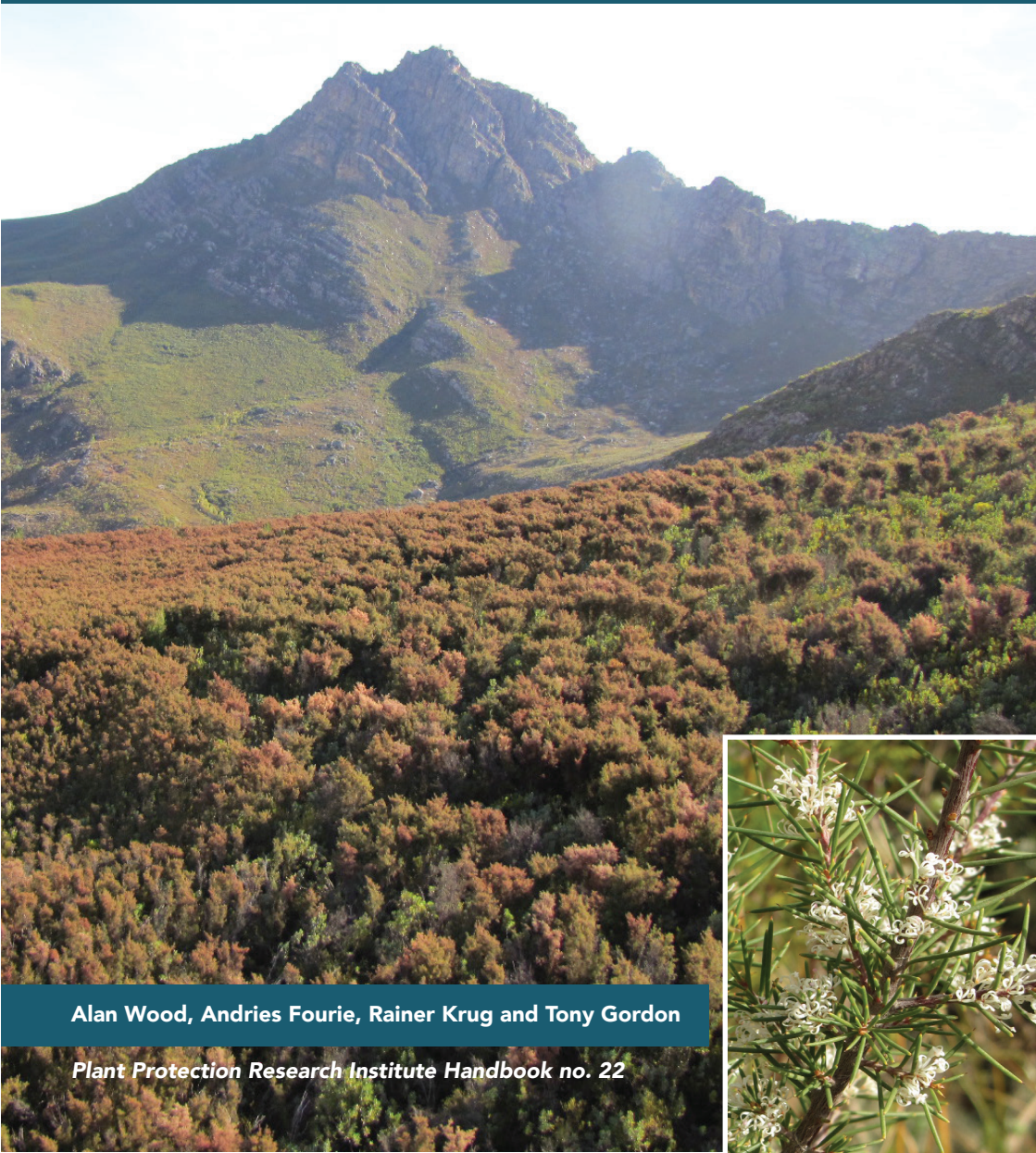
A GUIDE TO THE BIOLOGICAL CONTROL OF ALIEN INVASIVE HAKEA SPECIES



Alan Wood, Andries Fourie, Rainer Krug and Tony Gordon

Plant Protection Research Institute Handbook no. 22

Plant and biological control agent symbols used in this guide

also showing agents available, and their host plants, respectively

silky hakea (*Hakea sericea*) pg 7

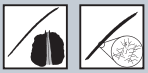
rock hakea (*Hakea gibbosa*) pg 9

sweet hakea (*Hakea drupacea*) pg 10

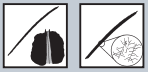
willow hakea (*Hakea salicifolia*) pg 11

hakea gummosis fungus (*Colletotrichum acutatum*) pg 13, 28

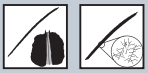
hakea seed weevil (*Erytenna consputa*) pg 15, 34



hakea seed moth (*Carposina autologa*) pg 18, 37



hakea stem-boring beetle (*Aphanasium australe*) pg 20, 39



hakea bud weevil (*Dicomada rufa*) pg 22, 42

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A GUIDE TO THE BIOLOGICAL CONTROL OF ALIEN INVASIVE HAKEA SPECIES

by

Alan Wood, Andries Fourie, Rainer Krug and Tony Gordon

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Contents

Dedicated
to
Stefan Neser
1942–2021

Extraordinary field biologist,
a pioneer in weed biocontrol,
including of hakea species.

Chapter 1: Introduction

Hakea species are serious invaders of the mountains of the Western and Eastern Cape provinces. It is by the effort of all affected private landowners as well as various government departments and agencies that effective management of these invaded lands will be achieved.

The purpose of this guide is to increase the knowledge of control options available to all involved in the management of the hakea species. There are a number of control methods available including mechanical, chemical and biological. This guide details the how, where and when to implement biological control against the hakea species.

Integrating the various control methods ensures maximum impact and makes the most efficient use of all available resources. Currently, there is a lack of readily accessible information on the practical use of biological control agents and integrating their use with other control methods. This guide provides this information, allowing for the active management of the biological control agents available and their integration into clearing operations.

It helps users to:

- Identify control options for each invasive hakea species.
- Identify the different hakea species and the biological control agents in the field.
- Know when and how to collect and release the agents against each hakea species.
- Source additional information and useful contact details.

Photo by Reley Bell

Preparing to collect, and then releasing, biological control agents (in this case the seed weevil) against silky hakea in the field.

The problem

Four species of hakea were introduced into South Africa from Australia between 1835 and 1858. They belong to the Protea family, and have similar adaptations to the environment as do our indigenous species in this family.

Three species are invasive plants and are declared category 1b weeds according to the NEMBA:AIS regulations:

- silky hakea
- rock hakea
- sweet hakea.

These species are therefore prohibited plants and must be controlled or eradicated on any land, unless under effective biological control. A fourth species (willow hakea) is a category 1b invader in the Western Cape province only. Silky hakea is the most serious and widespread of the hakeas.

Factors likely to have contributed to Silky hakea's success as an invader in South Africa are:

- its copious production of seeds which are released after the death of the plant in fires,
- the very long lifespan of the seed,
- efficient seed dispersal by wind,
- and the absence of natural herbivores and pathogens.

Dense infestation of Silky hakea in inaccessible mountain terrain.

Control options

Control measures currently available

Each of the three control measures discussed below can be used by themselves. However, they are not mutually exclusive and integrating their use will give the best results. Chemical control is the least used of these options.

Mechanical control

Mechanical control will be required at times, and is a valuable tool for control of hakeas. It will need to be used where biological control has not been actively implemented. It is the best method to use to deal with existing large dense stands in accessible terrain, or to clear high priority conservation areas. On the other hand, in certain situations, such as in inaccessible mountainous areas, mechanical control is not feasible and only biological control can be used. Integrating the use of mechanical and biological control within catchments is necessary to achieve control in the long term.

Hakea plants are cut down, and left in the field. Shortly after the plants are cut down, the fruits split open and the seeds fall to the ground. Many of the released seeds will be eaten by mice in the field. Surviving seed will germinate the following winter after the first good rains. Therefore, approximately 12 to 18 months after the first treatment, go back to the areas cleared and hand pull or cut down any hakea plants.

Fires frequently occur in the areas invaded by hakeas. If these occur after an area has been cleared, the fire will kill any young plants. Although felling followed by burning is an effective method of controlling hakeas, there are stringent legislative conditions around the use of fire, and therefore it is not recommended that fire is used deliberately. Also the increased fire intensities using this technique can destroy indigenous vegetation, as well as lead to severe soil erosion.

Seedlings and young plants can also be pulled out by hand.

General principles of mechanical control operations

- Loppers, hand saws and pangas can be used to fell trees of all sizes.
- The tips of the leaves of silky and rock hakea easily pierce skin, break off and can cause infection. Therefore, always wear appropriate protective clothing.
- Trees must be felled as close to the ground as possible, at least below the lowest leaf or branch. This is because trees can regrow from any pre-existing bud found at the base of leaves or on side branches.
- No chemical treatment is needed to treat the cut stump.
- Start in areas with scattered plants to arrest the expanding invasion. Then move on to clearing areas with a medium density of plants or small dense stands.
- Any regrowth in cleared areas should be treated before starting in areas which still require initial clearing.
- Large dense stands should ideally be left for last. Starting to clear dense areas requires a long term commitment to follow up the initial clearing with control of any regrowth.
- Confine large dense stands by clearing from the outside inwards. If necessary, clearing may be done over several years depending on available budget.
- Even after successful clearing, inspect all areas for new invasions and clear any plants that come up.
- Collective management and planning with neighbours allows for more cost effective clearing and maintenance.

Chemical control

The use of herbicides to control hakea species is effective, but is expensive, difficult to apply in inaccessible infestations, and negatively affects indigenous plant species. Tebuthiuron (active ingredient) is the only herbicide registered, and may only be used against silky hakea and rock hakea.

Because mechanical control is effective without negative impacts on indigenous plants, it is recommended that mechanical control, appropriately integrated with biological control, is used rather than chemical control.

Biological control

Biological control is the use of the weed's own natural enemies to slow the dispersal of the weed and reduce its population density. Biological control is a long-term, environmentally-friendly, cost-effective and often self-sustaining method of weed control. It is based on sound ecological principals aiming to reduce the competitive advantage a weed has over indigenous vegetation. In contrast, mechanical and chemical control are expensive and not always environmentally safe. Also repeated treatments are often needed and these only provide control in the area of application.

