Hakea sericea *young and ripe fruits. © Edoarado. CC BY-SA 3.0.*

The management of silky hakea (*Hakea sericea*)

Measures and associated costs

Scientific name(s)	*Hakea sericea* Schrad. and J.C. Wendl *sensu* Paiva (1997) (that is incorporating *Hakea decurrens* R.Br.). See the EPPO Pest Risk Assessment (in review) for further taxonomic detail.
Common names (in English)	Silky hakea
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Summary of the measures, emphasizing the most cost-effective options.

Hakea sericea is already present in the wild in the EU territory (Portugal, Spain and France) and the only pathway of introduction identified by the Pest Risk Assessment (PRA) was plants for planting. Therefore, the most cost-effective option to *Prevent the intentional introduction* of *H. sericea* into Member States (MS) where it is absent, and its spread in MS where it is present, will be banning its importing, breeding, transporting, selling, exchanging, growing and releasing in the environment within and into the EU.

The PRA does not identify other pathways of introduction apart from plants for planting. Additionally, unintentional introductions and spread of seeds as soil contaminants into MS where it is absent is not expected because *H. sericea* accumulates a canopy seed bank (such as, not in the soil), seeds are relatively big and most germinate in the following months after being released from the fruits, not accumulating in the soil. Nevertheless, citizens may introduce the species unaware of its identification or invasive potential, and so a public awareness campaign is proposed to *Prevent unintentional introduction and spread*. This may be combined with campaigns included in other *Preventions* and *Surveillance* sections or in general Invasive Alien Species awareness campaigns or activities existing in the MS.

Hakea sericea accumulates a canopy seed bank (not a soil seed bank; this is a fire adaptation – serotiny). After the death of a plant or branch, typically through fire but not exclusively, the fruits release their winged seeds, which germinate in the following months, at distances that can be of the order of tens of metres, but sometimes up to a kilometer or more. Therefore, fire and forestry interventions not directed to the control of *H. sericea* (for example, prescribed burning, regular forestry operations, preventive forestry interventions, road and railway maintenance, fire prevention/defense interventions, etc., such as, interventions that kill or dry the trees or branches and consequently promote the release of seeds), and which are unaware of the presence, invasiveness or ecology of the species, may further spread the species. In this context, in order to prevent secondary spread, awareness campaigns and/or training need to be implemented that target entities or stakeholders responsible for forestry interventions and fire prevention in MS where the species is present, namely public or private forest owners, forest associations, conservation entities, road and rail maintenance companies, etc. Fire prevention activities in general may also be beneficial for the prevention of secondary dispersal of this species.

Since *H. sericea* was used for apiculture, landscaping (hedging) and horticultural (ornamental) purposes, this species should be included in the MS Surveillance systems (existing or under development) considering these pathways of introduction. Surveillance needs to be done in MS included in the PRA endangered area: suitable areas for establishment of *H. sericea* in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions include Portugal (and the Azores and Madeira), and parts of France (and Corsica), Greece, Italy (and Sardinia), Spain (and Balearic Islands) and coastal areas of the Adriatic Sea (Croatia and Slovenia); areas with marginal suitability include the Netherlands, Belgium and Britain. Special attention should be given to surveillance in areas where there is a high risk the species may be introduced, for example, nurseries and gardens; or invade, for example, low nutrient (especially low P) soils and schistose bedrock, habitats where it is common where already established, including disturbed areas, particularly road margins or disturbed forests, and burned areas (since fire may promote its spread where it is present unnoticed), and especially in MS where it is already present. Surveillance measures may include surveys by trained staff or stakeholders and be complemented by additional methods and technologies such as remote sensing, modeling and citizen-science.

For *Rapid eradication* for new introductions, an integrated control methodology approach is necessary. Assuming an early stage of invasion, all young plants should be hand-pulled. Plants that are too big to be hand-pulled should be cut; although not frequent, trunks cut too high may re-sprout and so care should be taken to cut trunks as close to the soil as possible. If plants are bearing fruits (it must be kept in mind that 1-3 years after germination the next generation of plants can produce seeds), they should be eliminated immediately since fruits start opening and releasing the seeds after two days or less following the death of the branch or tree, or following drought conditions. If there are only a few plants, and this is viable, fruits may be incinerated, or plants buried or burned in a confined area. If plants are too many, or this option is not viable, they can be left in the ground to open the fruits and release the seeds and follow-up control is necessary, 12-18 months after removal: plants that germinate may be hand-pulled (for example, involving volunteers when possible), shredded, cut mechanically or grazed (for example, with goats). In the case of larger infestations, the most successful method for the control of *H. sericea* in South Africa has been the 'fell and burn' technique, where adult plants are cut down and left for 12-18 months before they are burnt through prescribed burning. This allows time for seed germination, meaning that the follow-up burn additionally destroys seedlings before they become reproductively mature.

One or two follow-up operations are necessary after the burn to eradicate any regenerating or re-sprouting plants. Alternatively to burning, germinated plants may be hand-pulled (for example, involving volunteers when possible), shredded, cut mechanically or grazed (for example, with goats) as in smaller areas.

For extensively invaded areas for which eradication is no longer an option, *H. sericea* populations need to be managed and controlled. As for eradication, an integrated control methodology may be used for management of this species, with methods being combined and selected according to the context. Methods used are the same as identified for eradication and in addition chemical and biological control (bio-control) may be used. Chemical control has not played a large role in the control of *H. sericea* in South Africa, as it can have a negative effect on native vegetation; in Portugal results were variable and inconclusive. In the EU no bio-control agent is yet available against *H. sericea,* while in South Africa a biological control programme against this species was initiated in 1962 and is ongoing with six agents being used. Although with some caveats, the economic benefits of preventing invasion due to the use of bio-control was estimated to be ZAR 3,410/ha/yr for *H. sericea* (values are discounted to the year 2000; ca. € 145/ha/yr) with a benefit: cost ratio of 251:1, considering benefits due to streamflow, land value and biodiversity, and costs of bio-control research.

There are gaps in information mostly of costs, cost-effectiveness and economic analysis of the different measures, particularly *Prevention* and *Surveillance*, but at all sections, which could facilitate understanding and decisions by public and private decision-makers. As much as possible, all interventions of management should monitor operational effectiveness (success in achieving control, eradication, detection and prevention of *H. sericea*) and outcomes (success in protecting biodiversity or other values), and also resources involved in the measures in order to build a growing database with information that can improve the way *H. sericea* is managed. This information should be published and shared with all MS.

Measures for preventing the species being introduced, intentionally and unintentionally.

This section assumes that the species is not currently present in a Member State, or part of a Member State's territory.

A ban on keeping, importing (pre-border measure), selling, breeding and growing as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *H. sericea*.

MEASURE DESCRIPTION

Hakea sericea is already present in the wild in the EU territory in Portugal, Spain and France (Ducatillion *et al.*, 2015; Marchante *et al.*, 2014; Pulgar Sañudo, 2006). The only pathway of introduction identified by the Pest Risk Assessment (PRA) was plants for planting (EPPO, 2017). Therefore, banning its importing, keeping, breeding, transporting, selling, exchanging, growing and releasing in the environment within and into the EU may prevent introduction into Member States (MS) where it is absent and further spread in MS where it is present.

Mostly in the past, the species has been used as an ornamental, for hedging, land reclamation (Marchante *et al.*, 2014) and honey production (Vieira, 2002). Although the species is already banned from breeding, keeping, using as ornamental, selling, buying and transporting in Portugal through Decreto-Lei nº 565/99 (Ministério do Ambiente, 1999), it is still available on other MS, for example, it is available at least from one ornamental supplier in the UK (https://www.rhs.org.uk/Plants/Nurseries-Search-Result?query=125445) and is also available via mail order from Australia (for example, from https://www.ebay.com/itm/HAKEA-SERICEA-pink-Silky-Hakea-10-seeds/232766134764?hash=item3631f159ec:g:~XUAAOSw9NdXt7gD), which may result in further introductions and spread.

If possible, operational effectiveness and outcomes (success in preventing new invasion foci) and resources involved should be monitored in order to build a growing database with information that can improve prevention on intentional introductions of *H. sericea*. This information should be published and shared with all MS.

EFFECTIVENESS OF MEASURE

Effective.

