolled but its lower mechanical strength can result in high seed damage unless the operation is managed carefully.

Snail-crushing rollers consist of opposing parallel rollers constructed from materials varying in hardness (steel, polyurethane or rubber compounds), rotating in the opposite direction, and set to a narrow clearance (less than 1mm, to several millimetres) to crush snails while minimising grain damage as the mixture passes through. Commercial snail-crushing rollers have the capacity to clean 25 to 75 tonnes per hour.

Cleaning performance depends on several variables including the gap between rollers, roller hardness, grain size, grain moisture content, roller speed, and the flow rate of grain into rollers. The size, shape and shell strength of snails present also affects crushing. Performance is maximised by a uniform gap between rollers and by keeping the hopper full to maintain a uniform feed rate of grain into rollers.

Setting up a roller for best performance requires continual monitoring of the rolling operation (Figure 6.3) and fine-tuning the settings as needed to maximise snail crushing, minimise grain losses and maximise throughput. Performance is checked by

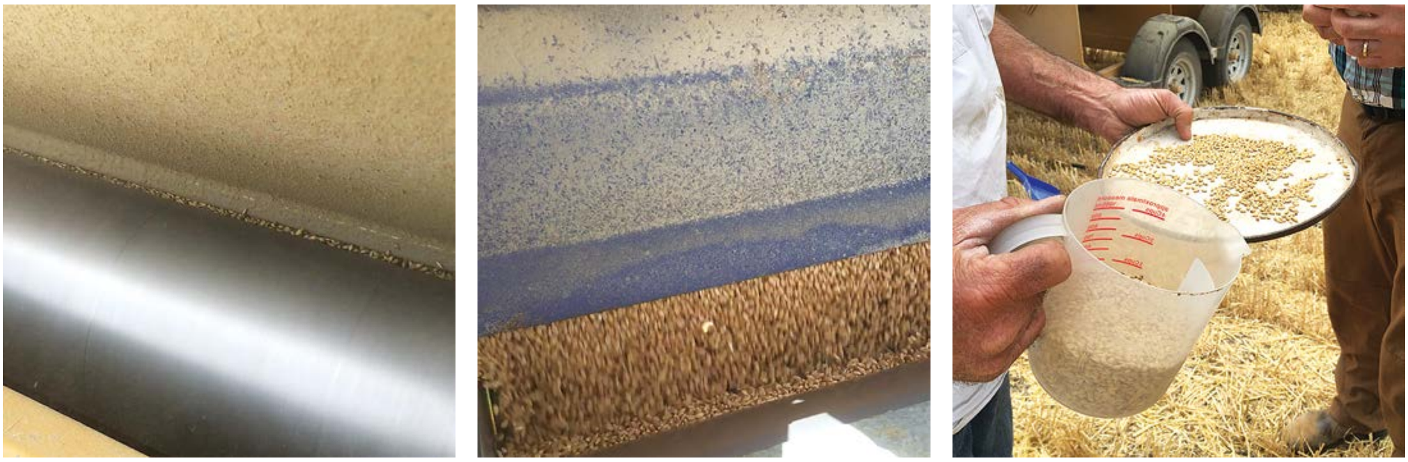
Figure 6.2: a) Rotary cleaner, b) snail-crushing roller and c) auger fitted with lower screens to remove small snails and fragments.

a) b) c)

Images: Kym Perry

Figure 6.3: a) and b) Snail rollers and c) monitoring the rolling operation.

a) b) c)



Images: Kym Perry

monitoring the rolled grain sample. If there are too many snails, tighten the roller clearance gap, or increase the flow of grain into rollers, or use harder rollers. If there is excessive grain damage, increase the roller clearance gap, reduce flow rate of grain or use softer rollers. Faster roller speeds do not necessarily crush more snails and may cause overheating. Roller temperatures should be maintained at about 50°C and not exceed 65°C[6] to avoid damage to rollers.

Efficient cleaning using rollers depends on the set-up and grain moisture content. Example roller setups are provided as a starting point (Table 6.2). To minimise grain damage and losses, grain should be rolled at the optimum moisture content of 13 to 16 per cent. Canola is rolled at lower speeds than harder grains by reducing the feed rate of grain into the rollers and reducing roller speeds. Typical rolling speeds are about 550 revolutions per minute (rpm) for cereals and 400rpm for canola[5], but should be adjusted as needed.