Biological control is a slow process and success is not always guaranteed. However, it is estimated that the successful implementation of biological control in general could bring about a significant saving of the total costs of controlling invasive species.

All available biological control agents have been through a vigorous screening process in quarantine to ensure that they only attack their host plant. This means they will not attack indigenous plants or plants of economic importance. The importing, transport, and release of any living organism other than an approved biological control agent is illegal and may have disastrous consequences.

The biological control programme against silky hakea started in 1962. It initially focused on two seed attacking insects: the seed weevil and the seed moth. Since then, three more biological control agents have been established on silky hakea: the leaf weevil, the bud weevil and the stem-boring beetle.

A locally occurring fungus, the gummosis fungus, has also been developed for the control of silky hakea. Several methods of application can be used to target both seedlings and mature plants of silky hakea. It does not attack any of the other hakeas, nor any indigenous or crop plant.

Strains of the seed weevil, seed moth and the stem-boring beetle have been introduced for rock hakea.

No biological control agents have been introduced for sweet and willow hakea.

Fires will kill any biological control agents in burnt stands, or at least force them to disperse to other areas. Therefore, it is necessary to re-introduce them into areas after fires, so that their numbers build up sufficiently quickly to have a substantial impact on the hakeas before the next fire.

A correctly implemented biological control programme is capable of suppressing silky hakea populations down to a level where mechanical control is seldom required.

The measures available for each of the hakeas are:

- **silky hakea:** mechanical, chemical, biological (all agents);
- **rock hakea:** mechanical, chemical, biological (seed moth, stem-boring beetle and seed weevil only);
- **sweet hakea:** mechanical only;
- **willow hakea:** mechanical only.

After fires occur, it is critical that the biological control agents are introduced as soon as possible after the young plants flower for the first time. This will greatly reduce the quantities of seed produced by the growing silky hakea trees. This is to minimise the re-establishment of stands after the following fire.

The introduction of biological control agents against rock hakea will help the control of this plant by reducing its density and seed production, but with the currently available agents, control of this plant is centered on mechanical control.

Comparison of the advantages and disadvantages of the different types of control available against hakea species

	Mechanical	Chemical	Biological
Advantages	➤ Highly effective. ➤ Rapid impact.	➤ Highly effective. ➤ Rapid impact.	➤ Sustained impact over many years. ➤ Relatively cheap. ➤ Agents spread by themselves throughout stands in inaccessible areas.
Disadvantages	➤ Labour intensive. ➤ Expensive. ➤ Can only be applied in accessible areas. ➤ Requires either frequent follow-up treatments or all plants must be eradicated.	➤ Labour intensive. ➤ Expensive. ➤ Can only be applied in accessible areas. ➤ Requires either frequent follow-up treatments or all plants must be eradicated. ➤ Drift of herbicide by wind kills indigenous plants.	➤ Requires informed management for successful implementation. ➤ Variable impact influenced by weather conditions. ➤ Slow attrition of weed population.

Planning hakea control operations

To carry out a successful control programme, it is necessary to plan ahead. To do this it is important to know what weeds are present and where these are – and the same for their biological control agents. Accessibility is the most important factor in considering which control method to use: clear easily accessible areas with mechanical control, use biological control in inaccessible areas, and integrate both biological and mechanical control options in areas accessible but with difficulty. In areas to be cleared, determine when they will be cleared according to availability of clearing teams and budget. Also follow the general principles set out on page 3 and below. In areas where biological control is to be implemented, know where you can source agents and when they should be released.

Information needed for planning

- Identify the species of hakea present (see Chapter 2).
- Identify the biological control agents already present (see Chapter 3).
- Map the areas infested with hakea, indicating density.
- Map where the agents occur.

Planning integrated mechanical and biological control

- Divide the areas invaded into management units using species and density of hakea present, land features such as roads or rivers etc, and whether the area is accessible or not.
- Identify control options available and appropriate for each management unit.
- Determine budget required, including all necessary follow-up treatments.

Accessible areas

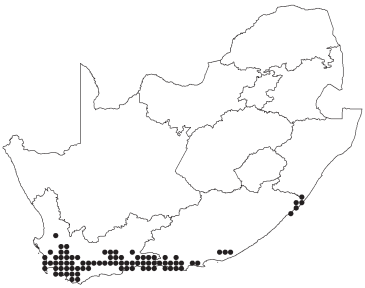
Implement integrated mechanical, chemical and biological control options (see Chapter 4).

Inaccessible areas

- Introduce agents not yet present.
- Introduce all agents after any fires (see Chapter 4).

Chapter 2: The invasive hakea species in South Africa

Silky hakea
(*Hakea sericea*)



Silky hakea is one of the most serious alien invasive trees in many of the coastal mountains of the Western and Eastern Cape provinces.

NEMBA:AIS Category 1b.

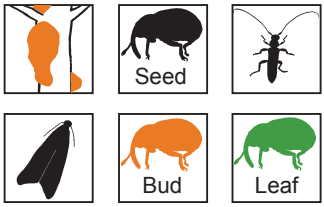
Description

- Silky hakea is an erect branched tree reaching 5m, though usually only 2–3m, in height. It has dark-green, smooth, needle-like leaves which are 1mm wide and up to 40mm long with sharply pointed tips.
- Seedlings and young growth are softly hairy, but the hairs are soon lost so that mature leaves are smooth (compare to rock hakea).
- The plant produces cream-coloured flowers in late winter, from June to September.
- The mature fruit of silky hakea is a heat-resistant woody follicle (25–30mm long and 20–25mm wide). Each fruit contains two black seeds with large wings.

Other characteristics

- The seeds produced are stored on the tree and are only released after the death of the plant, usually by fire.
- The seeds can germinate any time in the year provided good rainfall occurs.
- The young trees can start to produce fruit after one year, though most do so only after two or three years, and mature trees can live for thirty years.

Biological control agents available:



Silky hakea plant, and close-up of flowers and a mature and a young green fruit.

Needle-shaped leaves of silky hakea and their arrangement on branches together with young fruit, and cream coloured flowers in leaf axils.

Front and side view of silky hakea fruit showing shape, rough ornamentation and prominent horns at apex, an opened fruit, and seed.

Seedlings of silky hakea showing large round cotyledons (arrow), needle-like leaves and soft hairs that drop as the leaves mature. The combination of these characters distinguishes seedlings of silky hakea from most indigenous fynbos plants.

Rock hakea
(*Hakea gibbosa*)

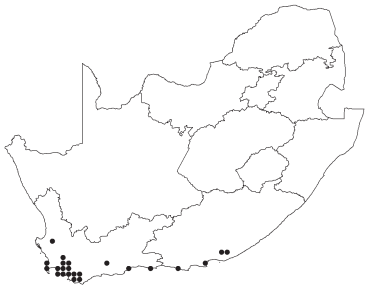
Rock hakea was widely planted in the Cape Peninsula and is common in the Kleinrivierberg and the adjoining mountains near Hermanus and Stanford.

Infestations also occur in the Steenbosksberg and Franschhoek mountains. It is not as widespread as silky hakea despite the fact that it was more widely planted.

NEMBA:AIS Category 1b.

Description

- Rock hakea is an erect branched tree growing to a height of 4m. It has stiff, hairy, grey-green needle-like leaves 1mm wide and up to 80mm long. The leaves have sharply pointed tips.
- The leaves have short persistent hairs.

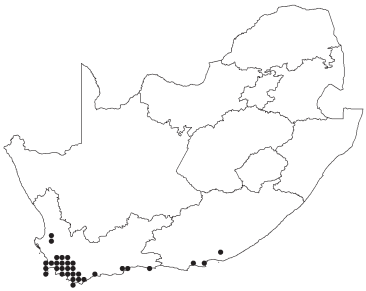


- Flowering occurs from June to early September.
- The mature fruit of rock hakea is similar to, but larger than, the fruit of silky hakea. Approximately 35mm long and 30mm wide. Two apical horns are present.

Biological control agents available:

Rock hakea plant, and close-ups of the leaves, flowers and fruit.

Sweet hakea
(*Hakea drupacea*)



Sweet hakea is largely restricted to the Cape Peninsula, Somerset West, Franschhoek, Bot River, Hawston and the Kleinrivier mountains.

NEMBA:AIS Category 1b.

Description

- Sweet hakea is a branched, rounded tree growing to a height of 6m.
- The adult leaves are dark green, hairless, up to 13cm long. The leaves are divided with 3 to 5 pairs of upright, 30–50mm long sharp-pointed needles.
- The flowers are white in colour with a pink tinge and are present from May to August.
- The mature fruit of sweet hakea is smaller than those of silky and rock hakea (approximately 25mm long and 20mm wide). They have a leathery yellowish-brown appearance with dark patches, and generally occur in clusters of 4 to 7.

Other characteristics

- The seeds are only released after the death of the plant.
- Sweet hakea produces few viable seeds and is not as invasive as silky hakea.
- Sweet hakea has a long juvenile stage and can take between four and six years to reach maturity and start flowering.

Biological control agents available:

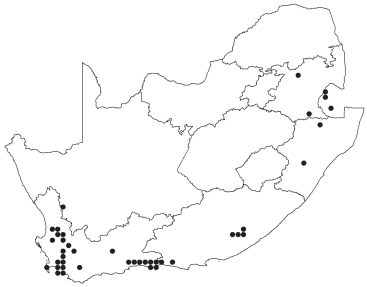
No biological control agents have been introduced for this weed.

Sweet hakea plant, and close-ups of leaves, flowers and fruit.

Willow hakea
(*Hakea salicifolia*)

Willow hakea occurs in open forests in its native range in Australia. It is not widespread in South Africa but small infestations occur near Du Toits Kloof (Paarl), Kleinmond, Bot River, George and Knysna in the Western Cape. Localised infestations also occur in Stutterheim and Hogsback in the Eastern Cape.

NEMBA:AIS Category 1b in Western Cape only (not elsewhere in country).



Description

- Willow hakea is a fast-growing small tree which grows up to 5m tall. The leaves are narrow and they grow up to 10cm long and 1cm wide.
- The flowers are white, small and occur in the leaf axils.
- The woody fruits are much smaller than those of silky hakea and rock hakea (20mm long and 15mm wide) and contain two winged seeds.

Other characteristics

- Fire kills the seed in the small woody fruit.
- The seed lose their viability in old fruit.

Biological control agents available:

No biological control agents have been introduced for this weed.