Despite being occasionally found listed by ornamental suppliers, there is no strong evidence that the species is commonly imported into the EU for horticultural purposes. However, the above measures still need to be implemented by all MS in order to be effective, preventing both introduction and further spread inside MS. To be effective, pre-border restrictions need to rely on high compliance of the stakeholders (Hulme *et al.*, 2018), but some studies in the USA show that regulation alone is not effective at reducing trade (Diaz *et al.*, 2012) and needs to be combined with education and awareness campaigns in order to improve compliance (Oele *et al.*, 2015). On the other hand, post-border sales bans become progressively less effective when the species is widespread in a region (Hulme *et al.*, 2018). In this context, this measure can be most effective in preventing the intentional introductions into MS where it is not present (complemented with efforts to ensure compliance), but in MS where the species is present and widespread, this measure may be less effective in preventing further spread, despite potentially being able to slow down its progress. For example, in Portugal, the species has been banned since 1999 (Decreto-Lei nº 565/99), but the species continues to spread by natural spread, frequently associated with fires (Marchante *et al.*, 2014).

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

No environmental or social side effects are expected. As for economic, although the species can be used as ornamental, there is no evidence of the species being commonly in trade and therefore such a ban on selling is not expected to have a significant negative effect.

ACCEPTABILITY TO STAKEHOLDERS

The species may be used as ornamental, for fencing or honey production (Marchante *et al.*, 2014; Vieira, 2002), but there is no strong evidence that the species is commonly imported into the EU (currently) for horticultural or other purposes and there is no available information allowing the quantification of these uses. As far as it is known, these uses

are not significant in the MS where it is present (ornamental and fencing are mostly historical uses, at least in Portugal) and the negative impacts of its invasion far exceed the positive effects and therefore its ban would most probably be easily accepted by stakeholders.

In Portugal, the species is valued by beekeepers because it flowers in the winter (in the northern hemisphere) when there are few species flowering (bees most probably use more nectar than pollen), but flowers are short-lived and when the species invades, it eliminates the other species used by bees, eliminating sources of nectar or pollen available the rest of the year (M. Maia, APISMAIA – Beekeeping Services, pers. comm., 2018). As such, although valuing its presence, beekeepers are most probably supportive of this or other measures intended to prevent *H. sericea* (M. Maia, APISMAIA – Beekeeping Services, pers. comm., 2018), although some beekeepers may prefer to keep some plants flowering in the winter (Pedro Mendonça, Cooperativa Terra Chã (includes beekeeping projects, pers. comm., 2018). *Hakea sericea* is normally considered pernicious by other stakeholders (public or private forest owners, forest associations, conservation entities, road and rail maintenance companies, etc.) and as such it is anticipated that they would accept measures that contribute to preventing its further spread.

ADDITIONAL COST INFORMATION

Prevention is widely accepted as highly **cost-effective** compared with other management measures (IUCN, 2018). A recent study shows that perfect prevention is neither feasible nor cost-effective, but investing in prevention efforts nonetheless provides benefits by reducing the likelihood of invasion and delaying impacts, thereby reducing expected damages (Epanchin-Niell, 2017).

Costs associated with the **implementation** of this measure for *H. sericea* are not available, but if these bans are to be part of general biosecurity policy and measures for comparable species of Union concern, for example, plants used for landscaping or horticulture, the resources and costs will be further reduced. Costs of compliance and implementation may differ across MS as technical know-how, biosecurity facilities, climate suitability, etc. are different across the EU.

Costs of inaction are also not available for this species, but considering the substantial negative impacts it promotes (see references above and EPPO, 2017) and that, according to the PRA, the endangered area includes MS in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions (EPPO, 2017), inaction will most probably result in the spread and establishment of the species in more MS with consequent **environmental, social and economic** negative impacts.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There are a limited number of studies about application, effectiveness, acceptability, costs etc. of the measures proposed, but the ones that are available generally agree.

1 See Appendix

Public awareness raising campaigns to reduce unintentional movement of seeds of the species.

MEASURE DESCRIPTION

The PRA has not identified further pathways on introduction apart from plants for planting (EPPO, 2017), which is dealt in the previous section (*Prevention of intentional introductions and spread*). Additionally, un-intentional introductions and spread of seeds as soil contaminants into MS where it is absent is not expected because *H. sericea* accumulates a canopy seedbank (such as, not in the soil), seeds are relatively big, and most germinate in the following months after being released from the fruits (Richardson and van Wilgen, 1984; Richardson, Wilgen, and Mitchell, 1987), not accumulating in the soil. The plant is not easily confounded with other European native or ornamental species and as such it is not expected that it can be unintentionally introduced due to misidentification.

Nevertheless, citizens unaware of its identification and invasion potential may eventually introduce the species, for example, collecting it somewhere in the wild or even buying/getting it in areas that do not comply with bans. Therefore, although no specific measures are proposed to prevent unintentional introductions and spread, considering the introduction into MS where it is absent, a public awareness campaign is proposed. This measure is to be combined with campaigns already included in other *Preventions* and *Surveillance* Sections of this document and may also be included in general Invasive Alien Species awareness campaigns or activities existing in the MS, reducing resources required for implementation.

Hakea sericea is morphologically quite distinct and can be easily identified in most stages of its life cycle (when seedling or sapling it may be confused with pines), and the characteristic spiny leaves help it to be quite impressive. Therefore, people can memorise it with relative ease and identify it if they find it. If they are aware of its invasive potential and risk, it is expected that they will not introduce it unintentionally (as they might if unaware of its identification or risk). Available information needs to include clear photographs and identification characteristics, as well as the ecology and control of the species, along with the risks. Information produced (or re-used) may be shared widely via online, printed leaflets, talks, training workshops, social media, traditional media, etc. In Portugal, much info is already available (for example, http://invasoras.pt/gallery/hakea-sericea/) and the species is already included in many public awareness activities (Marchante and Marchante, 2016).

If possible, operational effectiveness and outcomes (success in preventing new invasion foci) and resources involved should be monitored in order to build a growing database with information that can improve prevention on unintentional introductions of *H. sericea*. This information should be published and shared with all MS.

SCALE OF APPLICATION

All MS in the endangered area: suitable areas for establishment of *H. sericea* in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions include Portugal (and the Azores and Madeira), and parts of France (and Corsica), Greece, Italy (and Sardinia), Spain (and Balearic Islands) and coastal areas of the Adriatic Sea (Croatia and Slovenia); areas with marginal suitability include the Netherlands, Belgium and Britain (EPPO, 2017). .

EFFECTIVENESS OF MEASURE

Effective.

Although the measure is expected to be effective, there is a relatively low-risk of unintentional introductions.

EFFORT REQUIRED

Prevention of unintentional introductions needs to be done indefinitely or until the species is considered of no risk to the EU.

RESOURCES REQUIRED

Production and sharing of info about *H. sericea*, namely online info, printed leaflets, talks, training workshops, social media, traditional media, etc. In Portugal, much info is already available (for example, http://invasoras.pt/gallery/hakea-sericea/) and the species is already included in many public awareness activities (Marchante and Marchante, 2016) which may reduce resources needed. Additionally, resources may be further reduced if activities and material are shared with campaigns proposed in other *Prevention* and *Surveillance* sections, and activities underway to raise awareness about Invasive Alien Species in general. Although there is no specific information available, general information on the cost of awareness raising campaigns for invasive alien plants can be found, for example, in LIFE projects on invasive alien plants (http://ec.europa.eu/environment/life/project/Projects/) or in Marchante and Marchante (2016), which includes rough estimates of costs for different types of IAS awareness activities and approaches in Portugal.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

No significant side effects expected in Environmental, Social or Economic level. Nevertheless, if the campaign is not exclusive for *H. sericea* and includes other IAS, this measure can have positive effects in the prevention of other IAS.

ACCEPTABILITY TO STAKEHOLDERS

See section *Prevention of intentional introductions and spread.*

ADDITIONAL COST INFORMATION

See section *Prevention of intentional introductions and spread.*

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Not much info available, but not contradictory. Other possible measures to prevent the unintentional introduction of *H. sericea* need to be identified through a comprehensive analysis of its pathways of unintentional introduction and spread within the territory of the European Union.

1 See Appendix

Measures to prevent the species spreading once they have been introduced.

Awareness campaigns for forestry interventions and fire prevention.