Optimal roller settings should crush most snails with approximately two per cent grain loss in cereals and pulses[4]. In canola, up to 43 to 91 per cent of small conical snails can be removed with up to nine per cent losses[7]. Storing grain for several weeks before rolling can desiccate snails, making their shells brittle and easier to crush and increasing cleaning throughput[5]. Rolling fresh grain during harvest is also successful[5].

To meet delivery standards, a screen cleaner is often required either side of the rolling operation to pre-scalp larger snails and post-screen smaller snails and snail fragments. Augers fitted with lower screens help remove small snails and fragments (Figure 6.2). If snail numbers are high, grain can be rolled twice, but this incurs higher costs.

Screen cleaning

Screening and scalping rely on a size difference between snails and grain. Screening removes snails smaller than grain, whereas scalping removes snails larger than grain.

Table 6.2: Example roller set-up and grain moisture content from trial work[4].

Grain type	Grain moisture content	Roller clearance gap	Roller hardness
Cereals	12–14%	Less than 1mm	Hard
Peas	14–15%	1 to 2.5mm	Soft
Lentils	12–14%	1mm	Soft
Faba beans	14–15%	Less than half seed width	Soft

Separation to delivery standards using screen cleaning alone results in unacceptably high grain losses[4,10]. Rotary screen cleaners (Figure 6.2) are often used in combination with snail-crushing rollers and air separation (aspiration). Using finer sieves to remove more snails incurs higher grain losses.

In cereal and lentil grains, screening can remove up to 50 per cent of snails with five to six per grain losses (Table 6.3). For lentils, an aspirator is recommended to remove crushed shells and pods before entering a screen cleaner. In canola, rotary screen cleaners can remove up to 95 per cent of small conical snails with 5.5 per cent grain losses[6]. The size of canola seed can vary substantially and should determine the optimal screen size[5].

Air separation

Air separation (aspiration) is useful for pre-cleaning dust and light material from a sample, and for removing dried snail and shell fragments from grain after using a snail-crushing roller. Aspiration is often incorporated into rotary grain cleaners. Air separation results in high grain losses in barley, canola and lentils, which all have similar terminal velocities to round and conical snails[10]. Air separation is more effective in removing snails from larger grains, such as peas and beans[8].

Figure 6.4: Snails hitchhike on a) harvesters and b) other vehicles in summer.

a)

b)

Images: Kym Perry

Table 6.3: Typical results for screen tests to remove snails from grain[4,5,6]			
Grain type	**Screen size and type**	**Grain loss**	**Snail removal**
Barley, wheat	25mm x 2.6mm slot	5%	50%
Peas	5.15mm diameter round	2%	10%
Lentils	25mm x 2.65mm slot	6%	48%
Canola	2.2mm diameter round	5%	12%
Canola*	2.5mm slotted sieve	less than 1%	19% small pointed snails
Canola*	2.2mm slotted sieve	6%	95% small pointed snails

* Average seed size 1.85mm

Gravity separation

Gravity or density separation can separate snails from grain. There is a significant difference between the bulk density of round (3 to 12mm) and conical (2 to 8mm) snails, and canola, barley, peas and lentils[10]. As snails dry out, they become lighter and differences in bulk density between snails and grain increases. However, conical snails in harvested grain can take some months to die. After complete drying, loss of body mass is approximately 66 per cent for round snails (3 to 12mm) and 57 per cent for small pointed snails (2 to 8mm)[11].

Economic costs and benefits of grain cleaning

If snail presence will result in a price discount at delivery, growers can either accept the discount or clean the grain. The costs and benefits of different methods for cleaning small conical snails from barley and canola can be estimated using the Grain Cleaning Calculator For Small Conical Snails. This tool is based on an economic analysis from grain cleaning trials in Western Australia[6,9] and considers the grain price discount, capital costs of equipment, machinery depreciation, labour and fuel costs, changes to grain/seed quality, estimated grain/seed losses, and changing costs according to grain volumes cleaned. Estimated cleaning costs per tonne of grain cleaned with screen and snail-crushing rollers are available in GRDC *Managing Small Conical Snails Fact Sheet* (GRDC 2021).

Farm biosecurity and hygiene to prevent snail spread

Pest snails are highly invasive. New infestations start small and spread rapidly through hitchhiking[5]. Snails are readily transported on vehicles, infested hay or fodder, or by contractors. In summer, especially, snails that are dislodged will immediately climb onto nearby substrates, which may include machines, silos, augers, field bins and vehicles[5] (Figure 6.4).