Willow hakea plant and close-ups of fruit and leaves.

Ecology and spread of hakea species

- In South Africa, silky and willow hakea occur from the winter-rainfall region in the west of the country, to the summer rainfall region in the east.
- Sweet and rock hakea are largely restricted to the winter rainfall region in the west, though small stands occur eastwards into the summer rainfall area.
- Hakeas are restricted to sandy, nutrient poor, highly leached soils such as those derived from Table Mountain Sandstone.
- Silky and rock hakea have a juvenile period of 2 years, reaching adult levels of seed production by their third year. Silky hakea will produce some fruit within their first and second year, but at levels lower than that of an adult tree. The juvenile period is 4 years for willow hakea, and 6 years for sweet hakea.
- Widespread fires in the Western and Eastern Cape mountains have resulted in the spread and large scale regeneration of silky hakea. The rate of spread of silky hakea has been impressive in the south-western region of the Western Cape province, with 9,000ha, 111,345ha, 279,200ha and 360,000ha invaded by the years 1939, 1969, 1974 and 1983 respectively.
- Starting in 1976 and continuing into the 1980's, large-scale clearing operations of silky hakea were undertaken in water catchment areas. This resulted in the total extent of invasion being reduced by approximately half. The presence of biological control agents has reduced the re-invasion of these cleared areas.
- Re-invasion by silky hakea in some areas is currently happening, and it needs to be brought back under control.
- The winged seed of hakeas can be transported by wind for relatively long distances, as much as several kilometers, so that new infestations can develop in neighbouring valleys to where the plants have already invaded. Since these infestations may occur in remote or inaccessible areas, invasions can become extensive before they are noticed.
- The seed of silky, rock and sweet hakea remain viable even in the oldest fruits on the trees. However, the seed of willow hakea loses viability with time.
- The number of fruit produced by silky hakea is relatively large in comparison to rock hakea, whereas sweet hakea produces relatively few fruit in comparison to both of these species. These differences in relative seed production can explain the relative invasion rates of the different species, with silky hakea producing more seed and therefore dispersing much more rapidly than any of the other species. Seed banks of 1.5 million seed per hectare have been estimated for silky hakea.
- Dense stands of hakea can alter the composition of indigenous plant and animal communities, increase the risk of fires and increase their intensities, reduce water runoff in mountain catchments, and restrict access to mountain areas.

The hakea gummosis fungus
(*Colletotrichum acutatum*)

Description

- The indigenous gummosis fungus has spread into various parts of South Africa since the 1960's causing a serious disease of silky hakea. This fungus has been extensively tested to determine if it can infect indigenous proteas, but it does not. The fungus only attacks silky hakea and it is therefore safe to be used as a mycoherbicide in South Africa.
- Germination of the fungal spores occurs from 16°C to 32°C at a high humidity (>95% RH), with an optimum temperature for infection of 25°C. The spores are spread by rain splash. Consequently, treatment of silky hakea infestations must be done at the beginning of the winter rain season, to ensure infection and then further spread under field conditions.
- Like most fungi, the body of the fungus consists of tiny threads (approximately 0.005mm wide). Short branches develop on these threads and bud off the asexual spores. Dried spores are supplied for use.

Silky hakea trees killed after inoculation with the gummosis fungus, and the gum oozing from diseased bark from which the fungus gets its name.

Disease symptoms

The most characteristic symptoms of the disease are bark cankers (dead areas becoming deformed) on stems and branches from which gum oozes (gummosis). The affected areas become flattened or swollen and the bark splits. Infected shoot tips of mature plants die back progressively. When cankers girdle the stem near ground level the host plant is killed. A blight disease kills seedlings, the growing points of seedlings die and this extends down the stem.

Impact on silky hakea

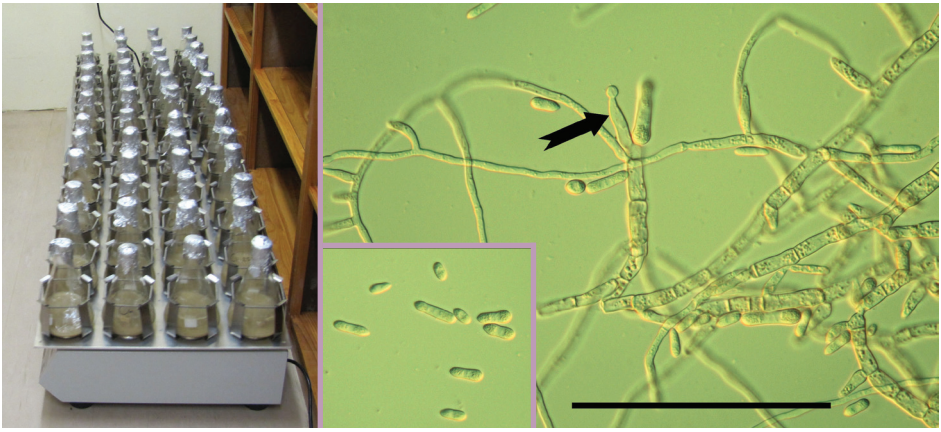
Seedlings as well as mature silky hakea plants are affected by the gummosis fungus. Although the effects manifest slowly over several months, the fungus is still capable of killing large stands of silky hakea trees. If applied correctly during cool months at the beginning of the rain season, it can cause severe disease of mature silky hakea plants.

Rainfall favors the spread of the fungus. Drought severely reduces levels of infection. Consequently, it disperses well in high rainfall areas and dispersal becomes progressively less effective in drier areas.

To compensate for this reduced spread of the fungus in drier regions, more plants need to be inoculated, and more frequent applications need to be applied (annually).

Seedlings killed by the fungus.

The strain of this fungus that is used has been shown to be host specific, causing disease only on silky hakea plants from all areas of South Africa. The only exception is plants from the Grahamstown area (Eastern Cape province) which are resistant.



Production facilities used to grow the gummosis fungus in the laboratory, and a tiny piece of the fungus as observed using a high powered microscope showing the threads (hyphae) which are the body of the fungus. The arrow marks a spore producing branch, and the inset shows several spores. The black bar represents 0.1 mm.

The hakea seed weevil

(*Erytenna consputa*)

Photo by Evert Nel

Adult hakea seed weevil.

Description

- Seed weevils are small beetles coloured a mottled grey, black and red-brown. They are 4–5mm long with a long snout.
- They are present on the plants throughout the year. They can be found on the branches or sheltering in the dry, brown husks of the damaged fruit. The husks are undeveloped, partially split-open, black fruits resulting from the larval stages of the weevil feeding on and hollowing out the immature fruits. The larvae are small white grubs and can usually be found inside the green developing fruits.
- The adults feed on new shoots, flower buds or young fruit as these become available. Two strains of the weevil have been introduced into South Africa; one strain targets silky hakea and the other strain targets rock hakea.

Life cycle

The adults lay their eggs into small holes that they make in leaf-tips and buds near to young fruits, or in the “horns” of the fruit between July and September. During the breeding season each female lays 100–130 eggs. After about two weeks, the eggs hatch and the larvae tunnel into the young growing fruits. Only one larva can live in each fruit. A larva may have to eat the seed of two to three fruits to complete its development.

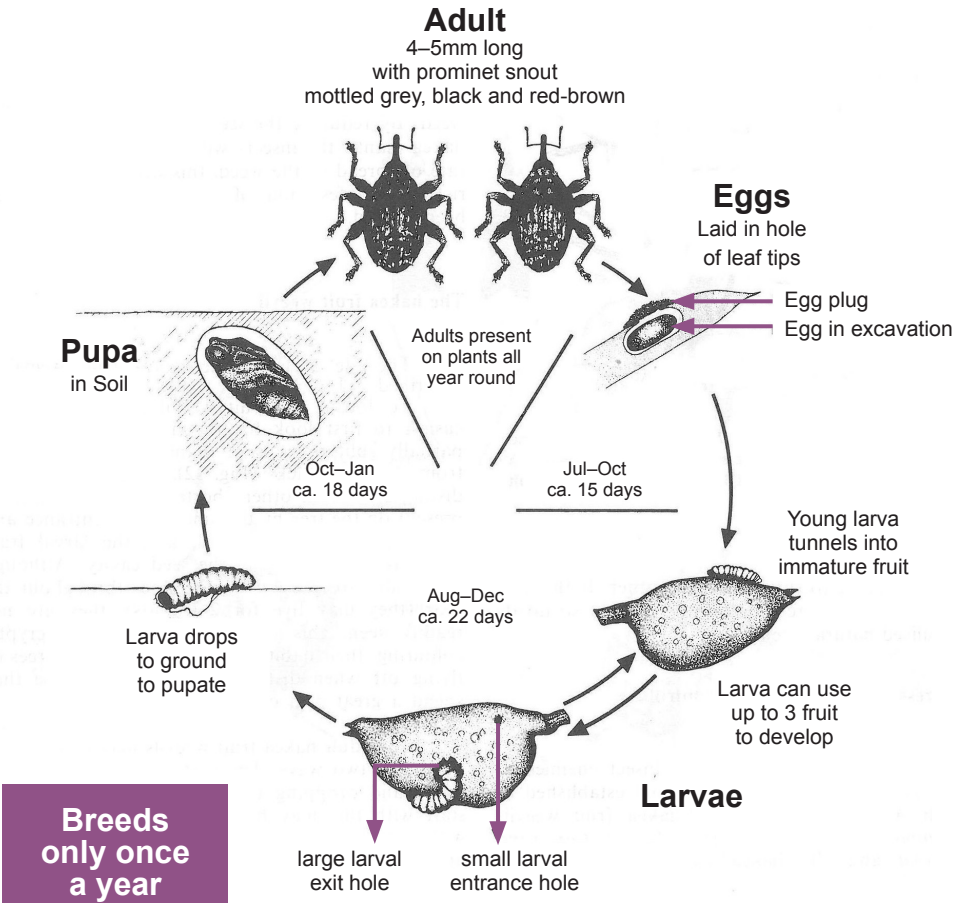
When fully grown in October, the larvae tunnel out through one side of the fruit and drop to the soil in which they pupate. The adults emerge from the soil in January. The seed-weevil has one generation a year and the adults can live for two to three years.

Feeding damage

A young fruit in which a seed weevil larva is feeding has a reddish colour at first and yellows as it withers and dies. Fruits attacked by weevils remain on the tree and have a small exit hole out of which the larva leaves to pupate. Signs of frass (faeces) occur around the eaten seed. The occurrence of black, dried, partially-split husks of young fruits on the trees is an indication of seed weevils being present.