MEASURE DESCRIPTION

Since *H. sericea* accumulates a canopy seedbank and most seeds rapidly germinate after being released from the fruits (Richardson and van Wilgen, 1984), therefore secondary spread of the species through seeds as contaminants is not expected. However, fire is a key part of the life cycle of *H. sericea*, with the heat-resistant fruits accumulating on a plant throughout its lifetime (Brown and Whelan, 1999). After plant death, typically through fire but not exclusively, the fruits release their seeds (Bradstock, 1991). Fruits in dead trees (for example, after clearing operations), dead branches (for example, broken or partial cut) or subjected to drought or heat can also release seeds (Marchante, pers. comm., 2017). Fire is an important ecological driver in many habitats, including in the Mediterranean climate which is part of the endangered area (EPPO, 2017). In this context, fire and forestry interventions not directed to the control of *H. sericea* (for example, prescribed burning, regular forestry operations, preventive forestry interventions, road and railway maintenance, fire prevention/defence interventions, etc., such as, interventions that kill or dry the plants or branches and consequently promote the release of seeds), and which are unaware of the presence, invasiveness or ecology of the species, may further spread *H. sericea*. Because of the winged seeds, dispersal distances can be in the order of tens of meters, but up to one km or more (Richardson *et al.*, 1987) and as such, one single plant may invade a large area (in the native range each plant is referred as accumulating around 1,600 seeds (Brown and Whelan, 1999), but in the invaded range values range from around 52,000 seeds in end-of-life plants (Ducatillion *et al.*, 2015), which are not common in invaded areas, to 7,500/m^2 in ash beds following a fire (Kluge, 1983). As such, in order to prevent secondary spread (post-establishment spread of the species in MS where it is present) awareness campaigns and training need to be implemented, targeting entities and stakeholders responsible for forestry interventions and fire prevention in MS where the species is present, namely public or private forest owners, forest associations, conservation entities, road and rail maintenance companies, etc. Forest fire defence strategies in general may also be beneficial for the prevention of secondary dispersal of this species, as they decrease the chance of fire occurrence.

Campaigns may include training about the identification, ecology and control of *H. sericea*, targeting the stakeholders referred to above, public talks, leaflets and online materials with information (for example, identification guides/factsheets, codes of conduct), social media, identification workshops, etc. Whenever possible, these activities may be included in the surveillance system of invasive alien species and existing fire prevention campaigns, forestry codes of conducts, invasive species campaigns, etc., therefore reducing costs.

If possible, operational effectiveness and outcomes (success in preventing new invasion foci) and resources involved should be monitored in order to build a growing database with information that can improve prevention of secondary spread of *H. sericea*. This information should be published and shared with all MS.

SCALE OF APPLICATION

These measures need to be implemented at national level in MS where the species is already present, namely France, Portugal and Spain and other(s) where the species may be later detected.

EFFECTIVENESS OF MEASURE

Effective.

The species accumulates a canopy seedbank and fruits release the seeds when the plant dies (frequently with fire but also after cutting), or when branches are cut or dry out. One single tree has the potential to invade a large area if seeds are released. Consequently, preventing actions that kill the trees (outside of a specific eradication or control programme), such as fire, or cut branches (without subsequently controlling seed dispersal/germination) will be a major contribution to prevent secondary spread of the species. Nevertheless, in fire prone climates and ecosystems, fire cannot be totally prevented, and this will decrease the effectiveness of this measure (or others) to prevent secondary spread.

Hakea sericea *in the Botanischer Garten, Berlin-Dahlem. © 'Krzysztof Ziarnek, Kenraiz. CC BY-SA 4.0.*

The effectiveness of awareness campaigns can be highly variable but may be more effective when targeting specific (and engaged) audiences and when actions are "hands-on" and not limited to leaflets or other information materials (Marchante *et al.*, 2017); short-term training and efforts to include the information in professional curricula of the target stakeholders identified, for example forest associations, may make the measure more effective.

EFFORT REQUIRED

These measures need to be maintained indefinitely (or until the species is considered of no risk to the EU) in MS where the species is already present, namely France, Portugal and Spain and other where the species may be later detected.

RESOURCES REQUIRED

Costs associated with targeted awareness campaigns Include staff time associated with training and awareness raising activities, printed and online information (leaflet, factsheets, etc.), etc. There is no estimation of costs for this specific measure, but it can be included in existing fire prevention campaigns, forestry codes of conducts, invasive species campaigns, existing curricula and short-term training, etc. therefore reducing the costs. It can also be combined with other public awareness schemes discussed in other sections of this report. The UK Government spends ca. GBP 90,000 per year (since 2008) on its invasive species awareness raising activity, including running two targeted campaigns Be Plant Wise and Check Clean Dry, training activities, public attitude surveys, and a website (GB NNSS, 2017).

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Positive
This measure may have positive effects in fire prevention policies and improve forestry interventions in general and as such may have positive environmental, social and economic effects.

ACCEPTABILITY TO STAKEHOLDERS

See section *Prevention of intentional introductions and spread.*

ADDITIONAL COST INFORMATION

See section *Prevention of intentional introductions and spread.*

LEVEL OF CONFIDENCE[1]

Established but incomplete.
There are a limited number of studies about application, effectiveness, acceptability, costs etc. of the measures proposed, but the ones available agree in general.

1 See Appendix

Measures for early detection of the species and to run an effective surveillance system to detect efficiently new occurrences.

Inclusion of this species in existing surveillance systems for invasive alien species – Physical targeted surveys by trained staff and volunteers.

MEASURE DESCRIPTION

Since *Hakea sericea* was used for apiculture, landscaping (hedging) and horticultural (ornamental) purposes (Marchante *et al.*, 2014; Vieira, 2002), this species should be included in existing surveillance systems (existing or under development) considering these pathways of introduction. This is applicable to MS included in the endangered area: suitable areas for establishment of *H. sericea* in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions include Portugal (and the Azores and Madeira), and parts of France (and Corsica), Greece, Italy (and Sardinia), Spain (and Balearic Islands) and coastal areas of the Adriatic Sea (Croatia and Slovenia); areas with marginal suitability include the Netherlands, Belgium and Britain (EPPO, 2017). Special attention should be given to surveillance in areas where there is a high risk of the introduction of the species, including nurseries, gardens, or where it can invade, for example, low nutrient (especially P) soils and schistose bedrock (Martins *et al.*, 2016), habitats where it is common in MS where it is already established, including disturbed areas, particularly road margins or disturbed forests (Marchante *et al.*, 2014), and burned areas (since fire may promote its spread), and especially in MS where it is already present.

Early detection, followed by *Rapid eradication* (next section), can detect and eradicate incipient populations of *H. sericea* before they establish (in a new MS or part of MS where it is absent), preventing costly and resource-intensive control programmes. When prevention fails, early detection and rapid eradication are the next and most cost-effective line of defence against invasive alien species (IUCN, 2018). Surveillance measures are used to support early detection and may include terrestrial land surveys (by foot or car) by trained staff or stakeholders, discussed in this section and be supported/complemented by additional methods/technologies such as remote sensing (Alvarez-Taboada, Paredes, and Julián-Pelaz, 2017), modelling (Martins *et al.*, 2016; Vicente *et al.*, 2016) and citizen-science (Cardoso *et al.*, 2017; Marchante *et al.*, 2017), discussed in the following sections.

Surveys may include systematic monitoring by staff and volunteers who are properly trained to identify the species, and awareness campaigns for public or private forest owners, forest associations, conservation entities, road and rail maintenance companies, general public, etc. Special attention should be placed in areas recently burned as the spread of *H. sericea* is frequently promoted when plants are killed by fire; if the species was present in small numbers may have passed undetected, but may increase substantially after fire.

Such approaches can be incorporated in existing surveillance schemes in MS, engaging citizens who can be trained and be a significant help in detecting the species, complementing surveys made by professionals, for example, of conservation and public agencies. In Australia, this proved to be efficient for other species, even when broad taxonomic skills are requested (Thomas *et al.*, 2017), and also in Croatia for *Ailanthus altissima* (Sladonja and Poljuha, 2018).

All invaded areas or single plants detected should be mapped in order to improve work of rapid eradication teams (section *Rapid eradication for new introductions*). Even after eradication measures, these areas need to be included in the Surveillance area in order to achieve complete eradication of populations detected at an early stage (this may be combined with follow-up monitoring). These surveys may be connected with awareness campaigns as described in the sections above, *Prevention of intentional introductions and spread* and *Prevention of secondary spread*.