Areas at high risk of potential new infestations include around sheds, gates and other areas where vehicles or machines are often parked. High-risk areas should be monitored regularly and baited if emerging snail infestations are observed. Ensure contractors do not bring snails on to the farm. Restrict paddock access and erect farm biosecurity signage at all entries. Ensure fodder brought into paddocks from elsewhere is free of snails.

Harvest operations are a key source of snail spread between paddocks[5]. Snails become attached to harvester fronts and to vehicles parked in paddocks (Figure 6.4). To minimise contamination, thoroughly clean harvesters before moving. Ideally clean, park overnight, then check and clean again before moving[5]. Another option is to harvest cleaner areas before more infested areas.

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Section 7 – Biocontrol of conical snails

Overview

Biological control, or biocontrol, is pest control provided by natural enemies of the pest. Natural enemies can be predators, parasitoids or pathogens. There are few natural predators of Mediterranean pest snails in Australia. Small numbers of snails are consumed by mice, lizards and birds. Naturally occurring nematodes and bacteria for snail control have been investigated in Australia[1,2,3]. Where there are not enough natural enemies to suppress an introduced pest, they can be imported from their native range following strict testing to ensure they attack only the target pest.

The parasitoid fly, *Sarcophaga villeneuveana*, is an imported biocontrol agent that attacks the Conical snail and the Small pointed snail[4] from spring to early autumn. The fly is established in the Yorke Peninsula and Eyre Peninsula regions of South Australia[4,6,7]. In cropping regions where the fly is present, biocontrol of conical snails can be encouraged by providing the flies with nursery areas of suitable habitat (Table 7.1).

Table 7.1: Key actions in regions where the fly is present.

Actions	Considerations
Spring to early autumn	
Promote flowering native plants around paddock perimeters where snails are a problem	• Native vegetation that flowers in spring and summer provides flies with shelter and food (nectar and pollen)
Reduce ground refuges for conical snails in and around paddocks	• Conical snails commonly shelter in and under weeds, canola stalks, and under rocks or other refuges • Reducing refuges forces snails to climb elevated objects, making them more vulnerable to fly attack
Minimise insecticide use near fly nurseries	• Flies are active from spring to early autumn and can be killed by broad-spectrum insecticides

Fly life cycle

Adult flies are active from spring to early autumn[4,8]. They attack aestivating conical snails at least 5mm in shell length[9]. After mating, female flies lay a single live larva near the shell opening of a resting snail[8] (Figure 7.1). The larva crawls inside the shell and consumes the flesh of the snail, killing it. The larva pupates inside the shell and emerges about eight days later as an adult fly. Adults live for approximately 60 days, and feed on floral nectar and pollen. The generation time is about 20 days[8]. Approximately six to eight generations are possible from spring to early autumn in southern Australia[8]. Flies enter diapause in autumn and overwinter in the pupal stage inside the snail shell, then emerge as adults in early spring.

Fly identification

Sarcophaga villeneuveana belongs to the family Sarcophagidae (flesh flies). Adults are similar in appearance to bush flies (Figure 7.1). They are 5 to 7mm in length with reddish eyes, and grey and white parallel stripes on the thorax between the wings. Larvae are white maggots up to 6mm in length. Pupal cases are brown in colour, and easily visible with the naked eye inside the shell opening of a parasitised snail.

Geographic distribution and parasitism levels

The fly is established on southern Yorke Peninsula and Lower Eyre Peninsula[4,7]. Up to 30 to 50 per cent of snails more than 5mm in length can be parasitised by flies at sites near flowering vegetation[7] (Figures 7.2, 7.3). These parasitism levels help suppress conical snails. Parasitism is often nil or less than three per cent in areas without native vegetation, even when populations of conical snails are high[4,6]. Flies need food and shelter for survival and reproduction. Snails resting on objects above ground level are most likely to be parasitised (Figure 7.4)[4,8].

Encouraging biocontrol of conical snails

In regions where *S. villeneuveana* is present, biocontrol can be encouraged by promoting spring and summer-flowering vegetation on property perimeters where conical snails are a problem. Providing flies with food and shelter can increase their survival and reproduction, so they can attack more snails. Flies feed on inflorescences with shallow nectaries. Promote a mix of native plant species endemic to local areas to give a continuous sequence of flowers accessible to flies in spring and summer. Potentially suitable species include *Melaleuca* spp, *Bursaria spinosa*, *Leptospermum* spp and *Hakea* spp.