The larvae destroy the green developing fruits of silky hakea and rock hakea, and in the case of silky hakea, more than 80% of seed that begin to develop may be destroyed annually. Unfortunately the strain on rock hakea has so far been less successful.

Life cycle of hakea seed weevil

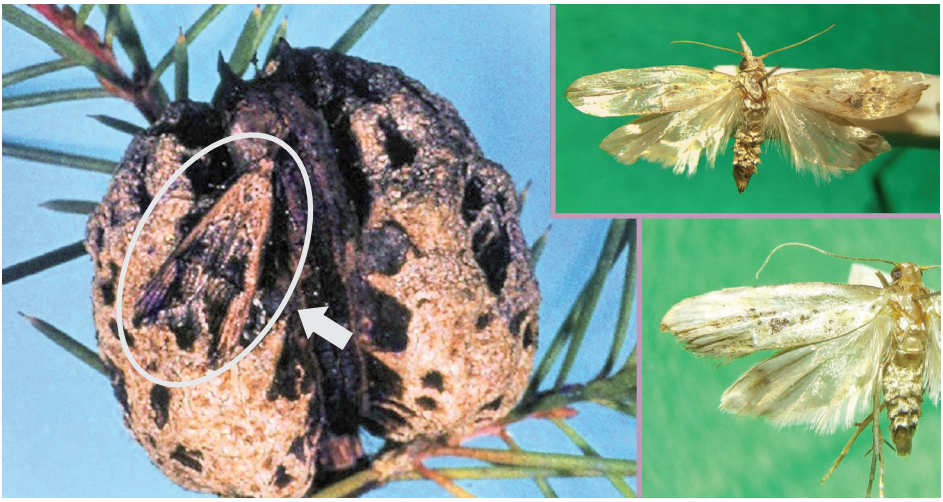


Breeds only once a year

The small brown silky hakea fruits damaged by the seed weevil (arrows) compared to the normal developing green fruits.

Damaged immature fruit of silky hakea are much smaller than healthy fruit.

The hakea seed moth
(*Carposina autologa*)



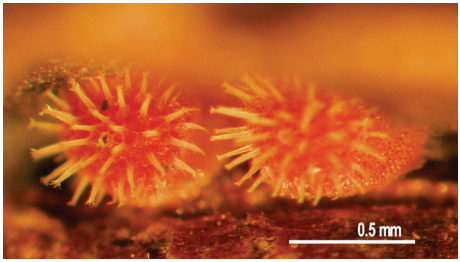
The hakea seed moth on mature silky hakea fruit, and 2 pinned specimens.

Description

- The adult moths are grey-brown, about 10mm long and not easy to find in the field.
- Adult moths are present between February and June and live about 30 days. They are active during the twilight hours and feed on nectar.
- Originally released in 1970 against silky hakea, a new strain was also released in 2014 against rock hakea.

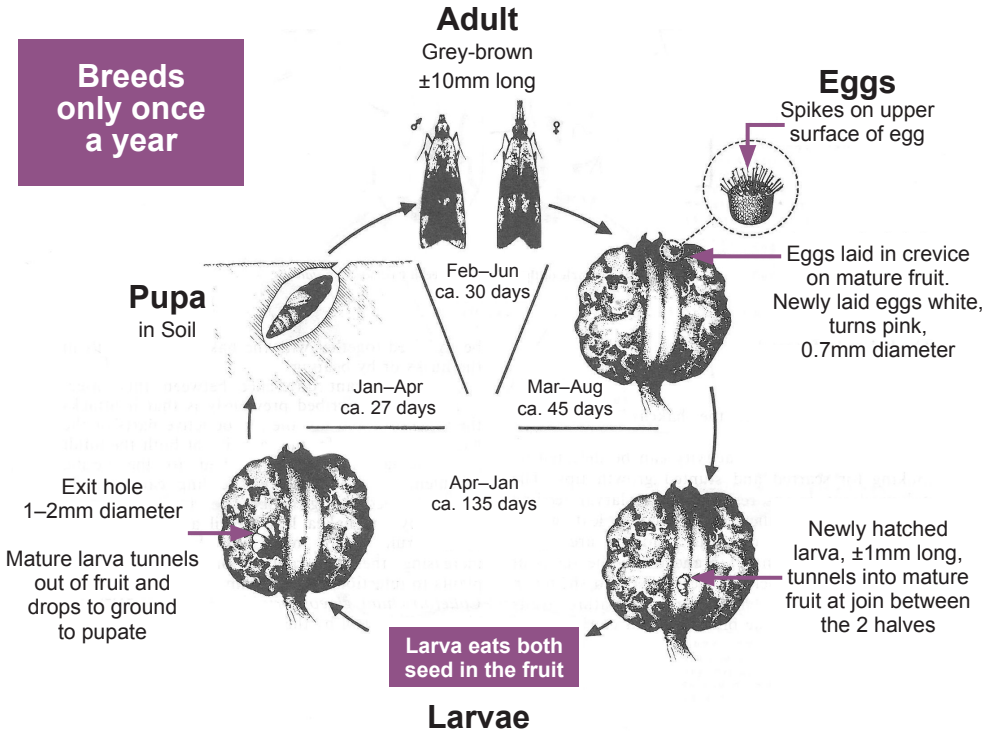
Life cycle

In autumn the females lay their eggs in crevices on the surface of mature silky hakea fruit, or between fruits that are touching. Each female can lay more than 100 eggs during her life time. The larvae hatch from the eggs after about 45 days and tunnel into the fruit through a tiny hole which they excavate at a point along the joint in the middle of the fruit. Each larva develops in the fruit by feeding on both seeds. Only one larva can develop in a fruit. The larval stage last about 135 days and the mature larva emerges from the mature fruit via its exit tunnel, falls to the ground, and pupates in the soil. The adult moths emerge in autumn and egg-laying begins in early March and generally last for three months until the middle of June. The hakea seed moth has only one generation a year.



Ornamented eggs of the seed moth.

Life cycle of hakea seed moth



Feeding damage

The hakea seed moth destroys the seeds in mature, woody fruits. It complements the hakea seed weevil because it destroys the seeds in fruits that have escaped attack by the seed weevil. The moth has reduced the accumulated seeds at some sites by up to 40% (usually less) over a period of several years. The hakea seed moth disperses slowly, though it can establish new colonies far away from release sites.

Larvae of the seed moth feeding on seed inside mature silky hakea fruit.

The hakea stem-boring beetle

(*Aphanasium australe*)

Photo by John Hoffmann

The hakea stem-boring beetle.

Description

- The adult stem-boring beetle is blackish-brown, long and thin, and it is about 20mm in length.
- They have a pair of long antennae, approximately one and a half times the length of their body. These antennae are typically held over their back.

Life cycle

The life cycle takes two years to complete. Clusters of 10–20 eggs are deposited on the stem at the base of the plant of silky hakea (or anywhere on the stem of rock hakea). The newly-hatched larvae eat into the stems directly from the eggs and reddish-brown gum is exuded by the plant tissue at the entry points of the larvae.

The larvae tunnel gregariously within the base of stems and in the sub-surface roots of the plants. Nearly mature larvae construct large tunnels, pushing frass (a mixture of sawdust and faeces) to the outside, weakening the stem. Once mature, after nearly two years, larvae move to just beneath the bark surface where they pupate. The adults then emerge during summer.

Larvae of the stem-boring beetle.

Feeding damage

This insect agent can kill the plant. Extensive tunneling by the larvae weakens the plants structurally and may cause them to fall over, particularly when subjected to the strong winds typical of summer in the Western Cape. The vigour of the plant is also reduced, causing slower growth rates and premature death of the plant.

Larva of stem-boring beetle tunneling in the crown region of a silky hakea stem.

Tree fallen over due to stem weakened by tunneling.

The hakea bud weevil

(*Dicomada rufa*)

Photo by Evert Nel

The hakea bud weevil.

Description

- The adult bud weevils are small beetles, dull-brown in colour, with a prominent snout. They are 2–3mm in length.
- The adults feed predominantly on the dormant axillary buds.

Life cycle

The eggs are laid singly in the flower buds of the plant. The larvae feed on the inflorescences and young succulent vegetative growth in protective capsules formed by “gluing” the flowers or individual young leaves together.

The larvae are cream-coloured, legless grubs with limited mobility. Once mature, the larvae emerge from the protective covering and drop to the ground where they pupate just under the soil surface. The weevil has one generation a year.

Feeding damage

The adults feed on the buds, and the larvae feed on the young succulent leaves and flowers. Feeding damage by the larvae to the flower buds and flowers reduces the number of fruits, and therefore seed, that is produced by the plants. However, their impact is still under investigation, as these weevils have established at only a few sites.

The hakea leaf weevil
(*Cydmaea binotata*)

Photo by Evert Nel

The hakea leaf weevil.

Description

- The adult leaf weevils are small beetles, with a prominent down-curved snout, and mottled dark coloured with a prominent pair of white spots on their wing covers. They are 1.5–2mm long.
- They feed on the young succulent leaves, stems and buds of the plant. They shelter in the fruit husks on the tree and are present on the trees throughout the year.

Life cycle

The adults lay their oval-shaped eggs singly, throughout the year, in holes they make in the succulent leaves or on sprouting buds when these are available. The larvae tunnel down the leaves or soft stems, this being the most damaging stage, especially when succulent shoots are attacked.

Fully developed larvae drop to the ground and pupation occurs in a flimsy cocoon just below the surface of the soil. There are at least four generations per year.

Feeding damage

The larvae tunnel down the succulent leaves or the soft stems of the plant causing die-back of the leaves or soft stems. The adults make feeding cavities in succulent leaves and axillary buds. Although this agent is fairly widespread it is not abundant and the damage to the plant is negligible. It was initially thought that their feeding damage may enhance the infection rate of the gummosis fungus, though there is no evidence this does happen.

Chapter 4: Guidelines for biological control implementation

Biological control against hakea species must not be seen as the only method of control, but rather as complimentary to other control measures.

General overview of a biological control strategy

Released biological control agents are used in two different ways:

- **General releases:** These releases are made to have an impact mainly on the target weed's seed production, and to an extent, also on population densities. These are for use in inaccessible areas where mechanical control is not feasible, as well as for use in areas that are not earmarked for mechanical control operations in the near future.
- **Biological control reserves:** These are areas which will not be cleared, to serve as breeding grounds from which the insects can re-colonise into re-establishing hakea populations, and where the agents can be collected for redistribution.