MS should facilitate regional collaboration with all stakeholders to enable early identification of the species, including education measures to promote citizen-science, sharing of information on site specific studies of the plant, control techniques and management available, linking researchers, land managers, government departments, environmental non-governmental organisations, etc.

If possible, operational effectiveness (success in achieving detecting the species), outcomes (success in preventing new invasion foci), and resources involved should be monitored

in order to build a growing database with information that can improve surveillance of *H. sericea*. This information should be published and shared with all MS.

SCALE OF APPLICATION

Surveys would need to take place in all MS in the endangered area: suitable areas for establishment of *H. sericea* in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions include Portugal (and the Azores and Madeira), and parts of France (and Corsica), Greece, Italy (and Sardinia), Spain (and Balearic Islands) and coastal areas of the Adriatic Sea (Croatia and Slovenia); areas with marginal suitability include the Netherlands, Belgium and Britain (EPPO, 2017).

At a smaller scale, considering that *H. sericea* seeds are winged and dispersal distances can be on the order of tens of meters but up to one km or more (Richardson *et al.*, 1987) a buffer area of at least 1 km around the areas where *H. sericea* is known to be present should be surveyed for new undetected populations.

EFFECTIVENESS OF MEASURE

Effective.

Hakea sericea is morphologically quite distinct and can be easily identified in most stages of its life cycle (although when seedling or sapling, it may be confused with pines), so surveillance is expected to be effective. However, it will be difficult to survey all possible areas where the species may be introduced, establish and spread. Priority should be given to habitats and land uses more prone to invasion, in MS where *H. sericea* is already present, areas with low nutrient (especially P) soils and schistose bedrock (Martins *et al.*, 2016), burned areas, and disturbed areas.

While not specifically targeted at the early detection for eradication, the effectiveness of incorporating trained volunteers to support scientists has also been shown in Croatia, where a team of scientists and volunteers mapped the presence and impacts of the alien invasive tree *Ailanthus altissima* in urban and semi-urban areas of Porec, Croatia (Sladonja and Poljuha, 2018).

EFFORT REQUIRED

Surveillance needs to be done indefinitely or until the species is considered of no risk to the EU. Even if the species is declared eradicated in the EU (which is not probable considering the areas already invaded), new introductions can occur from outside.

RESOURCES REQUIRED

The species should be incorporated into existing surveillance systems, reducing the costs and efforts required. Nevertheless, resources include staff, training (staff and volunteers), travel costs, health and safety measures, etc. Species specific information (online and printed) also need to be produced. Considering that the main pathway of introduction identified was 'Plants for planting', nurseries and gardens staff should also be trained and informed. Resources needed may be reduced if shared with awareness campaigns proposed in the *Prevention* sections.

In terms of physical active surveys, costs can be reduced by using volunteers (following a training session on species ID and recording methods). Sladonja and Poljuha (2018) used a mix of trained scientists and citizens (62 people in total) using smartphones (with GPS data recording) to survey 100 km of roads and trails in urban and semi-urban areas of Porec, Croatia to map the presence of *Ailanthus altissima* (Sladonja and Poljuha, 2018).

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

Potential side effects include the discovery of other non-target IAS through the surveys, and increase awareness by the public supporting the surveys.

ACCEPTABILITY TO STAKEHOLDERS

See section on *Prevention of intentional introductions and spread.* Access to private land would need to be negotiated, but this risk could be addressed through public awareness raising activities.

ADDITIONAL COST INFORMATION

Although surveillance may be costly, greater surveillance intensity (for example, more visual surveys conducted to detect new populations) generally increases the probability of detecting invasions earlier, when their control is less costly and more likely to be successful (Epanchin-Niell, 2017), justifying a strong investment in surveillance.

Cost of inaction, **cost-effectiveness** and **socio-economic aspects** are not available for this species and measure but considering the impacts it can have (see references above and EPPO, 2017) and that according to the PRA the endangered area includes MS in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions (EPPO, 2017), inaction will most probably result in the spread and establishment of the species in more MS with consequent environmental, social and economic negative impacts.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is some info available about surveillance although costs are not much quantified.

1 See Appendix

Remote sensing and modelling.

MEASURE DESCRIPTION

For the general text on surveillance measures see *Physical survey* section above.

Alvarez-Taboada *et al.* (2017) used Unmanned Aerial Vehicle (UAV/drone) and orbital platforms (WorldView-2: WV2) to map the distribution of *H. sericea*. Although this approach was not meant to be used for the early detection of small populations, it can be refined and used as a starting point to search for small undetected populations. This can be complemented with modelling, as shown by Martins *et al.* (2016), who identified environmentally suitable areas for *H. sericea* in both Portugal and Spain, which may be prioritised for surveillance.

SCALE OF APPLICATION

Alvarez-Taboada *et al.* (2017) used the UAV/drone to map an area of approximately 160 ha, during two separate flights, and the WV2 imagery covered almost 2550 ha.

EFFECTIVENESS OF MEASURE

Neutral.

Alvarez-Taboada *et al.* (2017) found that this combined UAV-WV2 method produced accurate maps of the species distribution within their study area, with ommission and commission errors smaller than 10% and 30%, respectively, which is sufficient for its operational implementation to create maps for locating and monitoring *Hakea sericea* in the north of Portugal. However, **they stress that results obtained in this paper are not meant to be used for the early detection of a small, nascent population of *Hakea sericea***. They also cite that the use of high resolution spatial data has been successfully used for detecting or monitoring other invasive alien species.

EFFORT REQUIRED

The selection of satellite imagery needs to take into consideration the species' flowering period (winter), so the spectral signature is easier to identify.

RESOURCES REQUIRED

Recent satellite imagery, modelling and analysis software and expertise, and access to a UAV/drone along with a trained pilot.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

Potential environmental side effects include the discovery of other non-target IAS through the surveys. However, despite the advantages of using drones, some mixed effects may arise because drones raise security and invasion of privacy issues (social effect) and may have unintended effects on wildlife (environmental effects, for example, Ditmer *et al.*, 2015).

ACCEPTABILITY TO STAKEHOLDERS

See section on *Prevention of intentional introductions and spread.* Some stakeholders may object to drones flying over private land due to privacy concerns. Also, different MS will have different legal restrictions on where and when drones can be flown. Access to private land would need to be negotiated, but this risk could be addressed through public awareness raising activities.

ADDITIONAL COST INFORMATION

Use of remote sensing may reduce costs of extensive field campaigns. Depending on the imagery used (type of satellite or UAV), costs and advantages/disadvantages can be quite variable (see, for example, Müllerová *et al.*, 2017).

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is some info available about remote sensing as a surveillance measures, although more information is needed on its application for early detection.

1 See Appendix

Citizen-science.

MEASURE DESCRIPTION

Inclusion of this species in existing surveillance systemsfor invasive alien species – Citizen-science platforms (targeted and general surveys).

For the general text on surveillance measures see *Physical targeted survey* section above.

Citizen-science platforms that are European wide (Invasive Alien Species in Europe app; http://digitalearthlab.jrc.ec.europa.eu/app/invasive-alien-species-europe), or within MS such as in Portugal (http://invasoras.pt/ (which already includes *H. sericea*); (Marchante *et al.*, 2017)) and Spain (http://www.eeiko.es/) gather citizen sightings on location data of invasive species distribution. Citizen-science programmes can be broad general surveillance, or species specific 'alert' systems and can incorporate both general public and highly skilled amateurs (Pescott *et al.*, 2015; Roy *et al.*, 2015). They can be linked to species specific activities or campaigns, such as Sladonja and Poljuha (2018) used for *Ailanthus altissima* (see section above).

In Europe there are several smartphone Apps for recording IAS (Adriaens *et al.*, 2015) and these may also be directed to early detection. The COST Action network ALIEN CSI (Citizen Science Investigate) aims to increase understanding of alien species through citizen-science; this Action started in 2018 and involves more than 30 countries (http://www.cost.eu/COST_Actions/ca/CA17122), further increasing the potential for using citizen-science in this context. Additionally, in some MS, ongoing citizen-science activities, such as the production of national Atlases and Floras, already provide nationwide general botanical monitoring, for example, Vigie-Flore in France, the BSBI and the NPMS in the UK (Pescott *et al.*, 2015) further showing that citizen-science does have potential for this purpose in the EU.