The fly is less successful attacking conical snails sheltering in refuges at ground level, such as under weeds, rocks and other objects (Figure 7.4)[4,8]. Removing refuges forces conical snails to rest on objects above ground level where they are more vulnerable to fly attack. Exposure to broad-spectrum insecticides is harmful to flies. Minimise insecticide use near fly refuges from spring to early autumn.

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Figure 7.1: Life cycle of the parasitoid fly, *Sarcophaga villeneuveana*.

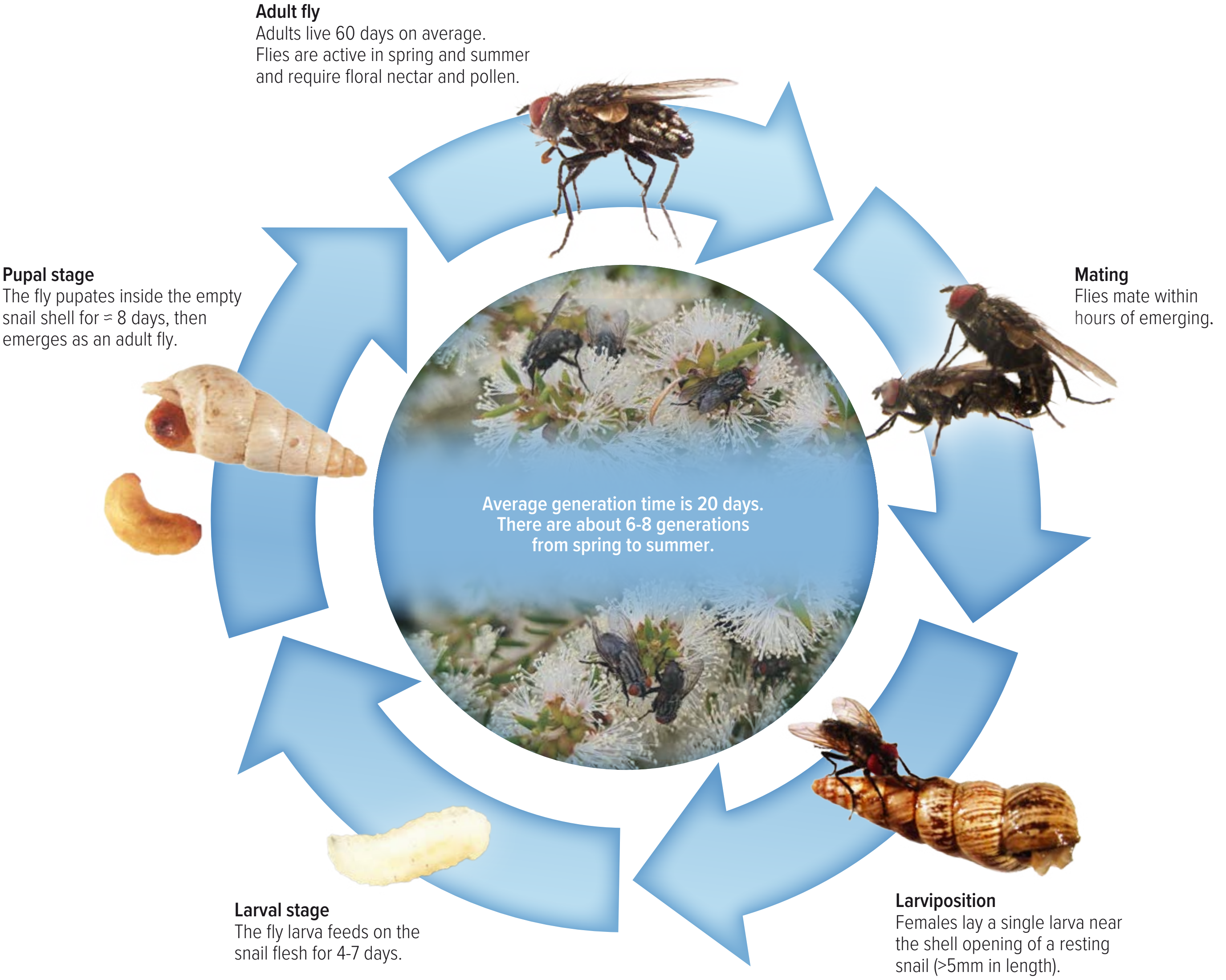
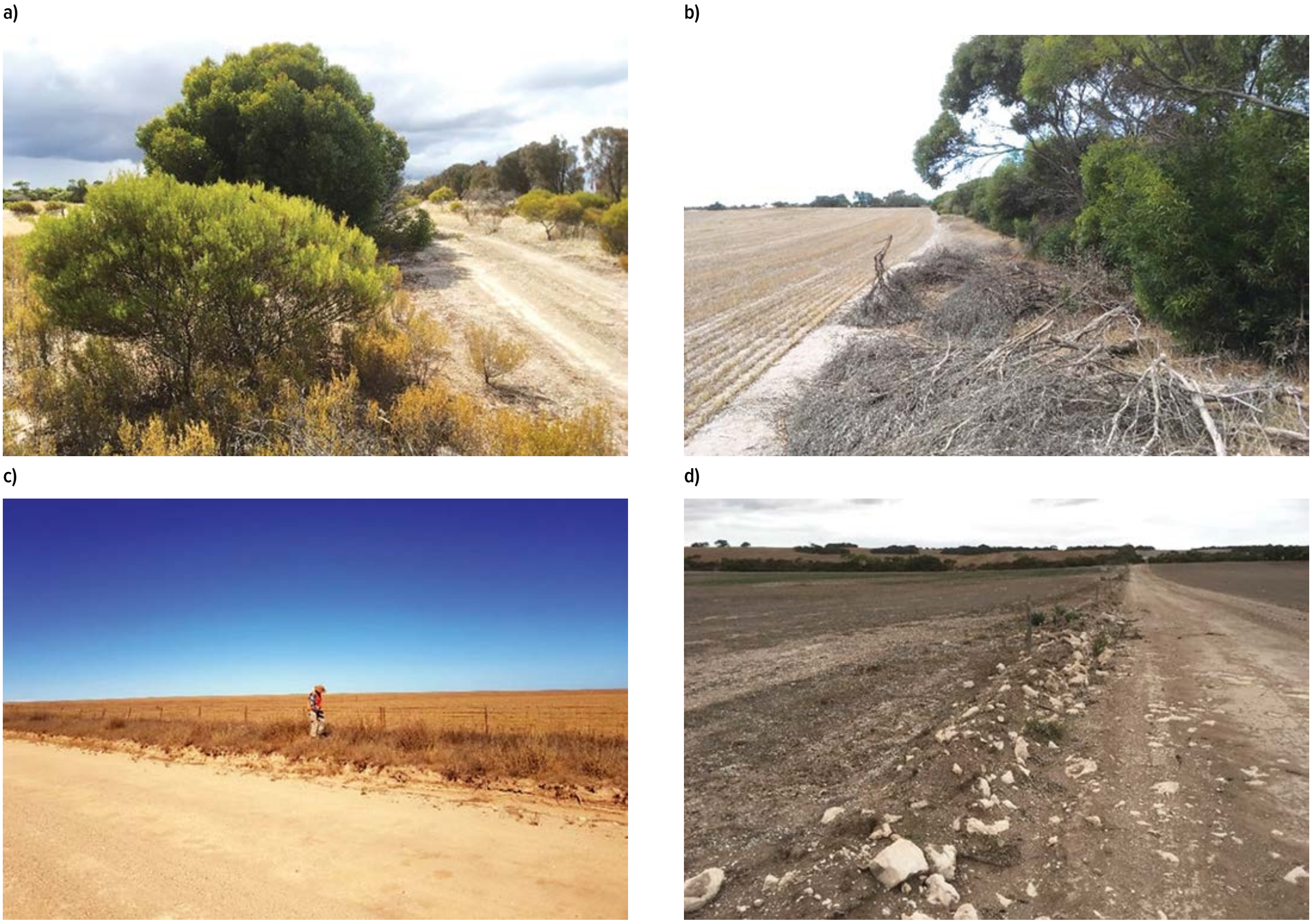


Image: Alex Seret, SARDI

Figure 7.2: a) and b) Areas with higher parasitism or c) and d) low parasitism of conical snails by the parasitoid fly.



Images: Kate Muirhead

Figure 7.3: *Sarcophaga villeneuveana* feeding on flowers of *Bursaria spinosa*.

Image: Nicole Fechner

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Figure 7.4: Conical snails resting in elevated positions are more vulnerable to fly attack than snails sheltering in refuges.

Image: Nicole Fechner

Image: Kym Perry

Image: Kym Perry

Image: Kym Perry

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