General releases

It is particularly important to ensure that all the available biological control agents are well established in all hakea stands in inaccessible areas, as this is the only feasible means of control in these areas.

In the long term, the ideal situation is to have all the available biological control agents well established in every stand of silky and rock hakea. This will greatly reduce the amount of seed produced, as well as thin out the stands, thus preventing these weeds from re-establishing large dense stands after fires, and improving the efficiency and reducing the cost of clearing operations.

Initially, release in areas that are not going to be cleared in the foreseeable future, but once the agents are established in these areas, then also release in areas that may well be cleared in the long term.

See below for the sequence in which the agents can be released, as well as how to collect and release these.

Biological control reserves

To prevent local extinction of insect agents during clearing operations, biological control reserves for the various insect agents must be established in areas where mechanical clearing is to be carried out. These reserves should be around 1–5ha in size and 5–10km apart, and should consist of plants that have healthy populations of the biological control agents on them. They need to be protected from fires.

It is recommended that all the agents, if available and not already present, be released in every biological control reserve.

Make sure that the reserves are well demarcated, to avoid accidental clearing.

The agents are collected from the reserves and redistributed into other areas as required, as general releases.

Flow diagrams of implementing biological control on hakea species

Planning

- Determine the best time for the collection and distribution of the selected biological control agents (see pages 44–46).
- Identify appropriate release sites.

Obtain biological control agents

- All insect agents can be ordered from the Implementation Officer of DEFF:NRMP (see contact details on page 53).
- The gummosis fungus can be ordered from ARC-PHP in Stellenbosch (see contact details on page 52).

Release of agents

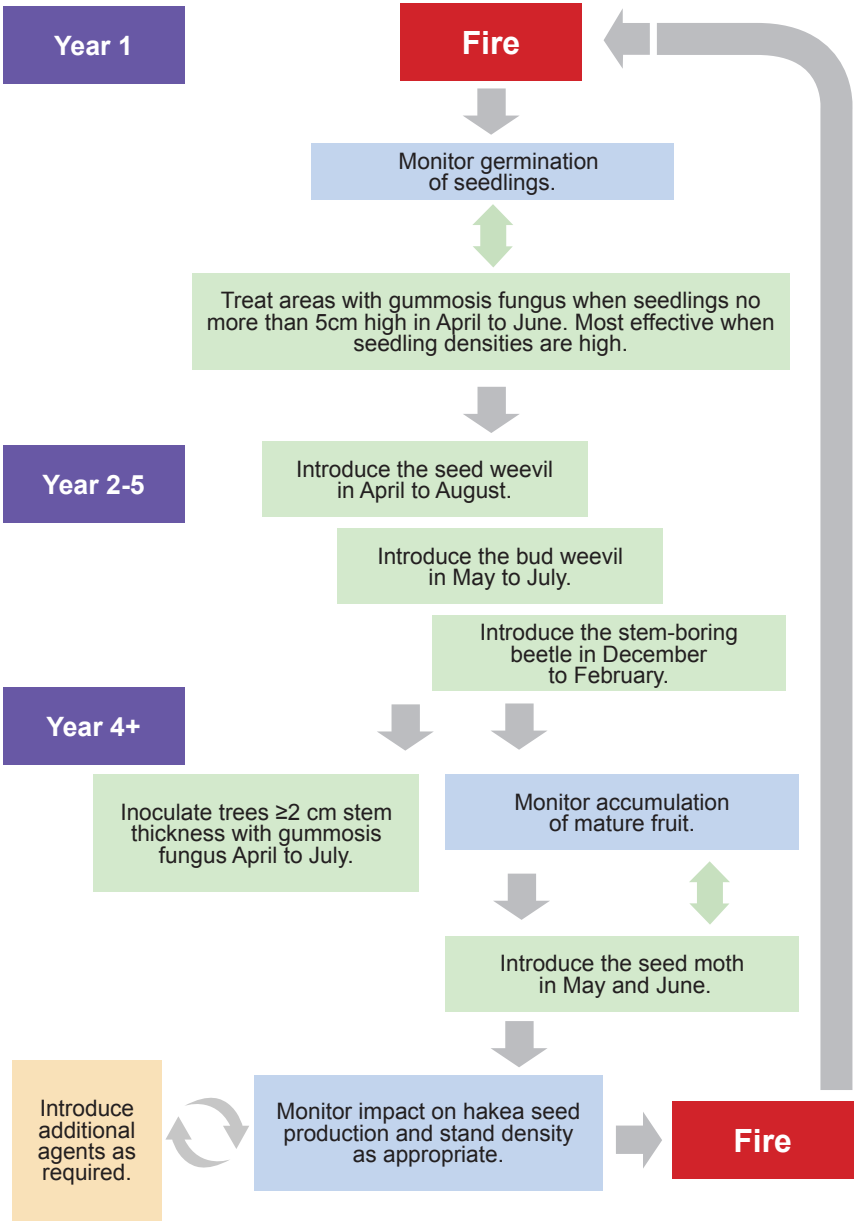
- Release agents as soon as possible after they are obtained. Ensure they are kept in a cool, dry place until released.

After release

- Monitor the presence and spread of the biological control agents.
- Perform follow-up treatments or re-introduce biological control agents where necessary.

Establish and maintain biological control reserves

- Reserves serve as a source of agents for later collection and distribution by yourselves for areas managed by you.


Year 1
Fire
Monitor germination of seedlings.
Treat areas with gummosis fungus when seedlings no more than 5cm high in April to June. Most effective when seedling densities are high.
Year 2-5
Introduce the seed weevil in April to August.
Introduce the bud weevil in May to July.
Introduce the stem-boring beetle in December to February.
Year 4+
Inoculate trees ≥2 cm stem thickness with gummosis fungus April to July.
Monitor accumulation of mature fruit.
Introduce the seed moth in May and June.
Introduce additional agents as required.
Monitor impact on hakea seed production and stand density as appropriate.
Fire

General planning tips

Some general planning tips for successful biological control usage for silky hakea following a fire are:

Year 1

- After a fire, young seedlings that emerge after the first rains should be targeted immediately with the gummosis fungus. This will reduce the silky hakea population especially if there was a high seed load present before the fire and so seedling densities are very high.
- Seedlings are best treated in April and May, once they start emerging after the onset of winter rain in March/April. In drought years, seedling emergence is late and treating seedlings has been found to not be effective in these years.

Year 2–5

- One year after a fire, release the seed weevil and the bud weevil, and repeat this for another two years. This is critically important as the plants may start developing fruits after one year and the agents need to be in place to prevent an accumulation of fruits on the plants. The ideal time to collect and release these agents is prior to flower bud formation in the case of the bud weevil and at flowering time in the case of the seed weevil.
- Release the stem-boring beetle when the silky hakea stems are about as thick as a pencil or wider.

Year 4+

- As soon as mature fruits appear on the plants, introduce the seed moth. The seed moth will attack the seeds in the mature woody fruits.
- Wound inoculate mature silky hakea trees (stem ≥2cm width) at the beginning of the rainy season with the gummosis fungus. Monitor the spread throughout the population and do follow-up treatments if necessary. It is important to remember that the gummosis fungus needs augmentation through constant and proper implementation to be successful.
- When a new fire occurs, start the process again. If the agents are correctly implemented, after two fire cycles the hakea stand densities should be greatly reduced and too low to cause environmental or economic damage.

These guide lines also apply to the implementation of biological control against rock hakea, after taking into account which agents are available and differences in their impact on this weed compared to silky hakea.

Gummosis fungus

Implementation procedure

The gummosis fungus can be used against silky hakea. All methods of application are based on the following basic principles:

- Wound-treat the stems of silky hakea trees (stems of ≥2cm diameter, approximately an adult's finger width or more), using a suspension of the gummosis fungus spores in water.
- The wound-treatment needs to be done at the base of tree stems, no higher than 10cm above soil level.
- Wounding the bark allows the gummosis fungus to grow into the bark and cause the gummosis disease, in the process killing the bark and in effect ring-barking the tree.
- The gummosis fungus only attacks the bark and not the wood of stems.
- The gummosis fungus only attacks silky hakea.

Implementation procedure of gummosis fungus against mature silky hakea trees

Stems of accessible silky hakea trees can be wound-treated with a spore suspension of the gummosis fungus using a hand-held jabbing device.

- Packets of dried spores (0.1g per packet) of the gummosis fungus are obtainable from ARC-PHP, Stellenbosch. See page 52 for contact details.
- Suspend the contents of a spore packet in 1-litre of water, by shaking the bottle.
- Do not leave the spore suspension in direct sunlight. If the water heats up (≥30°C), the fungus will be killed.
- If possible, only suspend the dry spores in water just before use.
- Wound-treat the base of stems (≥2cm diameter), as close to the ground as possible, not more than 10cm high, using a hand-held jabbing device (see pages 29–31 for designs).
- If jabbed higher up on the plant, the top parts of the plant will die but the plant will regrow from the base.

Packets and spores of the Gummosis fungus as supplied by ARC-PHP

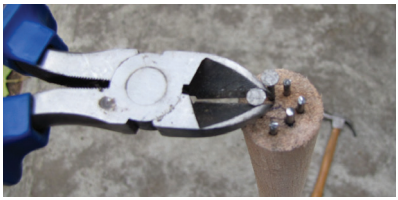
- One litre of fungal spore suspension is more or less enough to wound-inoculate 1 hectare of silky hakea trees.
- In dense stands in high rainfall areas, walk in a zigzag pattern to treat trees throughout the stand. The gummosis fungus will spread to untreated neighbouring plants.
- In drier areas, it is better to inoculate every second, or each tree, if possible.
- Monitor disease spread and re-introduce the fungus in areas when necessary, for instance after fires or hot dry summers.

Making and using your own jabbing implement

1) To make a basic jabber you need:

- a wooden broom handle (or similar wooden pole);
- 6 nails (approximately 2 × 30mm);
- a hammer and wire cutter.

The basic jabber is made by hammering the nails into the flat end of the broom handle, in a circular pattern. The nail heads are cut off using a wire cutter (it is easiest if you hammer in a nail and cut off its head before hammering in the next nail). Ensure the nail tips are all an even height above the broom handle. Cut the broom handle in order to make it a convenient length.