These surveys need to be connected with awareness campaigns discussed in the sections above, *Prevention of intentional introductions and spread* and *Prevention of secondary spread*.

SCALE OF APPLICATION

All MS in the endangered area: suitable areas for establishment of *H. sericea* in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions include Portugal (and the Azores and Madeira), and parts of France (and Corsica), Greece, Italy (and Sardinia), Spain (and Balearic Islands) and coastal areas of the Adriatic Sea (Croatia and Slovenia); areas with marginal suitability include the Netherlands, Belgium and Britain (EPPO, 2017).

EFFECTIVENESS OF MEASURE

Effective.

Hakea sericea is morphologically quite distinct and can be easily identified in most stages of its life cycle (although when seedling or sapling, it may be confused with pines), so surveillance through citizen-science programmes would be enhanced if done alongside awareness raising activities. Citizen-science programmes have also been shown to provide relatively reliable data which are highly valued (Schmeller *et al.*, 2009; Pescot *et al.*, 2015). These activities should be prioritised in areas and regions of high risk of invasion.

EFFORT REQUIRED

Surveillance needs to be done indefinitely or until the species is considered of no risk to the EU. Even if the species is declared eradicated in the EU (which is not probable considering the areas already invaded), new introductions can occur from outside.

RESOURCES REQUIRED

The species should be incorporated into existing citizen-science programmes if available, reducing the costs and efforts required in particular in relation to data recording apps and verification, etc. Species specific info (online and printed) would need to be produced but can be shared with awareness campaigns proposed in the *Prevention* sections.

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Neutral or mixed

Potential side effects include the discovery of other non-target IAS through the surveys and increase awareness by the public supporting the surveys.

ACCEPTABILITY TO STAKEHOLDERS

See section *Prevention of intentional introductions and spread.*

ADDITIONAL COST INFORMATION

Volunteer engagement and citizen-science can be heterogeneous among MS. Certain citizen-science approaches are not cost-free or cheap, because engaging citizens require adequate resources and competencies to address challenges such as data quality, privacy, intellectual property or ownership, to retain citizens' involvement and interest by providing them with training and feedback on their contributions, and to maximise their potential contributions (Cardoso *et al.*, 2017). However, there are examples of self-funded systematic 'expert volunteer'

led surveillance programmes, such as national recording schemes and species specific 'alert' systems which links volunteer experts with the wider recording (non-expert) community, both of which can support early detection activities (Pocock *et al.*, 2015; Roy *et al.*, 2015).

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Although there are several studies published on the costs and effectiveness of citizen-science surveys in a broad sense (for example, Pescott *et al.*, 2015), there is relatively little published about using citizen-science for early detection of IAS.

1 See Appendix

Measures to achieve rapid eradication after an early detection of a new occurrence.

Integrated control.

MEASURE DESCRIPTION

Assuming an early stage of invasion, all young plants should be hand-pulled. Plants that are too big to be hand-pulled should be cut; although not frequent, trunks cut too high may resprout and so care should be taken to cut trunks as close to the soil as possible. If plants are bearing fruits (it must be kept in mind that 12-18 months after germination, plants can produce seeds (Kluge, 1983) or more often after 2-3 years (Richardson *et al.*, 1987), Marchante, pers. comm.), they should be eliminated immediately since fruits start opening and releasing the seeds after two days or less (Diadema, Berre and Dixon, 2017; Richardson *et al.*, 1987). If there are only a few plants, and it is viable, fruits may be incinerated or plants buried or burned in a confined area. If the plants are too many, or this option is not viable, they can be left in the ground to open the fruits and release the seeds, and follow-up control is necessary 12-18 months after removal: plants that germinate may be hand-pulled (for example, involving volunteers when possible), shredded, cut mechanically or grazed (for example, with goats). In France, geotextile was used to cover the soil when cutting individuals with broken or dying branches (with seeds being released) to avoid release of the seeds to the ground (Ducatillion *et al.*, 2015). When plants are lying in the ground, seeds tend to disperse near the plants, although it must be kept in mind that seeds may have been dispersed farther away from the place where plants were deposited.

If a season for the peak of germination has been identified, tree cutting (with subsequent seed release) should be done after this peak, in order to promote maximum seed predation before the next germination peak occurs. However, in South Africa this peak is observed only in some habitats, taking place in midwinter, while in other habitats germination takes place soon after seed release in any season (Richardson and van Wilgen, 1984).

If the area invaded is extensive, and plants are scattered and no longer possible to eradicate quickly, priority should be given to isolated or small groups of plants in order to prevent them spreading and increasing the invaded area, although undisturbed plants most often do not release the seeds. In all cases, follow-up controls and monitoring is always necessary to assure that no plants survive in the eradication area.

All interventions of eradication should monitor operational effectiveness (success in achieving eradication) and outcomes (success in protecting biodiversity or other values) (IUCN, 2018), and also resources involved in order to build a growing database with information that can improve the way *H. sericea* is eradicated. This information should be published and shared with all MS.

SCALE OF APPLICATION

MS or part of MS territory where the species is detected. Considering that *H. sericea* seeds are winged and dispersal distances can be on the order of tens of meters but up to one km or more (Richardson *et al.*, 1987), a buffer area of at least 1 km around the areas where *H. sericea* was detected should be monitored.

If *H. sericea* is not more widespread than reported, and depending on the resources available, in Spain and France eradication may still be possible.

EFFECTIVENESS OF MEASURE

Effective.

When prevention fails, early detection followed by rapid eradication is cheaper and easier than managing established populations (IUCN, 2018). Eradication probability of success decreases as the size of the invaded area increases. An analysis of eradication attempts of 18 invasive plants in California showed that areas smaller than one hectare are usually possible to eradicate; additionally, about 1/3 of areas between 1 ha and 100 ha and 1/4 of invaded areas between 101 and 1000 ha have been eradicated (Rejmánek and Pitcairn, 2002). In the case of *H. sericea*, since live undisturbed plants most often do not release seeds, they will possibly remain "quiet" until the next fire or disturbance (cutting or some operation or climatic condition that breaks or dries a branch) providing a window of opportunity for eradication (even if local) greater than for species that disperse seeds annually.

EFFORT REQUIRED

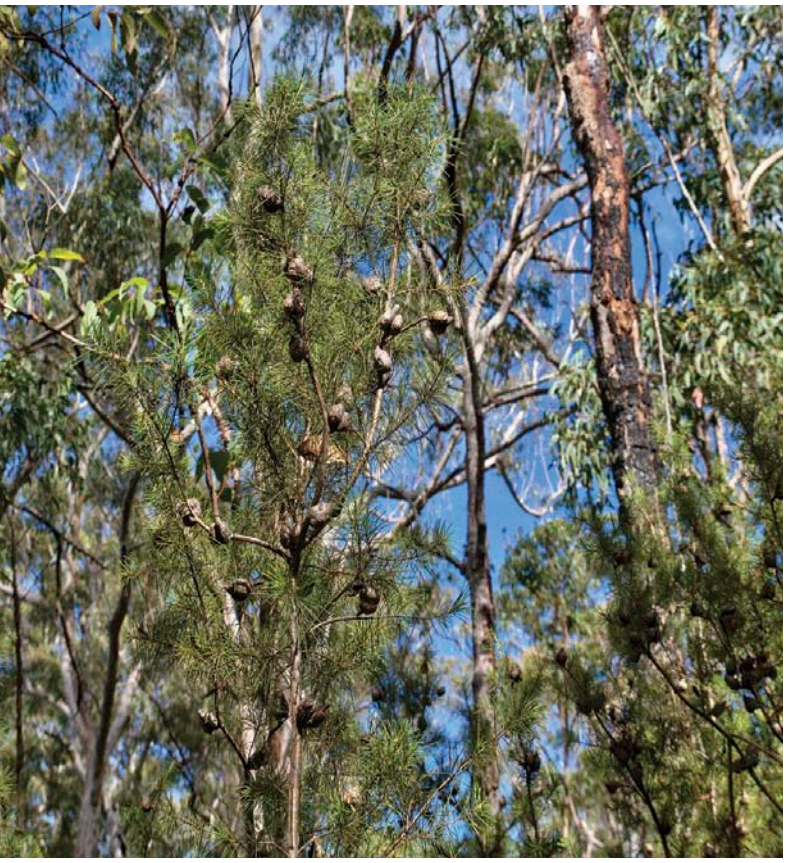
Effort required depends on the size of the area and time to implement the initial eradication measures. After plants have been removed, follow-up controls need to be done for 2-3 years after initial control and follow-up monitoring

should be guaranteed for a couple more years in order to detect plants that may have gone unnoticed in the first years or resprout. This is recommended as *H. sericea* does not accumulate a seedbank in the soil, that plants release the seeds accumulated in the canopy in the following days or few weeks after being cut (Diadema *et al*., 2017), and that these seeds will germinate in the following months, up to 18 months (Esler *et al*., 2010; Richardson *et al*., 1987).