Jab the base of the stems by thrusting this jabber directly into the bark, and immediately treat the resulting wound with a suspension of the gummosis fungus spores. The suspension can be kept in a 1-litre plastic spray bottle, and a single squirt directed over each wound is sufficient.

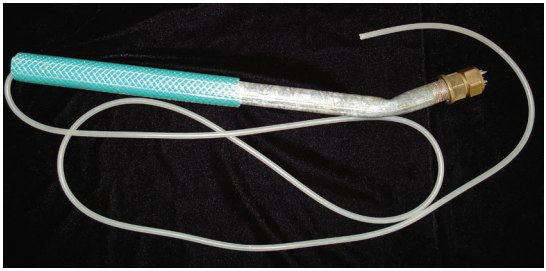
- All jabbers work by wounding the bark of the stem, allowing the fungus to grow into the bark and cause disease there.
- Jab the base of the tree and treat the resulting wound with a small amount of spore suspension (arrow).

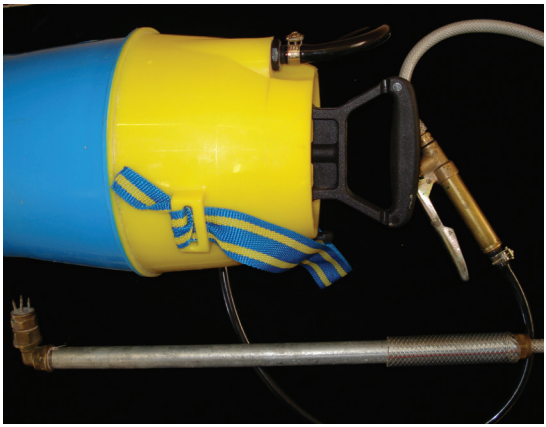
2) A pipe jabber can be made from an old piece of lead piping with a custom made jabbing head.

➤ See page 31 for a schematic drawing of this design.

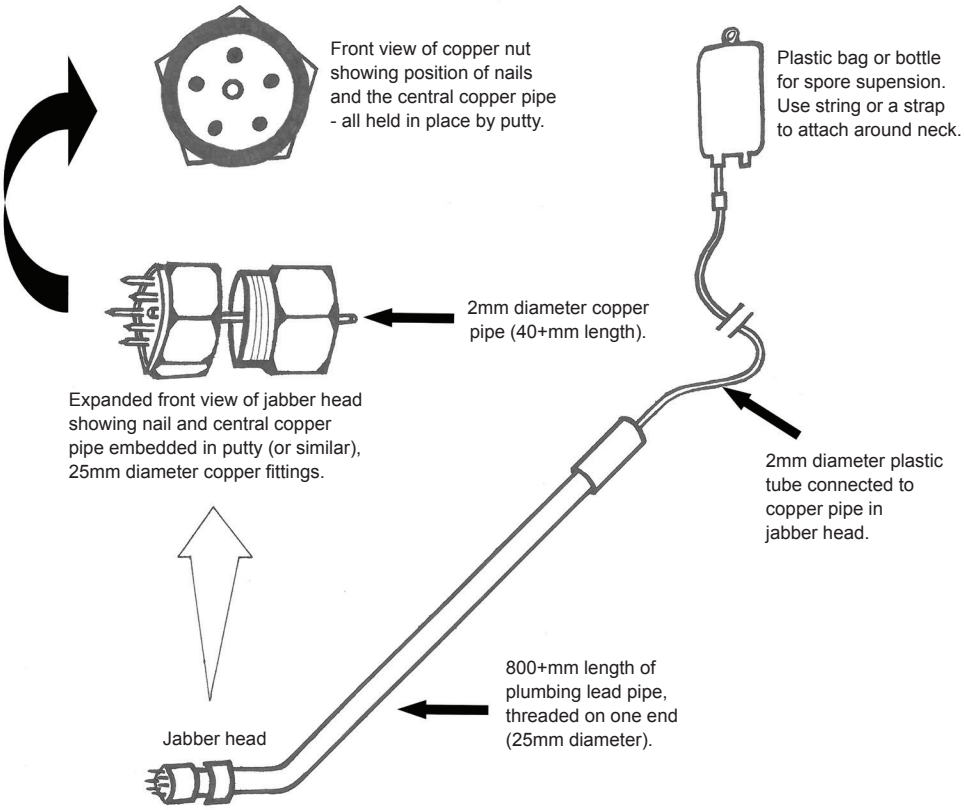
➤ To make the jabbing head, use a connector and a nut that fits on the end of the lead pipe. Insert 4 or 5 nails around the edge of the inside of the nut, and a thin (2–3mm thick) copper tube in the middle. Fill the space inside the nut around the tube and nails with a hard putty or similar substance, and allow to dry. Attach a plastic tube to the inner end of the metal tube. Then, screw the nut onto the end of the lead pipe, with the plastic tube running up the inside of the lead pipe. Attach the plastic tube to a plastic bottle or bag which holds the spore suspension. Finally, place a small piece of foam over the jabbing head and hold it in place with a rubber band.

➤ Test the jabber before going into the field, to ensure that the spore suspension does not drip through the sponge rapidly. The less dense the foam the thicker it needs to be, to prevent the spore suspension dripping through and therefore being wasted in the field.





➤ This design can be modified by attaching the tube to a ±5 litre spray can. With this design, no foam is required because the flow of the spore suspension is controlled by the spray can's own flow regulator.



Schematic view of pipe jabber tool used to wound-treat silky hakea with a spore suspension of the gummosis fungus. A piece of sponge is fitted over the jabber head to regulate the flow of the spore suspension.

Implementation procedure against seedlings of silky hakea

Young silky hakea seedlings that emerge following fire are susceptible to infection by the gummosis fungus. Successful establishment of the disease is however dependent on having ideal environmental conditions for both spore survival and germination. Seedlings can be treated with colonised bran inoculum.

- Distribute by hand a dried formulation of the gummosis fungus on wheat bran (1g bran per square meter of ground), amongst young emerging silky hakea seedlings.
- The bran is colonised by the gummosis fungus, on which it produces spores when moistened by rain. These spores are splash dispersed by rain onto nearby seedlings which are then infected.
- Treatment is most effective during early winter at the beginning of the rainy season, when seedlings have no more than 20 leaves (up to 4cm high). The tips of larger plants will die, but these larger seedlings will sprout a new branch from low down on the non-diseased stem and continue growing.
- The bran inoculum can be stored at room temperature (±20–25°C) for at least four weeks before it loses viability. Do not expose to heat or the sun, as this will kill the fungus.
- The disadvantage with the bran inoculum is that it is bulky, requiring approximately 10kg of bran inoculum per hectare. In addition, only sufficient bran for treating a few hectares can be produced at any one time.
- The bran-fungal inoculum is obtainable from the ARC-PHP in Stellenbosch. Place orders 3 months before the intended application, to allow sufficient inoculum to be produced. See page 52 for contact details.

Hand-distributing gummosis fungus bran inoculum amongst young emerging silky hakea seedlings once they have germinated following a fire.

Indication of presence

The most characteristic symptoms of the disease are stem and branch cankers (dead areas of the bark) typically with gummosis. The affected areas become flattened or swollen and the bark splits. Infected shoot tips of mature plants die back progressively. These cankers girdle the stem near ground level or on branches, killing the host plant. Growing points of seedlings die off, this extends down the stem.

Silky hakea trees with the typical gummosis that is a readily recognizable sign of infection. Note dried cracked bark of canker (arrow).

Silky hakea trees killed by infection at the base of the stem, and an infected stem showing cracked bark of a canker and twisting of the stem.

Seed weevil

use for 

Collection procedure

Seed weevils are most active and easiest to collect between May and July, before they start laying their eggs. The weevils can be collected by shaking the plant or branch over a large plastic sheet which has been spread over the ground under the tree. The weevils then fall to the ground and can be sucked up using an aspirator.

An aspirator is a simple device that is used for sucking up small insects and can be made from flexible plastic tubing and a small plastic bottle. A gauze filter is attached to the sucking end in order to prevent insects from entering the operator's mouth.

Once 20–50 weevils have been collected, place them in a plastic container (±500ml volume) with crumpled-up paper toweling in it, and a mesh lid (to allow fresh air into the container). Continue collecting, placing each batch of weevils into a different container. This method is more successful during hot days when the weevils are active on the plants.

Once collected the weevils must be placed in a cooler box (with frozen ice bricks) and placed in the shade, and kept cool at all times. They will die if they get too hot. The insects should be released within 1–3 days of collecting.

An aspirator used for collecting insects. Ensure that the gauze filter (arrow) is always in place.

Collecting technique

1) You need a large, light-coloured, plastic sheet, aspirator and a stick.

2) Place plastic sheet under a tree.

3) Bend branches over the plastic sheet and beat with the stick.

4) Suck up the fallen seed weevils using the aspirator.

Implementation procedure

- A new weevil colony can be started with as few as 200 adults per release site but ideally higher numbers (500 or more weevils) should be used. The weevils should be released throughout the hakea stand.
- The seed weevils are fairly hardy and the containers containing the weevils should be gently tapped so that the weevils can fall out onto the plants.
- The seed weevil is widespread throughout the South African range of silky hakea but needs to be introduced 1–2 years after a fire. They can be introduced for 2–3 years in a row to ensure a rapid build-up of the population. This ensures that the seed weevil prevents the production of seed from the first year they are produced.

Seed weevils ready for release in bottles (50 weevils per 500ml bottle), and being released in the field.

Indication of presence

Look for the black, dried, partially split remains of immature fruits (husks) on the plant or on the ground below the plant.