RESOURCES REQUIRED

The resources required will depend on the extent of the invaded area, accessibility, number of follow-up controls, methodologies used, etc. Besides staff (manpower, time, training), individual protection equipment, cutting equipment (when it is not possible to hand-pull), equipment and logistics to remove, burn (prescribed burning logistics) or destroy the plants, travel costs, health and safety measures, etc. will be needed. Follow-ups should always be considered in the resources needed.

In the south of France, up to €160,000 was spent in 2016-17 managing only 50% of an invasive population of approximately 12 ha in the Estérel Natural Park and Conservatoire du Littoral site (Theoule-sur-Mer, Maritimes Alps); this value includes costs of transport of removed plants by helicopters; it was further estimated that €10,000/ha was needed for the eradication of the species (EPPO, 2017 and refs therein). In Portugal, control costs (not specifically for eradication) were estimated for one area (much easier accessibility compared with Estérel Natural Park) at around €2,700/ha, including pulling/cutting of small, medium or large size specimens, and subsequent removal or shredding of all resulting material (R. Viterbo, Valongo Municipality, pers. comm.), but not long term follow up. Another estimate for Portugal, involving municipality staff, is €800/ha; this included initial cutting of plants and follow-up with cutting (moto-manual) of young plants (B. Cardoso, Vila de Rei Municipality, pers. comm.) In South Africa, Wilson *et al*. (2014) estimate that the overall cost of clearing *Hakea* spp. is around 15,400 ZAR/ha (ca. €950/ha).



Hakea sericea. © *Tatters. CC BY-SA 2.0.*

Depending on the accessibility and type of methodology and equipment necessary, involvement of volunteers may be considered.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Positive
Economic: Neutral or mixed

Depending on the type of area invaded, methods proposed may promote some disturbance during interventions which could promote invasion by other generalist invasive plants and disturb native communities.

ACCEPTABILITY TO STAKEHOLDERS

See section on *Prevention of intentional introductions and spread*. There may be issues related to accessing private land to undertake rapid eradication measures, this could be mitigated with increased public awareness.

ADDITIONAL COST INFORMATION

Known eradication **costs** have been included above. **Costs of inaction** are not available for this species but considering the impacts it has (see references above and EPPO, 2017) and that according to the PRA the endangered area includes MS in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions (EPPO, 2017), inaction will most probably result in the spread and establishment of the species in more MS with consequent **environmental, social and economic** negative impacts.

LEVEL OF CONFIDENCE[1]

Well established.

There are several studies about application, effectiveness, acceptability, costs, etc. of the measures proposed and they generally agree, although, for example, values can be variable depending on the context and methods.

1 See Appendix

Measures for the species' management.

Integrated control.

MEASURE DESCRIPTION

If the area detected is too extensive for eradication to be viable, containment, control and follow-up measures to monitor the success of such actions are necessary. Depending on the context, size and homogeneity of the invaded area and density of *H. sericea*, different methods, namely hand-pulling, the 'fell and burn' technique, chemical and biological control, may be applied in an integrated manner. Although different methods need to be combined, each is described in a different section below, with hand pulling mentioned in this table (but see *Rapid eradication* section above for more details). Independently of the extent of the invaded area and control method selected, all measures should assure the follow-up controls necessary to eliminate all plants that germinate after initial control. Otherwise, re-invasion is guaranteed and resources used will result in no success.

Management may start (or be limited to, if other measures are not realistic, considering the scale of invasion and resources available) with containment of the populations, in order to prevent further spread into new areas.

When plants are sparse and the invaded area is not very extensive, young plants should be hand-pulled, as per the methods described in the *Rapid eradication* section above. This measure (hand-pulling and cutting) may still be combined with measures in the following sections when there are sparse or isolated plants close to large invaded areas. If the area invaded is extensive and plants scattered and no longer possible to control completely, priority should be given to isolated or small groups of plants in the periphery of the area in order to prevent them to spreading and increasing the invaded area, although undisturbed plants most often do not release the seeds. In all cases, follow-up monitoring and controls is always necessary to assure that no plant survive in the managed area.

All interventions of management should monitor operational effectiveness (success in achieving control) and outcomes (success in protecting biodiversity or other values) (IUCN, 2018), and also resources involved in order to build a growing database with information that can improve the way *H. sericea* is managed. This information should be published and shared with all MS.

SCALE OF APPLICATION

These integrated measures may be applied to several hectares. MS where *H. sericea* is present, namely Portugal, France and Spain (if eradication is not possible in the last two MS). Despite the lack of accurate information on the area invaded, numerous areas with tens and hundreds of hectares occur in Portugal (Marchante and Marchante, 2016; Marchante *et al.*, 2014; Ministério do Ambiente, 1999); in France the distribution of *H. sericea* is limited to the Estérel Natural Park and Conservatoire du Littoral site (Theoule-sur-Mer, Maritimes Alps) in the south of the country (Diadema *et al.*, 2017; Ducatillion *et al.*, 2015); in Spain *H. sericea* is restricted to a few locations in Galicia (Pulgar Sañudo, 2006).

EFFECTIVENESS OF MEASURE

Effective.

The effectiveness is very dependent on the size of the area invaded, and other conditions (for example, accessibility, density of the invaded stand, type of habitat, resources available). Difficulty to control, and resources needed, increase with the size and complexity of the invaded areas. For small areas (up to a few hectares), these measures can be effective. For large infestations, long-term funding is necessary.

EFFORT REQUIRED

The measures need to be maintained long-term in the MS where the species is present. At least in Portugal, the extension of the invasion is too large for eradication to be viable and is not reasonable to expect that control can be attained in the short or medium-term. A particular area may be controlled in ca. 5 years (considering initial control and follow-up, monitoring and maintenance control) but all the invaded areas request long-term effort.

RESOURCES REQUIRED

The resources needed for an integrated control strategy require a dedicated management plan that will be dependent upon the context and size of invasion, number of follow-up controls, methodologies used, etc. Costs for the control of *H. sericea* can be very significant when a population is widespread, as in some regions in Portugal where sometimes several hundreds of hectares are invaded.

Resources required for physical removal include staff (manpower, time, training), individual protection equipment, cutting equipment (when it is not possible to hand-pull),

equipment and logistics to remove or destroy the plants, travel costs, health and safety measures, etc. will be needed. Follow-ups control measures should always be considered in determining the resources needed. Depending on the accessibility and type of methodology and equipment necessary, involvement of volunteers may be considered. See *Rapid eradication* section for examples of costs for physical removal of *H. sericea*.

SIDE EFFECTS

Social: Neutral or mixed
Environmental: Positive
Economic: Neutral or mixed

Depending on the type of area invaded, methods proposed may lead to habitat disturbance and affect native species, or may promote establishment of other invasive alien species. However, considering the negative impacts of the species, these effects are expected to be lower than the cost of inaction. Eventually, there may some residual negative effects concerning honey production as the species is occasionally appreciated by beekeepers (see *Prevention* sections above). Apart from this, control of *H. sericea* will prevent the establishment and spread of the species and consequently their negative effects, resulting in positive environmental, social and economic effects. In South Africa, reductions in streamflow associated with *H. sericea* were estimated as 1,034 m^3/ha/yr, and consequently the control of the species would have benefits in terms of water availability (van Wilgen *et al.*, 2004). However, these calculations need to be critically interpreted as there are a number of assumptions involved and as such uncertainty may be high.

ACCEPTABILITY TO STAKEHOLDERS

See section on *Prevention of intentional introductions and spread.* Awareness campaigns (as described in previous sections) can be used to inform stakeholders and improve acceptance of management measures. Access to private land would need to be negotiated, but this risk could be addressed through public awareness raising activities.

ADDITIONAL COST INFORMATION

Currently, the occurrence of *H. sericea* is concentrated in Portugal and France (and less in Spain) and for these MS inaction could significantly increase potential costs in the future as any management programme would have to take place on a larger scale reducing the **cost-effectiveness** of any measures. Considering the impacts from the species (see references above and EPPO, 2017) and the large endangered area which includes MS in the Mediterranean, Atlantic, Black Sea and Macaronesia biogeographical regions (EPPO, 2017), **inaction** will most probably result in the spread and establishment of the species in more MS with negative **environmental, social and economic** impacts, namely increasing management costs.

In South Africa, the economic benefits of preventing invasion due to the use of biocontrol was estimated to be ZAR3,410/ha/yr for *H. sericea* (values are discounted to the year 2000; ca. €145/ha/yr) with a benefit:cost ratio of 251:1, considering benefits due to streamflow, land value and biodiversity, and costs of biocontrol research (van Wilgen *et al.*, 2004). However it should be stressed that these calculations involve numerous assumptions and as such a high uncertainty may be associated to these numbers.

LEVEL OF CONFIDENCE[1]

Well established.

There are several studies about methods of control, effectiveness, costs, etc. of the measures proposed and they generally agree, however values can be variable depending on the context and measures used.

1 See Appendix

Fell and burn technique.

MEASURE DESCRIPTION

This measure may be combined with others as described in the other *Management* sections.

In the case of larger infestations, the most successful method referred for the control of *H. sericea* in South Africa has been the 'fell and burn' technique, where adult plants are cut down and left for 12-18 months before they are burnt through prescribed burning (Esler *et al.*, 2010). This allows time for seed germination, meaning that the follow-up burn additionally destroys seedlings before they become reproductively mature. One or two follow-up operations are necessary after the burn to eradicate any regenerating or re-sprouting plants. This is an extremely important aspect of the operation as it ensures that no plants are left to produce viable seeds. It is also important to check that prescribed burning is licensed for use.

Although this is a very effective control method, the increased fire intensities using this technique can have a negative effect on sensitive ecosystems (Breytenbach, 1989) and prescribed burning may be not viable in all places; additionally, in some situations (for example, when plants are not very big or do not form dense stands) the biomass accumulated may not gather conditions for a prescribed fire. Alternatively to burning, germinated plants may be hand-pulled (for example, involving volunteers when possible), shredded, cut mechanically or grazed (for example, with goats) as in smaller areas – but always before they start producing seeds. When cutting the plants is not viable, burning standing plants can be effective in some cases (for example, plant up to 1.5 m) but it probably results in dense stands of seedlings and widespread dispersal (Fourie, Gordon and Krug, 2012) and therefore is not a good option for initial control in most situations; additionally, it will require a greater effort on follow-up control in a larger area.

If a season for the peak of germination has been identified, tree cutting (with subsequent seed release) should be done after this peak, in order to promote maximum seed predation before the next germination peak occurs. However, in South Africa this peak is observed only in some habitats, taking place in midwinter, while in other habitats germination takes place soon after seed release in any season (Richardson and van Wilgen, 1984).

All interventions of management should monitor operational effectiveness (success in achieving control) and outcomes (success in protecting biodiversity or other values) (IUCN, 2018), and also resources involved in order to build a growing database with information that can improve the way *H. sericea* is managed. This information should be published and shared with all MS.

SCALE OF APPLICATION

This measures may be applied to several hectares (see *Integrated control* section above).

EFFECTIVENESS OF MEASURE

Effective.

The effectiveness of this measure is reported as very high in South Africa (Esler *et al.*, 2010). Nevertheless, effectiveness is always dependent on the size and other particular conditions (for example, accessibility, density of the invaded stand, type of habitat, resources available) of the invaded area. Difficulty to control and resources needed increase with the size and complexity of the invaded areas.

EFFORT REQUIRED

The measures need to be maintained long-term in the MS where the species is present. At least in Portugal, the extension of the invasion is too large to consider eradication viable and is not reasonable to expect that control can be attained in short or medium-term. A particular area may be controlled in ca. 5 years (considering initial control and follow-up, monitoring and maintenance control) but all the invaded areas require long-term effort.

RESOURCES REQUIRED

Resources required for fell and burn including; staff (manpower, time, training), individual protection equipment, cutting equipment (when it is not possible to hand-pull), equipment and logistics to remove, burn (prescribed burning logistics) or destroy the plants, travel costs, health and safety measures, also prescribed burn teams may be necessary if that option is selected. Depending on the accessibility and type of methodology and equipment necessary, involvement of volunteers may be considered for the "Fell" part, possibly reducing the costs.

Independently of the extent of the invaded area and control method selected, all measures should assure the follow-up controls necessary to eliminate all plants that germinate after initial control. Otherwise, re-invasion is guaranteed and resources used will result in no success.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

See first *Integrated management* section above. In addition, if use of prescribed burning is considered, although this control

method may be very effective, the increased fire intensities using this technique can have a negative effect on sensitive ecosystems (Breytenbach, 1989).

ACCEPTABILITY TO STAKEHOLDERS

See section *Prevention of intentional introductions and spread.* Prescribed burning may be viewed negatively by some stakeholders due to potential non-target damage, or because of lack of information or misinformation (mostly about prescribed burning and biocontrol). Awareness campaigns (integrated with the campaigns discussed in previous sections) can be used to inform, elucidate and train staff and other stakeholders and improve acceptance. Access to private land would need to be negotiated, but this risk could be addressed through public awareness raising activities.

ADDITIONAL COST INFORMATION

See first *Integrated management* section.

LEVEL OF CONFIDENCE[1]

Well established.

There are several studies about the use of 'fell and burn' as part of a control method and they generally agree, however values can be variable depending on the context.

1 See Appendix

Chemical control.

MEASURE DESCRIPTION

This measure may be combined with others as described in the other *Management* sections.

Chemical control has not played a large role in the control of *H. sericea* in South Africa as it can have a negative effect on native vegetation. The costs of chemical control are also high as *H. sericea* occurs in dense thickets and inaccessible areas. Tebuthiuron has been used successfully for the control of *H. sericea* shrubs, and triclopyr for seedlings (EPPO, 2012; Fourie *et al.*, 2012). In Portugal, glyphosate spraying was used in an area with dense thickets of small plants, but results were variable and inconclusive (Barbosa, Valminho Florestal, pers. comm., 2018). Considering the negative side-effects and variable efficiency of this method, this should be the last option when other methods may be used. It is important to note that EU, national, and local legislation on the use of plant protection products and biocides needs to be respected and authorities should check to ensure chemicals are licensed for use in their respective countries/regions.

All interventions of management should monitor operational effectiveness (success in achieving control) and outcomes (success in protecting biodiversity or other values) (IUCN, 2018), and also resources involved in order to build a growing database with information that can improve the way *H. sericea* is managed. This information should be published and shared with all MS.

SCALE OF APPLICATION

This measure may be applied to several hectares (see *Integrated control* section above).

EFFECTIVENESS OF MEASURE

The effectiveness is dependent on the size of the area invaded, and other associated conditions including accessibility, density of the invaded stand, type of habitat, resources available. Additionally, some experiments in Portugal were inconclusive (M. Barbosa, Valminho Florestal, pers. comm., 2018).

EFFORT REQUIRED

The measures need to be maintained long-term in the MS where the species is present. At least in Portugal, the extension of the invasion is too large to consider eradication viable and is not reasonable to expect that control can be attained in the short- or medium-terms. A particular area may be controlled in ca. 5 years (considering initial control and follow-up, monitoring and maintenance control) but all the invaded areas require long-term effort.

RESOURCES REQUIRED

Resources required for chemical control include; staff (manpower, time, training), individual protection equipment for chemical application, cutting equipment (when it is not possible to hand-pull), equipment and logistics to remove shrubs, travel costs, health and safety measures, etc., also special licenses for chemical application may be necessary.