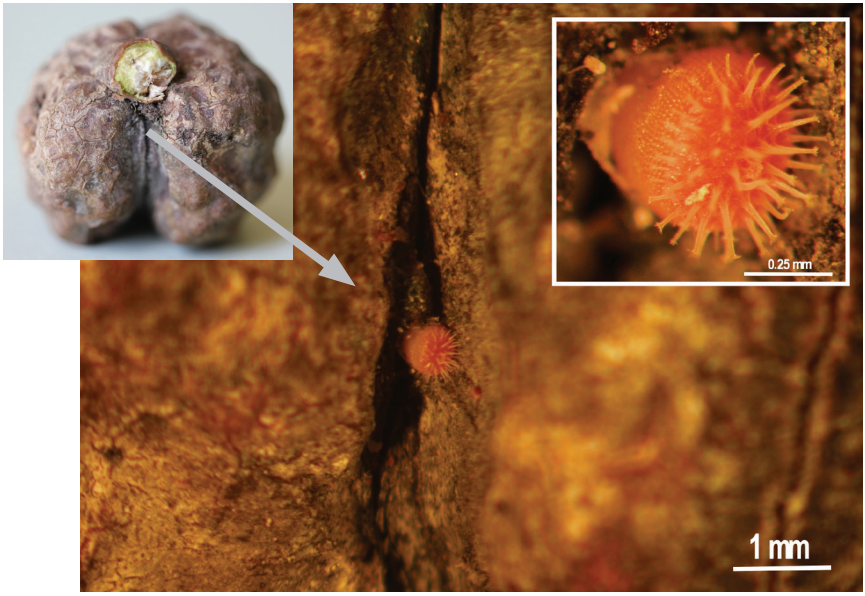
Dried husk of immature fruit after the seed weevil larvae have consumed the developing seed.

Seed moth

Collection procedure

The best method to redistribute the seed moth is to attach egg-bearing fruit halves to healthy fruits in the field.

- Numerous silky hakea fruits are harvested during the egg-laying period in May to June. The fruits are then inspected for eggs using a magnifier. The eggs (0.7 × 0.6mm) are reddish in colour with spikes on the top and resemble tiny pineapples. The eggs are generally laid in crevices on the surface of the fruit – often along the suture between the halves, or between two fruit that are touching.
- The egg-bearing fruits are split in half along the suture of the fruit and the half with eggs is kept.
- The egg-bearing halves are then taken to the field and attached to healthy fruits, using silicon sealant which is available at hardware stores.
- Although splitting the fruits involves additional work, half fruits are used instead of whole fruits because, (a) they are easier to attach than whole fruits, and (b) it eliminates the possibility of the larvae entering the attached fruit rather than the healthy fruit.



Eggs are hidden in crevices such as around the fruit stem. They are a pink or reddish colour with spikes on the top.

Implementation procedure

The fruit halves with eggs can be attached to healthy fruits using a silicon sealant. Care must be taken not to attach the follicle to, or near, the join between the two halves of the fruit as the larva enters the fruit at a point along this join.

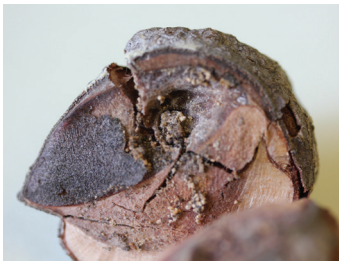
A minimum of 200 eggs should be released per site, though more is preferable.

The seed moth has been released into a number of sites in the Western Cape province. It is however not as widespread as the seed weevil due to its slow population growth. It is therefore necessary to release the moth into as many sites as possible.

Seed moth release technique.

Indication of presence

The only indication is an exit hole (approx. 2mm in diameter) in the side of a mature fruit. Otherwise an attacked fruit is indistinguishable from healthy fruit. To determine the presence of the seed moth, remove all fruits from a number of trees (20 trees), or a sample of fruits (100+), and then inspect them for exit holes using a magnifying glass. Also allow the removed fruit to dry and open (2–4 days), eaten seed is a sure indication of the seed moth's presence.



Remains of eaten seed within fruit.

Exit hole in old fruit, a wire can be pushed through the fruit wall from exit hole to seed cavity.

Stem-boring beetle

use for  

Collection procedure

The technique used for collecting the stem-boring beetle is fairly simple but labour intensive. Silky hakea plants infested with the beetle are easily recognisable due to the presence of sawdust (frass) at the base of the plant. This sawdust is ejected by the mature larvae from the tunnels made by them.

Rock hakea plants infested with the beetle have thickening and malformation of the stem.

- Silky hakea plants identified as being infested with beetles are cut down approximately 8cm above the ground in October and November. The stump and roots of each plant are dug out using a small pick and placed individually in plastic packets to prevent them drying out until returning from the field.
- Infested stems of rock hakea should be sawn off, leaving 10cm of stem on both sides of the swelling.
- The stumps or stems should then be kept in insect cages until the adults emerge. The cages should be inspected daily for emerging adults, which need to be placed individually in small plastic containers and released on silky hakea plants in the field. The plastic containers must have a mesh lid. Place some crumpled-up paper inside each container.
- The adults must be kept separately because they are cannibalistic when kept together in a confined space.
- Adult emergence is from the end of November to the end of February.

Removing a silky hakea plant containing larvae (arrow) of the stem-boring beetle.

Larvae of the stem-boring beetle, and silky hakea stems with stem boring-beetle larvae inside their tunnels are kept in individual muslin bags in insect cages, and regularly inspected for emerged adults.

Implementation procedure

Between 20 and 50 adults can be released at each site. Very little is known about the dispersal ability of the beetles and it is recommended that the beetle be released into as many sites as possible.

The stem-boring beetle has been released into a number of sites in the Western Cape province, but is not yet widespread due to its slow population growth. This insect is not yet available for widespread implementation.

Indication of presence

Silky hakea plants infested with the beetle are easily recognizable due to the presence of frass (sawdust + faeces) at the base of the plant. The bases of the stems also have characteristic thickening due to the formation of scar tissue.

Rock hakea plants infested with the beetle have swollen and twisted stems anywhere along the stems.

Stem damage and frass (arrow) at the base of silky hakea plants indicating larval activity.

Thickening and malformation of the stem of a rock hakea plant indicating larval activity, and tunnels within a stem.

Bud weevil

Collection procedure

The method used to collect this agent is the same as that used to collect the seed weevil (see page 35). The best time to collect the bud weevil is in May before the adults lay their eggs on silky hakea.

Implementation procedure

The release technique is the same as that of the seed weevil (see page 36). This insect has only recently been released and is not yet available for implementation.

Indication of presence

The damage caused by the bud weevils is not readily visible. The best indicator is the presence of the adults, obtained by beating trees. The larvae “glue” the flowers of the inflorescence together, which then do not open properly as a result.

Leaf weevil

Collection procedure

The collecting method is the same as for the seed weevil (see page 35) and the bud weevil (above).

Implementation procedure

The release technique is the same as for the seed weevil (see page 36).

Indication of presence

Look for hollowed-out leaves with tip die-back and scarred, wilted growth tips.

Monitoring after release

Monitoring is essential to confirm that the biological control agents have established after introduction, as well as having spread, in the years following any release(s). The signs to look for on the plant can be found in the "Indication of presence" section under each agent. The data collected during monitoring feeds into decision making for future control efforts.

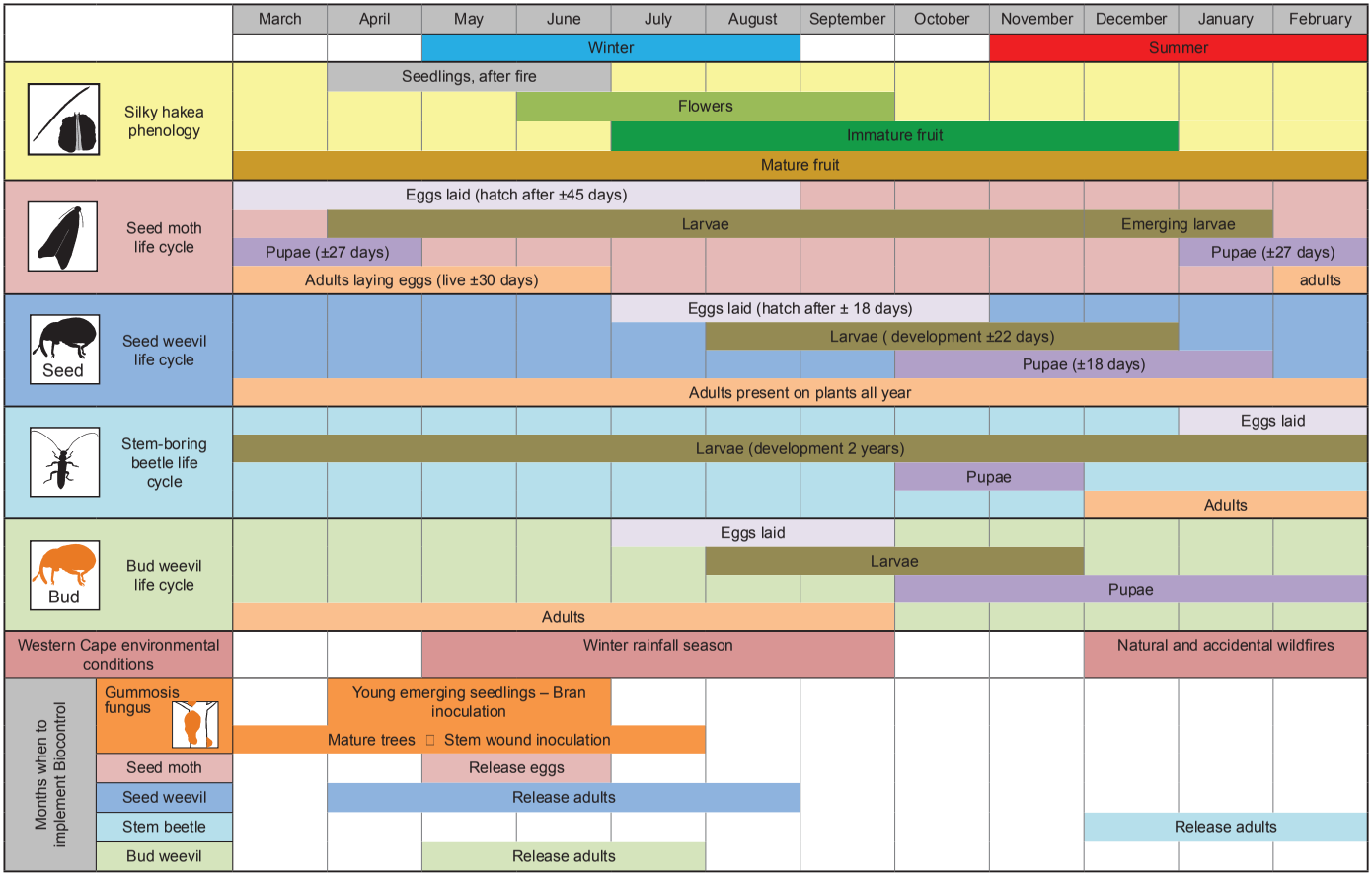
In general, a monitoring protocol should cover the following aspects:

- Monitoring should be done regularly, at least once per year.
- Monitor whether an agent has established where it was released.
- Monitor each stand of hakea in at least 3 places, at least 50m apart in smaller stands and 200m apart in large stands, to determine which agents are already present in that stand.
- Spend a minimum of 10 minutes at each monitoring point, and examine as many individual trees as possible in that time.
- The best time for monitoring the weevils is when they are active on the plants as adults, in May to June. The easiest method is to place a light-coloured ground sheet under a tree and beat the trees to dislodge any weevils onto the ground sheet where they can be easily seen.
- The presence of the seed weevil can also easily be determined by the presence of fruit husks.
- Adults of the seed moth and stem-boring beetle are not easy to find in the field and signs of their presence need to be looked for. The seed moth can be monitored throughout the year and the stem-boring beetle during October/November.
- Record the absence or presence of the agent, and damage caused, during each sampling period.
- Sampling should be conducted at the release site. To determine the spread of the agents, it is also necessary to sample the sites where the agents may have spread to in nearby stands of the weed.

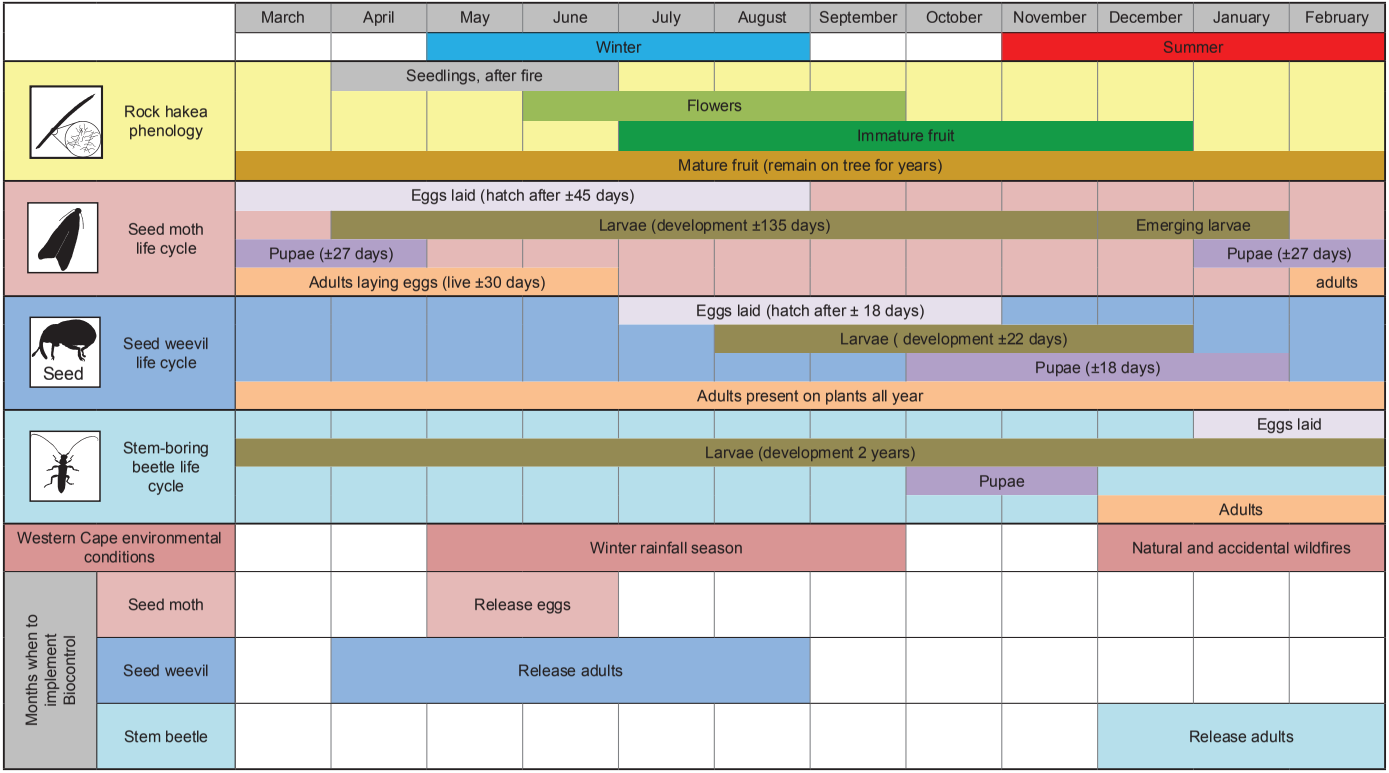
A pullout sheet is provided, which can be used in the field to help with identifying the hakea species present, as well as signs of the biological control agents present.

Target weed	Biological control agent	Main feeding guild	Agent status and damage to weed
Silky hakea 	Seed weevil 	Immature seed feeder	Released 1970. Can destroy most of the seed production on plants, thereby greatly reducing regeneration after fires. Most important agent.
	Stem-boring beetle 	Stem borer	Released 2001. Mechanically damages trees where established. Currently being spread by DEFF:NRMP and ARC-PHP.
	Seed moth 	Mature seed feeder	Released 1970. Slow to establish.
	Bud weevil 	Flower bud feeder	Released 2006. Not yet widely distributed.
	Leaf weevil 	Leaf & shoot borer	Released 1979. Low levels of damage to seed. A low priority for introduction.
	Gummosis fungus 	Stem gummosis disease	Naturally occurring. Has been observed to cause more than 50% mortality in stands, but impact variable. Available from ARC-PHP.
Rock hakea 	Seed weevil 	Immature seed feeder	Released1975. Low levels of damage to seed. Useful but a low priority for introduction.
	Stem-boring beetle 	Stem borer	Released 2004. Mechanically damages trees where established. Currently being spread by DEFF:NRMP and ARC-PHP.
	Seed moth 	Mature seed feeder	Released 2014. Slow to establish. Currently being spread by DEFF:NRMP and ARC-PHP.

Summary of the biological control agents available against silky hakea and rock hakea. See Chapter 3 for their identification.



Life cycle and timing of releases of biological control agents in relation to silky hakea phenology and environmental conditions.



Life cycle and timing of releases of biological control agents in relation to rock hakea phenology and environmental conditions.

Chapter 5: Additional information

Internet resources

Fact sheets of alien invasive weeds, and the biological control agents released for use against these, are available online at:

http://www.arc.agric.za/arc-ppri/Pages/Weeds%20Research/Fact-Sheets-on-Invase-Alien-Plants-and-their-Biological-Control-Agents.aspx

Fact sheets are available for silky hakea, rock hakea, hakea seed weevil, hakea seed moth, hakea stem-boring beetle, and the silky hakea gummosis fungus.

Further information on alien invasive weeds in South Africa and biological control in general are available online at:

http://www.arc.agric.za/arc-ppri/weeds/Pages/default.aspx

https://www.environment.gov.za/projectsprogrammes/wfw/biocontrol

http://www.capenature.co.za/care-for-nature/conservation-in-action/integrated-catchment-management/alien-vegetation-management/

http://www.capenature.co.za/care-for-nature/stewardship/

For international data sheets on silky hakea as an invader, see:

http://www.cabi.org/isc/datasheet/27302

http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=27302

https://gd.eppo.int/taxon/HKASE

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For general information on invasive alien organisms in South Africa, see:

http://www.invasives.org.za/

For information on emerging weeds, see SANBI's Invasive Species Programme:

https://www.sanbi.org/biodiversity/building-knowledge/biodiversity-monitoring-assessment/invasive-species-programme/

http://www.sanbi.org/information/infobases/invasive-alien-plant-alert

For information on hakea species in Australia, see:

http://www.anbg.gov.au/gnp/gnp3/hakea-sericea.html

http://plantnet.rbgsyd.nsw.gov.au/

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Glossary

NEM:BA = The National Environmental Management: Biodiversity Act (Act No 10 of 2004).

WfW = Working for Water Programme of the Department of the Environment, Forestry and Fisheries: Natural Resource Management Programmes

ARC = Agricultural Research Council

PHP = Plant Health and Protection (formerly Plant Protection Research Institute)

Notes:

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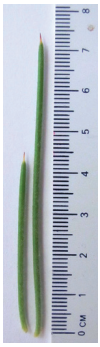
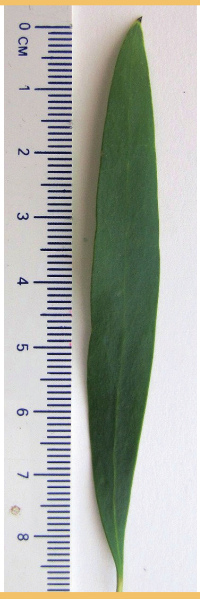
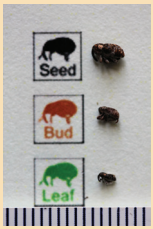
Silky hakea	Rock hakea	Sweet hakea	Willow hakea
			
	 × ½ life size 	× ¼ life size 	
➤ leaves needle like ➤ ≤40 × 1mm ➤ smooth	➤ leaves needle like ➤ ≤80 × 1mm ➤ shortly hairy	➤ leaves divided into paired needles	➤ leaf like
			
➤ 25–30 × 20–25mm ➤ round with 2 horns at apex	➤ 30 × 35mm (broader than long) ➤ round with 2 horns at apex	➤ 25 × 20mm ➤ oval with dark markings	➤ 20 × 15mm ➤ oval with prominent warts

Comparison of the invasive hakea species in South Africa.

Gummosis fungus	Seed weevil	Stem-boring beetle
 Gum oozing from stem	 Husks of undeveloped fruit on tree	 Frass at base of stems
Seed moth	**Bud weevil**	**Leaf weevil**
No visible signs. Harvest mature fruit, allow to open, and examine for seed eaten by larvae.	No visible signs. Beat trees – as for collecting adult.	No visible signs. Beat trees – as for collecting adult.

Signs of presence of each biological control agent that can be seen in the field.

	Seed weevil	Bud weevil	Leaf weevil
All are small round beetles with a prominent down-curved snout. 	 	 	 
Size	4–5mm long —— (actual size)	2–3mm long — (actual size)	1.5–2mm long – (actual size)
colour	mottled grey, black and red-brown	dull-brown	dark with a pair of white spots on their wing covers (arrow)

Comparison of the three weevil biological control agents.

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