Independently of the extent of the invaded area and control method selected, all measures should assure the follow-up controls necessary to eliminate all plants that germinate after initial control. Otherwise, re-invasion is guaranteed and resources used will result in no success.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

See first *Integrated management* section above. In addition, the use of chemical treatments may have undesired effects on native flora or fauna. Nevertheless, if control of *H. sericea* is achieved the net effect can still be probably neutral or mixed.

ACCEPTABILITY TO STAKEHOLDERS

See section *Prevention of intentional introductions and spread.*

Chemical control may be viewed negatively by some stakeholders due to potential non-target damage. In Portugal, there have been newspaper stories focusing on 'controversial' herbicide use (glyphosate) in the control of *H. sericea* over a large area. Access to private land would need to be negotiated, but this risk could be addressed through public awareness raising activities.

ADDITIONAL COST INFORMATION

No additional information.

LEVEL OF CONFIDENCE[1]

Unresolved.

Only a few studies exist on chemical control and its effectiveness, costs, etc.

1 See Appendix

Biological control.

MEASURE DESCRIPTION

Biocontrol is included here as it has the potential to be a cost-effective management measure, but it is not yet an option in Europe as no biocontrol agent is available and no MS has a programme to test and permit the introduction any of the agents that are available in South Africa. The release of macro-organisms as biological control agents is currently not regulated at EU level. Nevertheless national/regional laws are to be respected. Before any release of an alien species as a biological control agent an appropriate risk assessment should be made.

In South Africa, a biological control programme against *H. sericea* was initiated in 1962 and is ongoing. Priority was given to seed-attacking insects and the first insect releases were made in 1970 (Kluge, 1983). Several agents have been released or are currently under study, namely: *Erytenna consputa* (Curculionidae: Erirhininae) – a weevil that destroys seeds in green developing fruits; *Carposina autologa* (Lepidoptera: Carposinidae) – a moth that destroys seeds in mature plants; *Cydmaea binotata* (Curculionidae: Erirhininae) – a weevil that feeds in the leaves and shoots; *Aphanasium australe* (Coleoptera: Cerambycidae) – a beetle whose larvae feed in the roots and stem at base of the plant; *Dicomada rufa* – a weevil whose adult destroys flower buds and larvae feed on flowers; and *Colletotrichum acutatum* – a South African stem canker fungus on seedlings and mature plants (Fourie *et al.*, 2012).

In South Africa, the 'Working for Water' programme has been key for the mechanical control of *H. sericea* and has identified biological control as the only long-term solution to be combined with other control methods and prevent further spread of the weed and the re-invasion of cleared areas (Esler *et al.*, 2010). Biological control needs to be in place to prevent re-invasion by *H. sericea* and to limit the need for follow-up operations after other operations.

All interventions of management should monitor operational effectiveness (success in achieving control) and outcomes (success in protecting biodiversity or other values) (IUCN, 2018), and also resources involved in order to build a growing database with information that can improve the way *H. sericea* is managed. This information should be published and shared with all MS.

SCALE OF APPLICATION

Biological control has to be applied to sites that cover the range of the species in South Africa.

MS where *H. sericea* is present, namely Portugal, France and Spain (if eradication is not possible in the last two MS). Despite the lack of accurate information on the species distribution/area invaded, numerous areas with tens and hundreds of hectares occur in Portugal (E. Marchante and H. Marchante, 2016; H. Marchante *et al.*, 2014; Ministério

Hakea sericea, *dehisced mature fruit. © SAplants. CC BY-SA 4.0.*

do Ambiente, 1999); in France the distribution of *H. sericea* is limited to the Estérel Natural Park and Conservatoire du Littoral site (Theoule-sur-Mer, Maritimes Alps) in the south of the country (Diadema *et al.*, 2017; Ducatillion *et al.*, 2015); in Spain *H. sericea* is restricted to a few locations in Galicia (Pulgar Sañudo, 2006). In this context, although this measure may be applied to all MS it is probably more reasonable in Portugal and eventually France if the populations are not contained or eradicated.

EFFECTIVENESS OF MEASURE

Effective.

The effectiveness of each individual agent that is already well established (*Erytenna consputa*, *Carposina autologa*, *Colletotrichum acutatum* and *Cydmaea binotata*) on *H. sericea* is complicated because the three insect species and the fungus all interact with each other and their combined impact is superimposed on manual clearing interventions (Gordon and Fourie, 2011). However, surveys at selected sites showed that *E. consputa* and, to a lesser extent, *C. autologa*, destroy most of the seeds produced by *H. sericea*, and where *C. acutatum* was established 40% of *H. sericea* trees showed disease symptoms with an average mortality rate of 15% (Gordon and Fourie, 2011).

Integrated control using bio-control and manual clearing reduced *H. sericea* distribution in South Africa by 64% from 530,000 ha in 1979 to 190,000 ha in 2001, and over the same time period the species either decreased in density or was eradicated from 492,113 ha (Esler *et al.*, 2010). Manual control was deemed to be responsible for the initial reduction in extent and density of infestations, and bio-control was largely responsible for the failure of the species to re-colonise (Esler *et al.*, 2010).

Biocontrol integrated with other measures could increase significantly the cost-effectiveness of management (Esler *et al.*, 2010; Fourie *et al.*, 2012; van Wilgen *et al.*, 2004), with some estimations saying that the successful implementation of biological control in general could bring about a saving of more than 50% of the total costs of controlling invasive species (Fourie *et al.*, 2012).

EFFORT REQUIRED

The measures need to be maintained long-term in the MS where the species is present. If one or more biocontrol agents are released they will not eradicate *H. sericea*, but if they establish and are effective will remain in the system as long as *H. sericea* is present.

RESOURCES REQUIRED

Resources required for a biocontrol programme can be extensive particularly for initial research into the agent identification and host-specificity testing. However, since there are agents effective and specific to *H. sericea* already selected in South Africa, the research costs associated to biocontrol could be significantly reduced. Nevertheless, host-specificity testing, risk assessment and implementation costs would still be included. Additional costs would need to include participatory stakeholder engagement and decision making, communication of risk and risk management options, and long-term monitoring to evaluate impacts.

Independently of the extent of the invaded area and control method selected, all measures should assure the follow-up controls necessary to eliminate all plants that germinate after initial control. Otherwise, re-invasion is guaranteed and resources used will result in no success.

SIDE EFFECTS

Environmental: Positive

Social: Positive

Economic: Positive

In South Africa, the biocontrol agents used are specific to *H. sericea* and as such no non-target effects have been observed. Although specificity testing has not been performed in Europe, the family Proteaceae is restricted to the Southern Hemisphere today, which may be an indication that non-target direct effects may not be expected. Biological control of invasive plants can be a sustainable, self-perpetuating, and effective control method (McFadyen, 1998), reducing costs and un-intended environmental effects.

ACCEPTABILITY TO STAKEHOLDERS

See *Prevention of intentional introductions and spread* section. Biocontrol may be viewed negatively by some stakeholders due to potential non-target damage, and a lack of information or misinformation. Awareness campaigns (integrated with the campaigns discussed in previous sections) can be used to improve acceptance.

ADDITIONAL COST INFORMATION

The economic benefits of preventing invasion using biocontrol was estimated to be ZAR 3,410/ha/yr for *H. sericea* (values are discounted to the year 2000; ca. €145/ha/yr) with a benefit: cost ratio of 251:1, considering benefits due to streamflow, land value and biodiversity, and costs of biocontrol research (van Wilgen *et al.*, 2004). However, it should be stressed that these calculations involve numerous assumptions and as such a high degree of uncertainty may be associated to these numbers. In this context, the management of *H. sericea*, in particular when biocontrol is used, may be **cost-effective** and decrease the negative **socio-economic** impacts. Additionally, considering that several highly specific biocontrol agents have already been selected in South Africa, this could reduce the investment in research in Europe, further decreasing costs of this measure.

LEVEL OF CONFIDENCE[1]

Well established.

There are several studies about effectiveness, costs-benefits, etc. of biocontrol.

1 See Appendix

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Appendix

Level of confidence provides an overall assessment of the confidence that can be applied to the information provided for the measure.

- **Well established:** comprehensive meta-analysis or other synthesis or multiple independent studies that agree. *Note:* a meta-analysis is a statistical method for combining results from different studies which aims to identify patterns among study results, sources of disagreement among those results, or other relationships that may come to light in the context of multiple studies.
- **Established but incomplete:** general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps.

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